Modern technology uses compound machines.

BEFORE, you learned
• Simple machines change the size or direction of a force
• All machines have an ideal and an actual mechanical advantage

NOW, you will learn
• How simple machines can be combined
• How scientists have developed extremely small machines
• How robots are used

THINK ABOUT
How does a tow truck do work?

When a car is wrecked or disabled, the owner might call a towing service. The service sends a tow truck to take the car to be repaired. Tow trucks usually are equipped with a mechanism for freeing stuck vehicles and towing, or pulling, them. Look at the tow truck in the photograph at the right. What simple machines do you recognize?

Compound machines are combinations of simple machines.

Like the tow truck pictured above, many of the more complex devices that you see or use every day are combinations of simple machines. For example, a pair of scissors is a combination of two levers. The cutting edges of those levers are wedges. A fishing rod is a lever with the fishing line wound around a wheel and axle, the reel. A machine that is made of two or more simple machines is called a compound machine.

In a very complex compound machine, such as a car, the simple machines may not be obvious at first. However, if you look carefully at a compound machine, you should be able to identify forms of levers, pulleys, and wheels and axles.

How are simple machines related to compound machines?
Gears

Gears are based on the wheel and axle. Gears have teeth on the edge of the wheel that allow one gear to turn another. A set of gears forms a compound machine in which one wheel and axle is linked to another.

Two linked gears that are the same size and have the same number of teeth will turn at the same speed. They will move in opposite directions. In order to make them move in the same direction, a third gear must be added between them. The gear that turns another gear applies the input force; the gear that is turned exerts the output force. A difference in speed between two gears—caused by a difference in size and the distance each turns through—produces a change in force.

Mechanical Advantage of Compound Machines

The mechanical advantage of any compound machine is equal to the product of the mechanical advantages of all the simple machines that make up the compound machine. For example, the ideal mechanical advantage of a pair of scissors would be the product of the ideal mechanical advantages of its two levers and two wedges.

The mechanical advantage of a pair of gears with different diameters can be found by counting the teeth on the gears. The mechanical advantage is the ratio of the number of teeth on the output gear to the number of teeth on the input gear. If there are more than two gears, count only the number of teeth on the first and last gears in the system. This ratio is the mechanical advantage of the whole gear system.

Compound machines typically must overcome more friction than simple machines because they tend to have many moving parts. Scissors, for example, have a lower efficiency than one lever because there is friction at the point where the two levers are connected. There is also friction between the blades of the scissors as they close.
Modern technology creates new uses for machines.

Sophisticated modern machinery is often based on or contains simple machines. Consider Jaws of Life tools, which are used to help rescue people who have been in accidents. These cutters, spreaders, and rams are powered by hydraulics, the use of fluids to transmit force. When every second counts, these powerful machines can be used to pry open metal vehicles or collapsed concrete structures quickly and safely. The cutters are a compound machine made up of two levers—much like a pair of scissors. Their edges are wedges.

Contrast this equipment with a drill-like machine so small that it can be pushed easily through human arteries. Physicians attach the tiny drill to a thin, flexible rod and push the rod through a patient’s artery to an area that is blocked. The tip rotates at extremely high speeds to break down the blockage. The tiny drill is a type of wheel and axle.

Microtechnology and Nanotechnology

Manufacturers make machines of all sizes by shaping and arranging pieces of metal, plastic, and other materials. Scientists have used technology to create very small machines through miniaturization—the making of smaller and smaller, or miniature, parts. Micromachines are too small to be seen by the naked eye but are visible under a microscope. There is a limit, however, to how far micromachines can be shrunk.

To develop even tinier machines, scientists needed a new approach. Scientists have used processes within the human body as their model. For example, inside the body a protein molecule carries materials back and forth within a cell on regular paths that are similar to little train tracks. The natural machines in the human body inspired scientists to develop machines that could be 1000 times smaller than the diameter of a human hair.
These extremely tiny machines are products of nanotechnology, the science and technology of building electronic circuits and devices from single atoms and molecules. Scientists say that they create these machines, called nanomachines, from the bottom up. Instead of shaping already formed material—such as metal and plastic—they guide individual atoms of material to arrange themselves into the shapes needed for the machine parts.

Tools enable scientists to see and manipulate single molecules and atoms. The scanning tunneling microscope can create pictures of individual atoms. To manipulate atoms, special tools are needed to guide them into place. Moving and shaping such small units presents problems, however. Atoms tend to attach themselves to other atoms, and the tools themselves are also made of atoms. Thus it is difficult to pick up an atom and place it in another position using a tool because the atom might attach itself to the tool.

Nanomachines are still mostly in the experimental stage. Scientists have many plans for nanotechnology, including protecting computers from hackers and performing operations inside the body. For example, a nanomachine could be injected into a person’s bloodstream, where it could patrol and search out infections before they become serious problems. When the machine had completed its work, it could switch itself off and be passed out of the body. Similar nanomachines could carry anti-cancer drugs to specific cells in the body.

Nanotechnology could also be used to develop materials that repel water and dirt and make cleaning jobs easy. Nanoscale biosensors could be used to detect harmful substances in the environment. Another possible use for nanotechnology is in military uniforms that can change color—the perfect camouflage.

In the future, nanotechnology may change the way almost everything is designed and constructed. As with any new technology, it will be important to weigh both the potential risks and benefits.
Scientists are using a robot to unlock the secrets of the Great Pyramid in Egypt.

The frame of the Pyramid Rover is 12 centimeters (about 5 in.) wide and 30 centimeters (about 1 ft) long. As it moves, it uses two sets of flexible treads to grip the top and bottom of the narrow shafts inside the pyramid. The robot is linked to a computer by a fiber-optic cable.

What simple machines do you think might be part of the Pyramid Rover?
Robots

Humans have always taken risks to do jobs in places that are dangerous or difficult to get to. More and more often, robots can be used to do these jobs. A robot is a machine that works automatically or by remote control. When many people hear the word robot, they think of a machine that looks or moves like a person. However, most robots do not resemble humans at all. That is because they are built to do things humans cannot do or to go places where it is difficult for humans to go.

The Pyramid Rover, shown on page 174, is an example of a robot developed to go where people cannot. After a camera revealed a door at the end of an eight-inch-square shaft inside the Great Pyramid, the Pyramid Rover was sent through the shaft to explore the area. While researchers remained in the Queen’s Chamber in the center of the pyramid, the robot climbed the shaft until it came to a door. Using ultrasound equipment mounted on the robot, researchers determined that the door was three inches thick. The robot drilled a hole in the door for a tiny camera and a light to pass through. The camera then revealed another sealed door!

Many companies use robots to manufacture goods quickly and efficiently. Robots are widely used for jobs such as welding, painting, and assembling products. Robots do some repetitive work better than humans, because robots do not get tired or bored. Also, they do the task in exactly the same way each time. Robots are very important to the automobile and computer industries.

How are robots better than humans at some jobs?

**5.4 Review**

**KEY CONCEPTS**

1. How do you estimate the mechanical advantage of a compound machine?
2. What are some uses of nanotechnology? Can you think of other possible uses for nanomachines?
3. What are three types of jobs that robots can do?

**CRITICAL THINKING**

4. **Synthesize** What factors might limit how large or how small a machine can be?
5. **Infer** How do you think the size of a gear compared with other gears in the same system affects the speed of its rotation?

**CHALLENGE**

6. **Apply** Robots might be put to use replacing humans in firefighting and other dangerous jobs. Describe a job that is dangerous. Tell what a robot must be able to do and what dangers it must be able to withstand to accomplish the required tasks.