BIG Idea
Materials are compounds and mixtures that are made by nature or by humans.

25. 1 Materials with a Past
An alloy is a mixture of elements that has metallic properties such as luster, ductility, malleability, and conductivity.

25. 2 Versatile Materials
Ceramics and semiconductors have conductivities that can range from highly insulating to superconductive.

25.3 Polymers and Composites
A huge variety of human-made products, from plastics to aircraft components, are made from polymers and composites.

Chemistry on the Slopes
If you enjoy boarding down a snowy slope, you'll appreciate that most of your equipment is made from materials that have been engineered specifically to meet the challenges of a demanding sport.

Science Journal
How do manufacturers find materials to meet their needs?
Launch LAB

Chemistry and Properties of Materials
When an engineer designs a vehicle, bridge, or building, the materials used for construction must be selected to match the function. Can the manufacturing process affect a material’s performance?

WARNING: Use proper protection when handling hot objects or working near an open flame. Tie back hair; roll up sleeves.

1. Using tongs, hold a 5-cm piece of steel wire in a lab burner flame until the wire glows red-hot for 30 seconds.

2. Quickly drop the hot wire into a beaker of cold water.

3. Repeat step 1 with another 5-cm piece of steel wire, but place this hot wire on a heatproof surface to cool instead of in water.

4. After both pieces of wire are cool, compare the flexibility of the wires.

5. Think Critically Write what you observe about the flexibility of the two wires. Suggest reasons.

FOLDABLES Study Organizer

Materials Classification Make the following Foldable to help you organize materials into groups based on their common features.

STEP 1 Draw a mark at the midpoint of a sheet of paper along the side edge. Then fold the top and bottom edges in to touch the midpoint.

STEP 2 Fold in half from side to side.

STEP 3 Turn the paper horizontally. Open and cut along the inside fold lines to form four tabs.

STEP 4 Label the tabs Alloys, Ceramics, Polymers, and Composites.

Classify As you read Chapter 25, list three or more examples of common materials for each group.

Science/nine

Preview this chapter’s content and activities at gpscience.com

(bkgd.)David Stoecklin/CORBIS, (inset)Matt Meadows
Materials with a Past

Reading Guide

What You’ll Learn
- Identify how different alloys are used.
- Explain how the properties of alloys determine their use.

Why It’s Important
Alloys make modern cities, space travel, and many other things possible.

Review Vocabulary
physical properties: characteristics that can be observed or measured without changing the composition of the material

New Vocabulary
- alloy
- luster
- ductility
- malleability
- conductivity

Alloys
For ages, people have searched for better materials to use to make their lives more comfortable and their tasks easier. Ancient cultures used stone tools until methods for processing metals became known. Today, advances in metal processing are still occurring as scientists continue to improve the art of blending metals, or making alloys, to make better metal products. An alloy is a mixture of elements that has metallic properties. For example, pewter is a mixture of the elements tin, copper, and antimony. If you were to see a pewter mug or a pewter figurine, you probably would not hesitate to say that the objects are metallic. Alloys can produce materials with improved properties such as greater hardness, strength, lightness, or durability.

Alloys Through Time
In about 3500 B.C., historians believe that ancient Sumerians in the Tigris-Euphrates Valley (now Iraq) accidentally discovered bronze. They believe that Sumerians used rocks rich in copper and tin ore to make fire rings to keep their campfires from spreading. The hot campfire melted the copper and tin ores within the rocks, creating bronze. This first known mixture of metals became so popular and widely used that a 2,000-year span of history is known as the Bronze Age. The ancients did not have a chemical language for their discovery, but the bronze tools and objects, such as those shown in Figure 1, helped change the history of civilization.

Figure 1 Artifacts from the Bronze Age prove that alloys of metal were used as early as 3500 B.C.
Materials Change  Typical objects from the Bronze Age and the following Iron Age include spearheads, tools, and even body armor. Bronze and iron are still used today, but it is doubtful that ancient people would recognize them. The methods of processing these alloys have undergone many changes. Other alloys also have been developed through the ages, giving people a large selection of materials to choose from today.

Properties of Metals and Alloys

Alloys retain the metallic properties of metals, some of which are shown in Figure 2, but what are the properties of metals? Metals have luster, which means they reflect light or have a shiny appearance. The shiny appearance of aluminum foil and a new copper coin demonstrates the property of luster. Ductility (duk TIH luh tee) means the metal can be pulled into wires. The copper electrical wire in your home demonstrates the ductility of metals and alloys. Malleability (mal yuh BIH luh tee) is the property that allows metals and alloys to be hammered or rolled into thin sheets. Aluminum foil that is used in food preparation and food storage demonstrates the malleability of aluminum. The French horn above demonstrates the luster and malleability of brass. Conductivity (kahn duk TIH vuh tee) means that heat or electrical charges can move easily through the material. Metals and alloys have high conductivity because some of their electrons are not tightly held by their atoms. Metals and alloys usually are good conductors of heat and electricity because of these loosely bound electrons. Copper is used to carry electricity because it is conductive and ductile.

What are five other examples of items that you know of that have metallic properties?

Observing Properties of Alloys

Procedure
1. Observe a small sheet of aluminum foil.
2. Using a conductivity tester, test the following items for their ability to conduct electric current: aluminum foil, paper, pencil, ink pen, and paper clip.

Analysis
1. What metallic properties of the foil do you observe?
2. Explain why each item was or was not able to conduct electric current.
Choosing an Alloy  What properties of an alloy are most important? The answer depends upon how the alloy will be used and which characteristics are the most desirable. Look at the characteristics of familiar objects made from alloys such as the gold jewelry shown in Figure 3. The rings appear to be made of pure gold, but they are made from alloys.

Gold is a bright, expensive metal that is soft and bends easily. Copper, on the other hand, is an inexpensive metal that is harder than gold. When gold and copper are melted, mixed, and allowed to cool, an alloy forms. The properties will vary depending upon the amount of each metal that is added. A ring made with a higher percentage of gold will bend easily due to gold’s softness. This ring will be more valuable because it contains a higher percentage of gold. A ring with a higher percentage of copper will not bend as easily because copper is harder than gold. This ring will be less valuable because it contains more copper, a less-expensive metal.

Which properties are needed?  The alloy chosen for jewelry and the alloy chosen for a drill bit probably will not be the same. However, the characteristics of the final product must be considered in both situations before the product is constructed.

How hard does the alloy have to be to prevent the object from breaking when it is used? Will the object be exposed to chemicals that will react with the alloy and cause the alloy to fail? These questions relate to the properties of the alloy and its intended use. This represents only two of the many possible questions that must be answered while a product is being designed.
Uses of Alloys

Alloys are used in a variety of products, as shown in Table 1. If you see an object that looks metallic, it is most likely an alloy. Alloys that are exceptionally strong are used to manufacture industrial machinery, construction beams, and railroad cars and rails. Automobile and aircraft bodies that require strong materials are constructed of alloys that are corrosion resistant and lightweight but able to carry heavy loads. Other types of alloys are used in products such as food cans, carving knives, and roller skates. Figure 4 shows some additional examples of alloys.

If you have a tooth filling, your dentist might have used a silver and mercury alloy to fill it, preventing further tooth decay. Other alloys that are resistant to tissue rejection can be used inside the human body. Special pins and screws made from alloys are used by surgeons to connect broken bones, as shown in Figure 4. Alloys also are used as metal plates to repair damage to the skull. These plates protect the brain from injury and are safe to use inside the body.

Table 1  Common Alloys

<table>
<thead>
<tr>
<th>Name</th>
<th>Composition</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bronze</td>
<td>copper, tin</td>
<td>jewelry, marine hardware</td>
</tr>
<tr>
<td>Brass</td>
<td>copper, zinc</td>
<td>hardware, musical instruments</td>
</tr>
<tr>
<td>Sterling silver</td>
<td>silver, copper</td>
<td>tableware</td>
</tr>
<tr>
<td>Pewter</td>
<td>tin, copper, antimony</td>
<td>tableware</td>
</tr>
<tr>
<td>Solder</td>
<td>lead, tin</td>
<td>plumbing</td>
</tr>
<tr>
<td>Wrought iron</td>
<td>iron, carbon</td>
<td>porch railings, fences, sculpture</td>
</tr>
</tbody>
</table>

Reading Check  What are several uses for alloys?

Figure 4  The fork and saw blade, on the right, are both steel alloys, but they differ in chemical composition. Surgical steel, shown below, can be used to join bones. Identify the properties of steel that are most important.
Steel—An Important Alloy  There are various classes of steel. They are classified by the amount of carbon and other elements present, as well as by the manufacturing process that is used to refine the iron ore. The classes of steel have different properties and therefore different uses. Steel is a strong alloy and is used often if a great deal of strength is required. Office buildings have steel beams to support the weight of the structure. Bridges, overpasses, and streets also are reinforced with steel. Ship hulls, bedsprings, and automobile gears and axles are made from steel. Another class of steel, called stainless steel, is used in surgical instruments, cooking utensils, and large vessels where food products are prepared.

**Why is steel an important alloy?**

New Alloys

Steel is not the only common type of alloy. Aluminum is familiar because it is used to make soda cans and cooking foil. Did you know that engineers also are using new aluminum and titanium alloys to build large commercial aircraft? The aircraft shown in Figure 5 shows how extensively alloys are used in new aircraft construction. The new alloys are strong, lightweight and last longer than alloys used in the past. Also, a lighter plane is less expensive to fly.

**Space-Age Alloys**  Titanium alloy panels, developed for the space shuttle heat shield, might be used on future reusable launch vehicles that are designed to carry payloads to the International Space Station. Titanium and metallic alloys with similar heat-resistive and strength properties may prove to be key materials for other space applications as well.

![Figure 5](image.png)  This commercial aircraft uses new alloys in its construction. Notice that the aircraft skin is mostly alloy construction. **Infer why alloys are important to manufacturers.**
New Titanium Alloy Heat Shield
The original heat shield on the space shuttle uses ceramic tiles that are prone to cracking as a result of the high temperature and stress they experience during reentry into Earth’s atmosphere. Each broken ceramic tile must be removed carefully and a new one glued into place before the shuttle can be used on another mission. This maintenance is expensive, and damaged tiles are physically difficult to replace.

The new titanium alloy tiles, shown in Figure 6, are much larger and easier to attach to the heat shield than the ceramic tiles are. A lower maintenance cost for the heat shield is expected by using the new alloy. Scientists and engineers also predict that the new alloy will protect the space shuttle as well as the old ceramic tiles did.

Figure 6 New alloys are being tested for use on the space shuttle. An experimental titanium alloy heat-resistant tile similar to this example may cover space shuttles in future flights.

Summary
Alloys
- Alloy metals defined several historical time periods, including the Bronze Age and the Iron Age.
- An alloy has characteristics that are different from, and often improved upon, the individual elements of the alloy.

Properties of Metals and Alloys
- Alloy materials are defined by their physical properties.

Uses of Alloys
- Alloy materials are used in industry, food service, medicine, and aeronautics.

New Alloys
- New alloys that are strong and lightweight can be used for high-tech applications including aircraft and spacecraft.

Self Check
1. Identify two medical uses of alloys.
2. List the properties of metals and alloys.
3. Describe how steels are classified.
4. Explain the effects of adding small amounts of another substance to a material.
5. Think Critically If you were designing a skyscraper in an earthquake zone, what properties would the structural materials need?

Applying Math
6. Calculate Use the information from Figure 3 to calculate the actual amount of gold in a 65-g, 14-karat gold necklace.
7. Find Mass If a 7.6-g sample of copper can be hammered into a 2-cm × 2-cm sheet, calculate the number of grams necessary to hammer a 17-cm × 17-cm sheet under the same manufacturing conditions.
Ceramics

Do you think of floor tiles, pottery, or souvenir nicknacks when you see the word ceramic? By definition, ceramics are materials that are made from dried clay or claylike mixtures. Ceramics have been around for centuries—in fact, pieces of clay pottery from 10,000 B.C. have been found. The first walled town, Jericho, was built about 8,000 B.C. The wall surrounding Jericho, as well as the homes inside the walls were constructed of bricks made from mud and straw that were baked in the Sun. Around 1,500 B.C., the first glass vessels were made and kilns were used to fire and glaze pottery. By 50 B.C. the Romans developed concrete and used it as a building material. Some of the structures built by the Romans still stand today. About the same time that Romans were developing concrete, the Syrians were developing glass-blowing techniques to make glass vessels. Pottery, bricks, glass, and concrete are examples of ceramics.

How are ceramics made? Traditional ceramics are made from easily obtainable raw materials—clay, silica (sand), and feldspar (crystalline rocks). These raw materials were used by ancient civilizations to make ceramic materials and still are used today. However, some of the more recent ceramics are made from compounds of metallic elements and carbon, nitrogen, or sulfur.

**Reading Check**

What raw materials are used to make traditional ceramic objects?
Firing Ceramics After the raw materials are processed, ceramics usually are made by molding the ceramic into the desired shape, then heating it to temperatures between 1,000°C and 1,700°C. The heating process, called firing, causes the spaces between the particles to shrink, as shown in Figure 7. The entire object shrinks as the spaces become smaller. This extremely dense internal structure gives ceramics their strength. This is demonstrated by the use of ceramics on the space shuttle heat shield. They are able to withstand the high temperatures and stress of reentry into Earth’s atmosphere. However, these same ceramics also are fragile and will break if they are dropped or if the temperature changes too quickly.

Traditional Ceramics Ceramics are known also for their chemical resistance to oxygen, water, acids, bases, salts, and strong solvents. These qualities make ceramics useful for applications where they may encounter these substances. For instance, ceramics are used for tableware because your foods contain acids, water, and salts. Ceramic tableware is not damaged by contact with foods containing these substances.

Traditional ceramics also are used as insulators because they do not conduct heat or electricity. You may have seen electric wires attached to poles or posts with ceramic insulators. These insulators keep the current flowing through the wire instead of into the ground.

The properties of ceramics can be customized, which makes them useful for a wide variety of applications as shown in Figure 8. Changing the composition of the raw materials or the manufacturing process changes the properties of the ceramic. Manufacturing ceramics is similar to manufacturing alloys because scientists determine which properties are required and then attempt to create the ceramic material.

**WARNING:** Wear goggles and an apron while doing this lab. Wash your hands before leaving the lab.

1. Mix four tablespoons of sand, four tablespoons of aquarium gravel or small pebbles, and six tablespoons of white glue in a paper cup.
2. Add enough water to thoroughly mix the ingredients.
3. Stir the mixture until it is smooth.
4. Allow the mixture to sit for several days and observe.
5. Dispose of the cup as instructed by your teacher.

**Analysis**

1. Describe what happened to your mixture after several days. Is it a ceramic?
2. How is your mixture similar to concrete?
3. What are some of the properties of your product?
Modern Ceramics  Ceramics can be customized to have non-traditional properties, too. Ceramics traditionally are used as insulators, but there are exceptions. For instance, chromium dioxide conducts electricity as well as most metals, and some copper-based ceramics have superconductive properties. One application of nontraditional ceramics uses a transparent, electrically conductive ceramic in aircraft windshields to keep them free of ice and snow.

Ceramics have medical uses. Figure 9 shows a ceramic replacement hip socket for use in the human body. Ceramics can be used in the body because they are strong and resistant to body fluids, which can damage other materials. In the medical field, surgeons use ceramics for the repair and replacement of joints such as hips, knees, shoulders, elbows, fingers, and wrists. Dentists use ceramics for tooth replacements, repair, and braces.

Identifying the Problem

As an engineer working on the design of a new car, you need to select the right ceramic materials to build parts of the car’s engine and its onboard computer. The table above shows the materials you have to choose from. Using the properties given in the table, decide which materials should be used for the engine parts and the onboard computer. Be prepared to explain your answer.

Solving the Problem

1. Which of the above materials would you use when you build the engine? Explain the factors that you considered to make your decision.
2. Which of the above materials would you select when building the onboard computer? Explain your selection.
3. If you had to choose a material for building the car’s bumper, what factors would you consider? Do you think that a ceramic material would be the best choice? Explain your answer.
**Semiconductors**

Another class of versatile materials is semiconductors. Semiconductors are the materials that make computers and other electronic devices possible.

**The Periodic Table** What are semiconductors? To answer this, think about the periodic table. The elements on the left side and in the center of the table are metals. Metals are good conductors of electricity. Nonmetals, located on the right side of the table, are poor conductors of electricity and are electrical insulators. The small number of elements found along the staircase-shaped border shown in Figure 10 between the metals and nonmetals are metalloids. Some metalloids, such as silicon (Si) and germanium (Ge), are semiconductors. Semiconductors are poorer conductors of electricity than metals but better conductors than nonmetals, and their electrical conductivity can be controlled. This property makes semiconductor devices useful.

**Controlling Conductivity** Adding other elements to some metalloids can change their electrical conductivities. For example, the conductivity of silicon can be increased by replacing silicon atoms with atoms of other elements, such as arsenic (As) or gallium (Ga), as shown in Figure 11. If the added atoms, called impurities, have fewer electrons than silicon atoms, the silicon crystals will contain holes, or areas with fewer electrons. Electrons now can move from hole to hole across the crystal, increasing conductivity.

Adding even a single atom of one of these elements to a million silicon atoms significantly changes the conductivity. By controlling the type and number of atoms added, the conductivity of silicon can vary over a wide range.
Doping  The process of adding impurities or other elements to a semiconductor to modify the conductivity is called **doping**. Depending on the element added, the overall number of electrons in the semiconductor is increased or decreased. If the impurity causes the overall number of electrons to increase, the semiconductor is called an *n-type* semiconductor. If doping reduces the overall number of electrons, the semiconductor is called a *p-type* semiconductor.

Integrated Circuits  By placing *n*-type and *p*-type semiconductors together, semiconductor devices such as transistors and diodes can be made. These devices are used to control the flow of electrons in electrical circuits, as shown in Figure 12. During the 1960s, methods were developed for making these components extremely small. At the same time, the integrated circuit was developed.

An **integrated circuit** contains many semiconducting devices. Integrated circuits as small as 1 cm on a side can contain millions of semiconducting devices. Because of their small size, integrated circuits are sometimes called microchips. Figure 13 shows how small an integrated circuit chip can be.

Being able to pack so many circuit components onto a tiny integrated circuit was a technological breakthrough. This makes it possible for today’s televisions, radios, calculators, and other devices to be smaller in size, cheaper to manufacture, and capable of more advanced functions than older versions. Also, because the circuit components are so close together, it takes less time for electric current to travel through the circuit. This enables electronic signals to be processed more rapidly by computers, cell phones, and other electronic appliances. Figure 14 illustrates how integrated circuits have given us faster, smaller, and more capable computers since the 1940s.
The earliest, room-size computers relied on vacuum tubes to store data. Today’s computers use microchips, tiny flakes of silicon engraved with millions of circuit components. A selection of computers is shown here, beginning with the Electronic Numerical Integrator and Computer (ENIAC), developed by the Army in 1946.

A technician programs the ENIAC, the first electronic computer. Some of the 18,000 vacuum tubes that ran the ENIAC are shown at right.

A young woman operates a 1960s-era computer. The inset photo shows an integrated circuit from such a computer.

Teenagers surf the Internet on a modern personal computer. The microchips that store computer programs are now smaller than a fingernail.
Self Check
1. Describe how ceramic materials are made.
2. List five uses of ceramic materials.
3. Describe electrical conductivity of ceramics.
4. Explain what semiconductors are and where they are used.
5. Think Critically Computers and software have changed the way businesses operate. If you operated a distribution center for a manufacturer, how would you use computers to assist you?
6. Calculate Ceramic A forms when heated to 1,400°C and has a density of 5.3 g/cm³. Ceramic B forms at a temperature 675°C cooler and is four times as dense. What temperature is required to form Ceramic B and what is its density?
7. Solve a Problem A developmental ceramic is designed to be 35% silica and 65% sulfur. If a researcher needs 75 g of this material for a test, how many grams of each component will she need?

Semiconductors and Computers
Semiconductors make today’s computers possible. A desktop computer is an example of a device that uses semiconductors. A computer has three main jobs. First, it must be able to receive and store the information that is needed to solve a problem. Next, it must be able to follow instructions to perform tasks in a logical way. Finally, a computer must communicate information to the outside world. All three jobs can be done with a combination of hardware and software components.

Computer hardware refers to the major permanent components of a computer, such as the keyboard, monitor, mouse, and central processing unit (CPU). These components are shown in Figure 15. Software refers to the instructions that tell the computer what to do. When a computer system is functioning properly, the hardware and software work together to perform tasks.

Figure 15 Desktop computers use semiconductors to perform their tasks. Infer what you think computers will look like in twenty years.
Polymers

Polymers are a class of natural or manufactured substances that are composed of molecules arranged in large chains with small, simple, repeating units called monomers. A monomer is one specific molecule that is repeated in the polymer chain. Each link in the chain is a monomer. Polypropylene, for example, might have 50,000 to 200,000 monomers in its chain. Several examples of manufactured polymers are shown in Table 2.

Not all polymers are manufactured. Some occur naturally. Proteins, cellulose, and nucleic acids are polymers found in living things. In this section, the focus will be on manufactured or synthetic polymers. Synthetic means that the polymer does not occur naturally, but it was manufactured in a laboratory or chemical plant. Many synthetic polymers are designed to outperform their natural counterparts.

Table 2 Common Polymers

<table>
<thead>
<tr>
<th>Polymer</th>
<th>Monomer</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyethylene</td>
<td>[—CH₂—CH₂—]</td>
<td>bottles, garment bags</td>
</tr>
<tr>
<td>Polyvinyl chloride (PVC)</td>
<td>[—CH₂—CHCl—]</td>
<td>pipe, bottles, compact discs, computer housing</td>
</tr>
<tr>
<td>Polypropylene</td>
<td>[—CH₂—CH—]</td>
<td>rope, luggage, carpet, film</td>
</tr>
<tr>
<td>Polystyrene</td>
<td>[CH₂—CH₂—]</td>
<td>toys, packaging, egg cartons, flotation devices</td>
</tr>
</tbody>
</table>
History of Synthetic Polymers Humankind has used natural polymers for centuries. The ancient Egyptians soaked their burial wrappings in natural resins to help preserve their dead. Animal horns and turtle shells, which contain natural resins, were used to make combs and buttons for many years. In the 1800s, scientists began developing processes to improve natural polymers and to create new ones in the laboratory.

In 1839, Charles Goodyear, an American inventor, found that heating sulfur and natural rubber together improved the qualities of natural rubber. By treating the rubber with sulfur, the natural rubber was no longer brittle when it became cold or soft when it became hot. In the late 1860s, John Hyatt developed celluloid as a replacement for ivory in billiard balls. Celluloid was used in other products such as umbrella handles and toys. These early polymers had many drawbacks, but they were the beginning of the development of a huge class of materials now referred to as polymers. Today, so many types of synthetic polymers exist that they tend to be divided into groups such as plastics, synthetic fibers, adhesives, surface coatings, and synthetic rubbers. Figure 16 shows a time line of when some of these materials were created.

Hydrocarbons Today, synthetic polymers usually are made from fossil fuels such as oil, coal, or natural gas. Fossil fuels are composed primarily of carbon and hydrogen and are referred to as hydrocarbons. Because synthetic polymers are made from hydrocarbons, carbon and hydrogen are the primary components of most synthetic polymers.

**Synthetic Polymers** Many disposable items such as plates, diapers, trash bags, and utensils are made from synthetic polymers. These products are used once, then thrown away. Most synthetic polymers do not decompose in landfills. In your Science Journal, infer the problems that this might cause and suggest solutions to these problems.

**Figure 16** Polymers were developed in the late 1800s, but they did not become widely used until after World War II in 1945.
Changing Properties  Polymers are a class of materials with a wide range of uses. The reason that polymers can be used for so many applications is directly related to the ease with which their properties can be modified. Polymers are long chains of monomers. If the composition or arrangement of monomers is changed, then the properties of the material will change. 

**Figure 17** shows that the monomer ethylene can be modified to produce a polymer with different properties and uses. Ethylene has only two carbon atoms and six bonding sites. The number of carbon atoms in the polymer can be high, and each bonding site represents a possibility of a change in properties. Polyethylene can be high density or low density depending upon how the molecules are attached to the monomer. One of the substances on the monomer can be replaced by another substance or a group of substances and the properties will change, too. The possibilities for creating new materials are almost limitless.

The Plastics Group  Plastics are widely used for many products because they have desirable properties. Plastics are usually lightweight, strong, impact resistant, waterproof, moldable, chemical resistant, and inexpensive. Examples of plastics are easy to find. They are used to make toys, computer housing, telephones, containers, plates, and so on. The properties of plastics vary widely within this group. Some plastics are clear, some melt at high temperature, and some are flexible. Transparency, melting temperature, and flexibility are properties of plastics that relate to the composition of the polymer.

High-density polyethylene, HDPE, is firmer, stronger, and less translucent than LDPE. This chain has little side-branching, which allows the chain to pack closer together, thus giving it a higher density and different properties.

Low-density polyethylene, LDPE, is flexible, tough, and chemical resistant. The chain has a great deal of side-branching, which causes low density.

Polyvinyl chloride (PVC) is used in building materials. The substitution of chlorine for a hydrogen in the polyethylene chain makes the polymer harder and more heat resistant.


**Synthetic Fibers** Nylon, polyester, acrylic, and polypropylene are examples of polymers that can be manufactured as fibers. Most synthetic fibers are composed of carbon chains because they are produced from petroleum or natural gas. Synthetic fibers can be mass-produced to almost any set of desired properties. Nylon is often used in wind and water-resistant clothing such as lightweight jackets. Polyester and polyester blended with natural fibers such as cotton often are used in clothing. Polyester fiber also is used to fill pillows and quilts. Polyurethane is the foam used in mattresses and pillows.

Synthetic fibers called aramids are a family of nylon with special properties. **Figure 18** shows some uses for these materials. Aramids are used to make fireproof clothing. Firefighters, military pilots, and race car drivers are examples of professionals that make use of this special fabric. Another aramid fiber is used to make bulletproof vests, race car survival cells, puncture-resistant gloves, and motorcycle clothing. Although they are lightweight, these aramids are five times stronger than steel.

**Adhesives** Synthetic polymers are used to make adhesives that can be modified to provide the best properties for a particular application. Contact cements are used in the manufacture of automobile parts, furniture, leather goods, and decorative laminates. They adhere instantly and the bond gets stronger after it dries. Structural adhesives are used in construction projects. One structural adhesive, silicone, is used to seal windows and doors to prevent heat loss in homes and other buildings. Ultraviolet-cured adhesives are used by orthodontists to adhere brace brackets to teeth. These adhesives bond after exposure to ultraviolet light. Other types of adhesives are hot-melts and transparent, pressure-sensitive tape.

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**Reading Check** What are five uses of adhesives?
Surface Coatings and Elastic Polymers  Many surface coatings use synthetic polymers. Polyurethane is a popular polymer that is used to protect and enhance wood surfaces. Many paints use synthetic polymers in their composition, too.

Synthetic rubber is a synthetic elastic polymer. It is used to manufacture tires, gaskets, belts, and hoses. The soles of some shoes also are made from this rubber.

Taking a Cue from Nature  Spinning long fibers into threads and fabrics is not an original idea. Spiders spun fibers for their webs long before humans copied the idea and began spinning fibers themselves. Nylon fiber is another idea borrowed from nature. The silkworm produces a highly desirable fiber that is woven into fabric for items such as blouses and stockings. Can you imagine how long it would take a silkworm to produce enough silk for one blouse? Nylon was produced in the laboratory as a possible substitute for silk. Why do you think natural silk fabric is more expensive than nylon fabric?

Composites  

The properties of a synthetic polymer can be altered by using more than one material. A composite is a mixture of two or more materials—one embedded or layered in the other. Composite materials of plastic are used to construct boat and car bodies, as shown in Figure 19. These bodies are made of a glass-fiber composite that is a mixture of small threads or fibers of glass embedded in a plastic. The structure of the fiberglass reinforces the plastic, making a strong, lightweight composite. If a substance is lightweight but brittle, such as some plastics, embedding flexible fibers into it can alter the brittleness property. After the substance has the flexible fibers embedded, the product is less brittle and can withstand greater forces before it breaks. Glass fibers are used often to reinforce plastics because glass is inexpensive, but other materials can be used as well.
**Composites in Flight** Composite materials are used in the construction of satellites. Lighter-weight satellites are less expensive to launch into orbit, yet the structure still is able to withstand the stress of the launch. Carbon fibers are used to strengthen the plastic body, creating a material that is four times more firm and 40 percent stronger than aluminum. Satellites made of graphite composites are about 13 percent lighter than satellites made of aluminum. The composite material is stronger and lighter in weight than aluminum, therefore it is less expensive to launch and can endure the stress of the launch better.

Commercial aircraft use composite materials in their construction, as shown in Figure 20. Aircraft made of composites also benefit from the strong yet lightweight properties of composite materials. The weight of this aircraft was reduced by more than 2,600 kg by using advanced alloys and composite materials. The lower weight results in cost savings by reducing the amount of fuel required to operate the aircraft.

**Why are composites used in aircraft?**

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**Summary**

**Polymers**
- The composition and chemistry of the polymers allows almost limitless modifications.
- Synthetic polymers are those that have been developed in the lab or manufacturing facility; they do not occur naturally.
- Some of the common classes of synthetic polymers include plastics, fibers, adhesives, and surface coatings.

**Composites**
- Composites are a class of materials made by embedding one or more components into another.
- Composite materials often are selected for products because their properties offer savings and performance benefits.

**Self Check**

1. Explain what a polymer is and give three examples of items that are made from polymers.
2. Identify the raw materials that are used to make most synthetic polymers.
3. Explain what a composite material is and give three examples of items that are made from composites.
4. Classify synthetic polymers into groups based upon their uses.
5. Think Critically How are synthetic polymers creating waste-disposal problems? Discuss possible solutions to this problem.

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**Applying Math**

6. Find Mass A telecommunications company launches 10,000-kg satellites. A new satellite made from composites promises to reduce that mass by 25%. What is the mass of the new satellite?
This substance is fun to play with. But how do you describe its properties?

**Real-World Question**

What are the properties of this new material and what can it be used for?

**Goals**

- **Predict** the properties of this material.
- **Determine** possible uses for the material.

**Materials**

- white glue
- borax laundry soap
- warm water
- 250-mL beaker or cup

**Safety Precautions**

**WARNING:** Never eat lab materials.

**Procedure**

1. Prepare a data table to record your observations of the following: stretched slowly, stretched quickly, rolled into a ball and left alone, pressed onto newspaper ink, dropped on a hard surface.
2. Put about 100 mL of warm water in the larger beaker and add borax laundry soap until soap no longer dissolves.
3. Put 5 mL of water and 10 mL of white glue into the smaller beaker and mix completely.
4. Add 5 mL of the borax solution to the glue solution and continue mixing for a couple of minutes.
5. When the substance firms up, remove it from the container and continue to mix it by pressing with your fingers until it is like soft clay.
6. **Examine** the properties of this material and record them in your data table.

**Conclude and Apply**

1. **Identify** the properties of this material.
2. **Evaluate** Get together with other students and brainstorm. What could this material be used for, and which of its properties would make it useful for that purpose?
3. **Apply** You’re in charge of marketing this product. Prepare an advertisement with text and graphics on a sheet of notebook paper. Which magazine would you place this ad in and why?

**Communicating Your Data**

Compare your conclusions with those of other students in your class. For more help, refer to the **Science Skill Handbook**.
Can polymer composites be stronger than Steel?

Real-World Question

Why are composite materials used instead of wood or metal in high-performance applications? Scientists and engineers test many materials before selecting the best one for a specific use. Composites are used in aircraft parts, sports equipment, and space vehicles because of their strength and low weight. What other factors might be important? How do you measure performance and choose the best material for an application?

Procedure

1. Hook the spring scale to the center of the fiberglass rod. Have a team member pull down on the spring scale until the top of the test rod moves down 1 cm from the zero point. Record the scale reading on the data table.

Goals

- **Model** appropriate equipment to test wood, steel, and fiberglass composite rods.
- **Measure** the force required to flex the test rods.
- **Calculate** the relative flexibility of each rod.
- **Estimate** the performance of each material.

Possible Materials

- meterstick
- spring scale (0–12-kg range and 0–2-kg range)
- wood, steel, and fiberglass composite rods (6.35 mm in diameter by 50 cm long)
- supports to hold the test rods
- graph paper

Safety Precautions

WARNING: Wear safety goggles at all times during this lab.
2. Pull down on the spring scale until the rod flexes 2 cm, then 3 cm. Record both of the spring scale readings on the data chart.

3. Repeat steps 1 and 2 on the steel and wood rods. Record the data in your table. Refer to the example table shown here.

**Analyze Your Data**

1. **Graph** For each of the rods, graph the force measured on the y-axis and the distances on the x-axis.

2. **Calculate** the slope of each line in kilograms per centimeter. The slope is a relative measure of the flexibility of the samples.

3. **Determine** the specific performance number, which is used to compare different materials, by dividing the slope of each line by the density of the corresponding material. The densities are: composite = 1.2 g/cm³, steel = 7.9 g/cm³, and wood = 0.5 g/cm³.

**Conclude and Apply**

1. **Identify** which rod had the highest specific performance number. What is meant by the statement that a polymer composite is twice as strong as steel?

2. **Analyze** which variables could affect the flexibility measurement.

3. **Model** Using the data that you have gathered, create a model exhibit showing possible construction uses for each of these materials. Indicate the reason the specific material was chosen.

**Communicating Your Data**

Give an oral presentation on choosing the best material for a specific application to another class of students using your model.
In 1964, Stephanie Kwolek was a chemist working at a research laboratory. Her assignment? Create a new type of tough, lightweight fiber. Kwolek’s routine at the lab was about the same each day. She combined different substances in test tubes. She stirred them. She heated them. Then she would have any new substance spun into fibers and tested.

A Shocking Discovery

At one point, Kwolek was working with two polymers. She wanted to use heat to combine them, but they would not melt. So she decided to use a solvent to dissolve them. But when she poured the solvent onto one of the polymers, she got something unlike anything she had ever seen. Not only did it look different, it behaved differently when she stirred it. It separated into two distinct layers.

Kwolek thought this strange liquid might be something special. She asked one of her coworkers to spin it into fibers using a machine called a spinneret. The other chemist refused at first, saying the liquid wouldn’t form fibers. And besides, it would probably gum up the equipment. But Kwolek had a hunch about this liquid. So she persisted until the other chemist agreed to try to spin the liquid into fibers.

A New Type of Fiber

What they found was shocking. The fibers that formed in the spinneret were very lightweight, but also extremely stiff and strong. Kwolek had accidentally discovered a new type of synthetic fiber—a fiber made from a new substance called a liquid-crystal solution.

This new fiber was five times stronger than steel, and over the decades since its discovery, it has been put to many uses, such as in bulletproof vests, boat hulls, fiber-optic cables, cut-resistant gloves, airplane parts, skis, tennis rackets, and parts of spacecraft. The discovery was a huge accomplishment for Kwolek and has benefited many people in the form of bulletproof vests used by police officers and the tough clothing used by firefighters.

This police dog can thank Stephanie Kwolek for its bulletproof vest!

Research  Visit your school’s media center or the link to the right to find out more about the superfiber Kwolek discovered. Compare what you uncover with what others in the class find.

For more information, visit gpscience.com/time
Section 1 Materials with a Past

1. People have been making and using alloys for thousands of years. Some common alloys include bronze, brass, and various alloys of iron.

2. An alloy is a mixture of a metal with one or more other elements. Metals and alloys, like those shown here, have the properties of luster, ductility, malleability, and conductivity.

Section 2 Versatile Materials

1. Ceramics are used in a wide range of products, such as aircraft windshields. This is due to the ability of scientists to customize the properties of ceramics.

2. Semiconductors are made from silicon doped with other elements.

3. Ceramic materials are made by molding the object, and then heating the object to high temperatures. This process increases the density of the material.

4. Integrated circuits contain n-type and p-type semiconducting devices.

Section 3 Polymers and Composites

1. Polymers are a class of natural or human-made substances that are composed of molecules that are in large chains with simple repeating units called monomers.

2. Synthetic polymers can be produced in many forms, ranging from thin films to thick slabs or blocks. Synthetic fibers are produced in thin strands that can be woven into fabrics.

3. A composite is a mixture of two materials, one embedded in the other. Reinforced concrete and fiberglass are examples of composites. The skateboard in the figure to the right is constructed of a fiberglass composite. The composite material is strong and flexible.

Foldables Use the Foldable that you made at the beginning of this chapter to help you review classifications of materials.
**Using Vocabulary**

- alloy p. 758
- ceramics p. 764
- composite p. 775
- conductivity p. 759
- doping p. 768
- ductility p. 759
- luster p. 759
- malleability p. 759
- monomer p. 771
- polymer p. 771
- semiconductor p. 767
- synthetic p. 771

**Fill in the blank with the correct word or words.**

1. _______ is the property of metals and alloys that describes their ability to be hammered or rolled into thin sheets.
2. _______ are used to make heat shield tiles for the space shuttle, but may be replaced by an alloy that is less fragile.
3. Fiberglass is a(n) _______ material that is used to make boats and skateboards.
4. Fiberglass is a(n) _______.
5. Chrome and other shiny, reflective surfaces illustrate the property of _______.
6. _______ are used to make plastics for products such as food containers, toys and electronic cases.

**Checking Concepts**

Choose the word or phrase that best answers the question.

7. Which metal replaces bronze as a widely used metal?
   A) copper    C) zinc
   B) tin       D) iron

8. Why are metals and alloys good conductors of heat and electricity?
   A) They have loosely bound electrons within the atom.
   B) They have luster and malleability.
   C) They are composed of mixtures.
   D) They have a shiny appearance.

9. An alloy of steel will contain iron and what element?
   A) mercury    C) zinc
   B) tin        D) carbon

10. What raw materials are many synthetic polymers made from?
    A) hydrocarbons    C) fiberglass
    B) iron ore       D) ceramics

11. What type of fibers, shown above, are often used to reinforce polymers in automobile bodies?
    A) ceramic    C) hydrocarbon
    B) metal alloy    D) glass

12. Which element below is found in both brass and bronze?
    A) mercury    C) tin
    B) copper     D) zinc

13. Which of the following is a natural fiber?
    A) nylon    C) silk
    B) polyester    D) acrylic

14. Which group of materials below is not classified as synthetic?
    A) ceramics    C) composites
    B) alloys       D) metal ores

15. Customizing properties is NOT likely in which of the following?
    A) alloys    C) ceramics
    B) synthetic polymers

16. Which of the following elements is used to dope silicon crystals?
    A) carbon    C) copper
    B) zinc     D) gallium

_gpscience.com/vocabulary_puzzlemaker_
17. Copy and complete the following concept map using the terms composites, hydrocarbons, polymers, adhesives, plastics, synthetic fibers, and surface coatings.

18. Look at the polymer below. Draw the monomer upon which the polymer is based.

```
[ H H H H H H ]
[ C C C C C C ]
[ H CN H CN H CN ]
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19. Infer A lower-karat gold has less gold in it than a higher-karat gold. Why might you prefer a ring that is 10-karat gold over a ring that is 20-karat gold?

20. Explain the advantages and disadvantages of using composites in the world of sports.

21. Explain A synthetic fiber might be preferred over a natural fiber for use outdoors because it will not rot. How could this negatively affect the environment?

22. Compare and contrast alloys and ceramics.

23. Recognize Cause and Effect A student performing the two-page lab did not see any difference in the flexing of the rods. What are some possible causes of this result?

24. Measure in SI A bronze trophy has a mass of 952 g. If the bronze is 85 percent copper, how many grams of tin are contained in the trophy?

25. Interpret Graphs Tensile strength is a measure of the amount of “pulling” stress an object can withstand before it breaks or becomes damaged. The graph above shows a comparison of tensile strength for four materials that an engineer is considering for a new product. Which material should be considered if the product must be tear-resistant?

26. Compare Materials Refer to the chart above and calculate, in percent, how much more stress material 4 can withstand than material 3.

27. Find Mass An experimental alloy is made up of 28 percent gold and equal parts of two other elements, X and Y. How many grams of the other elements are in a 75-g sample of the alloy?
Record your answers on the answer sheet provided by your teacher or on a sheet of paper. Use the photo below to answer questions 1–3.

1. Which property of metals and alloys makes the French horn in the photograph above appear shiny?
   A. conductivity  
   B. ductility  
   C. luster  
   D. malleability

2. The French horn is made of brass. What element was combined with copper to make the brass?
   A. antimony  
   B. silver  
   C. tin  
   D. zinc

3. What property allowed the metal from which the instrument is made to be shaped into a French horn?
   A. conductivity  
   B. ductility  
   C. luster  
   D. malleability

4. Approximately when was the alloy bronze first discovered?
   A. 3500 B.C.  
   B. 350 B.C.  
   C. 1400 A.D.  
   D. 1800 A.D.

5. A 14-karat gold ring is 58% gold and 42% copper by mass. If the ring has a mass of 5.3 g, what is the mass of the gold used to make the ring?
   A. 2.2 g  
   B. 3.1 g  
   C. 5.3 g  
   D. 5.8 g

6. Which of the following terms refers to substances and materials that are created in a laboratory or chemical plant?
   A. component  
   B. composite  
   C. integrated  
   D. synthetic

Use the photo below to answer questions 7 and 8.

7. The photograph above shows a roll of copper electrical wire with a polymer coating. Which of the following properties are needed for the wire?
   A. ductility and malleability  
   B. ductility and conductivity  
   C. malleability and luster  
   D. malleability and conductivity

8. What property should the polymer coating on the wire have?
   A. low melting point  
   B. high conductivity  
   C. high malleability  
   D. high resistivity

Test-Taking Tip
Relax Stay calm during the test. If you feel yourself getting nervous, close your eyes and take five slow, deep breaths.
9. Which of the two semiconductors shown in the illustration above is an n-type and which is a p-type? How can you tell?

10. Explain how adding an impurity increases the conductivity of the semiconductor shown in the illustration.

11. What properties of ceramics make them suitable for use as heat shields on the space shuttles? What properties of ceramics are drawbacks to their use as shields?

12. The production of fibers from nylon is an idea that was borrowed from nature. Name two animals that produce fibers.

13. Where on the periodic table are semiconductors located?

14. Name three properties of traditional ceramics that make them useful as food serving bowls.

15. Why do manufacturers frequently use alloys when making different products, rather than just using metals?

16. Describe the process of firing traditional ceramics. Explain how this process affects the properties of the ceramics.

17. Explain what polymers are. There are so many types of polymers that they are divided into different groups. What are some of these groups?

18. Explain what is meant by a hole in a semiconductor. Describe what happens to holes as current flows through the semiconductor.

19. Describe some properties of modern ceramics that traditional ceramics do not have. What are some uses of modern ceramics?

20. The pet food and water bowl shown in the figure above is made of high-density polyethylene, HDPE. Describe the structure of HDPE and explain how its properties make it a good material for use as a pet bowl.

21. Explain why the pet bowl could not be made from low-density polyethylene, LDPE. What are some products that could be made from LDPE?

22. Name and describe the glass-fiber composite that is often used to make boat and car bodies. What are some properties of this composite?