section 1

Structure of Matter

as you read

What You'll Learn

- **Describe** characteristics of matter.
- **Identify** what makes up matter.
- **Identify** the parts of an atom.
- **Compare** the models that are used for atoms.

Why It's Important

Matter makes up almost everything we see—and much of what we can't see.

Review Vocabulary
density: the mass of an object divided by its volume

New Vocabulary
- matter
- atom
- law of conservation of matter
- electron
- nucleus
- proton
- neutron

What is matter?

Is a glass with some water in it half empty or half full? Actually, neither is correct. The glass is completely full—half full of water and half full of air. What is air? Air is a mixture of several gases, including nitrogen and oxygen, which are kinds of matter. **Matter** is anything that has mass and takes up space. So, even though you can't see it or hold it in your hand, air is matter. What about all the things you can see, taste, smell, and touch? Most are made of matter, too. Look at the things pictured in **Figure 1** and determine which of them are matter.

What isn't matter?

You can see the words on this page because of the light from the Sun or from a fixture in the room. Does light have mass or take up space? What about the warmth from the Sun or the heat from the heater in your classroom? Light and heat do not take up space, and they have no mass. Therefore, they are not forms of matter. Emotions, thoughts, and ideas are not matter either. Does this information change your mind about the items in **Figure 1**?

Reading Check *Why is air matter, but light is not?*

Figure 1 A rainbow is formed when light filters through the raindrops, a plant grows from a seed in the ground, and a statue is sculpted from bronze.
Identify *which are matter.*

Figure 2 Early Beliefs About the Composition of Matter

Many Indian Philosophers (1,000 B.C.)	Kashyapa, an Indian Philosopher (1,000 B.C.)	Many Greek Philosophers (500–300 B.C.)	Democritus (380 B.C.)	Aristotle (330 B.C.)	Chinese Philosophers (300 B.C.)
• Ether—an invisible substance that filled the heavens • Earth • Water • Air • Fire	• Five elements broken down into smaller units called parmanu • Parmanu of earth elements are heavier than air elements	• Earth • Water • Air • Fire	• Tiny individual particles he called *atomos* • Empty space through which atoms move • Each substance composed of one type of *atomos*	• Empty space could not exist • Earth • Water • Air • Fire	• Metal • Earth • Water • Air • Fire

What makes up matter?

Suppose you cut a chunk of wood into smaller and smaller pieces. Do the pieces seem to be made of the same matter as the large chunk you started with? If you could cut a small enough piece, would it still have the same properties as the first chunk? Would you reach a point where the last cut resulted in a piece that no longer resembled the first chunk? Is there a limit to how small a piece can be? For centuries, people have asked questions like these and wondered what matter is made of.

An Early Idea Democritus, who lived from about 460 B.C. to 370 B.C., was a Greek philosopher who thought the universe was made of empty space and tiny bits of stuff. He believed that the bits of stuff were so small they could no longer be divided into smaller pieces. He called these tiny pieces atoms. The term *atom* comes from a Greek word that means "cannot be divided." Today an **atom** is defined as a small particle that makes up most types of matter. **Figure 2** shows the difference between Democritus's ideas and those of other early scientists and philosophers. Democritus thought that different types of atoms existed for every type of matter and that the atom's identity explained the characteristics of each type of matter. Democritus's ideas about atoms were a first step toward understanding matter. However, his ideas were not accepted for over 2,000 years. It wasn't until the early 1800s that scientists built upon the concept of atoms to form the current atomic theory of matter.

INTEGRATE History

Atomism Historians note that Leucippus developed the idea of the atom around 440 B.C. He and his student, Democritus, refined the idea of the atom years later. Their concept of the atom was based on five major points: (1) all matter is made of atoms, (2) there are empty spaces between atoms, (3) atoms are complete solids, (4) atoms do not have internal structure, and (5) atoms are different in size, shape, and weight.

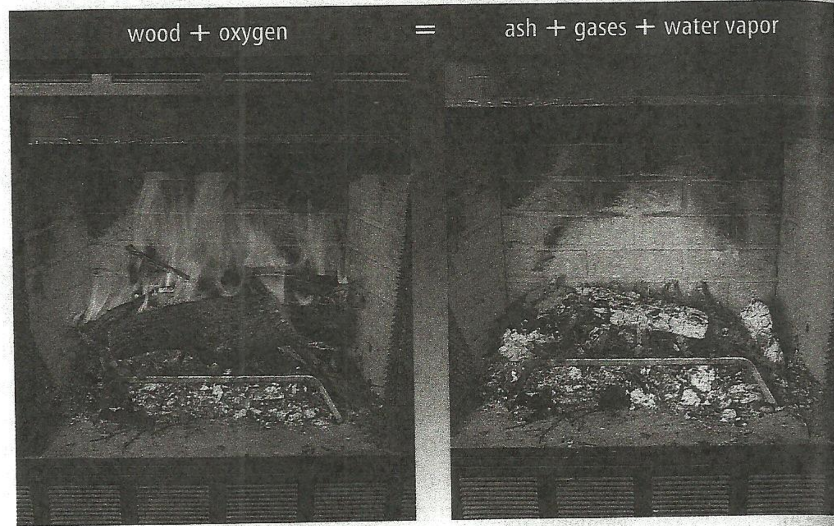


Figure 3 When wood burns, matter is not lost. The total mass of the wood and the oxygen it combines with during a fire equals the total mass of the ash, water vapor, carbon dioxide, and other gases produced.
Infer *When you burn wood in a fireplace, what is the source of oxygen?*

Mini LAB

Investigating the Unseen

Procedure

1. Your teacher will give you a **sealed shoe box** that contains **one or more items.**
2. Try to find out how many and what kinds of items are inside the box. You cannot look inside the box. The only observations you can make are by handling the box.

Analysis

1. How many items do you infer are in the box? Sketch the apparent shapes of the items and identify them if you can.
2. Compare your procedure with how scientists perform experiments and make models to find out more about the atom.

Lavoisier's Contribution Lavoisier (la VWAH see ay), a French chemist who lived about 2,000 years after Democritus, also was curious about matter—especially when it changed form. Before Lavoisier, people thought matter could appear and disappear because of the changes they saw as matter burned or rusted. You might have thought that matter can disappear if you've ever watched wood burn in a fireplace or at a bonfire. Lavoisier showed that wood and the oxygen it combines with during burning have the same mass as the ash, water, carbon dioxide, and other gases that are produced, as shown in **Figure 3**. In a similar way, an iron bar, oxygen, and water have the same mass as the rust that forms when they interact. From Lavoisier's work came the **law of conservation of matter**, which states that matter is not created or destroyed—it only changes form.

Models of the Atom

Models are often used for things that are too small or too large to be observed or that are too difficult to be understood easily. One way to make a model is to make a smaller version of something large. If you wanted to design a new sailboat, would you build a full-sized boat and hope it would float? It would be more efficient, less expensive, and safer to build and test a smaller version first. Then, if it didn't float, you could change your design and build another model. You could keep trying until the model worked.

In the case of atoms, scientists use large models to explain something that is too small to be looked at. These models of the atom were used to explain data or facts that were gathered experimentally. As a result, these models are also theories.

Dalton's Atomic Model In the early 1800s, an English schoolteacher and chemist named John Dalton studied the experiments of Lavoisier and others. Dalton thought he could design an atomic model that explained the results of those experiments. Dalton's atomic model was a set of ideas—not a physical object. Dalton believed that matter was made of atoms that were too small to be seen by the human eye. He also thought that each type of matter was made of only one kind of atom. For example, gold atoms make up a gold nugget and give a gold ring its shiny appearance. Likewise, iron atoms make up an iron bar and give it unique properties, and so on. Because predictions using Dalton's model were supported by data, the model became known as the atomic theory of matter.

Sizes of Atoms Atoms are so small it would take about 1 million of them lined up in a row to equal the thickness of a human hair. For another example of how small atoms are, look at **Figure 4.** Imagine you are holding an orange in your hand. If you wanted to be able to see the individual atoms on the orange's surface, the size of the orange would have to be increased to the size of Earth. Then, imagine the Earth-sized orange covered with billions and billions of marbles. Each marble would represent one of the atoms on the skin of the orange. No matter what kind of model you use to picture it, the result is the same—an atom is an extremely small particle of matter.

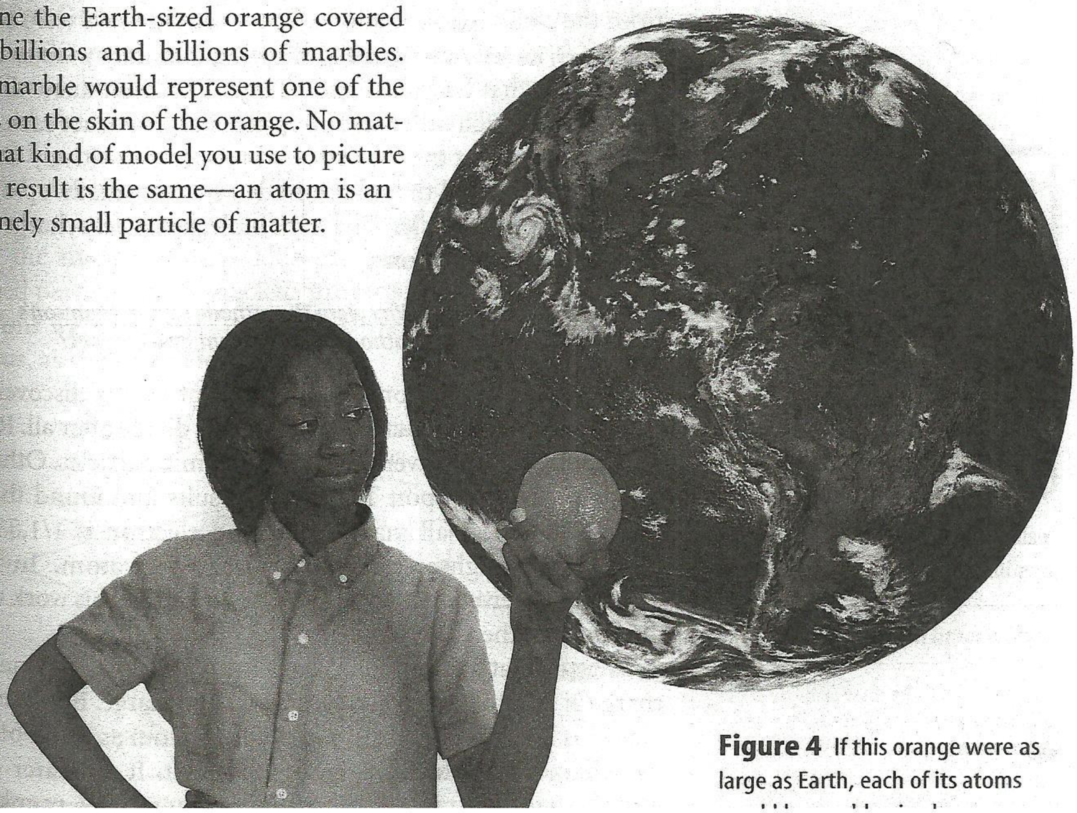
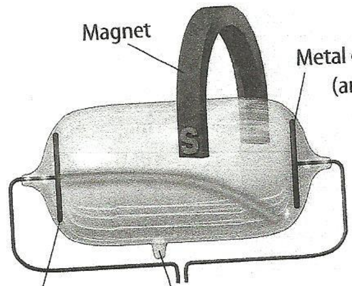


Figure 4 If this orange were as large as Earth, each of its atoms



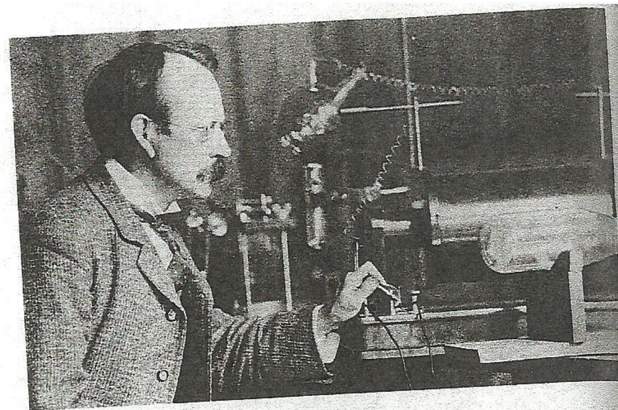


Figure 5 In Thomson's experiment, the magnet caused the cathode rays inside the tube to bend. **Describe** *what you think would happen to the cathode rays if the magnet were removed.*

Discovering the Electron One of the many pioneers in the development of today's atomic model was J.J. Thomson, an English scientist. He conducted experiments using a cathode ray tube, which is a glass tube sealed at both ends out of which most of the air has been pumped. Thomson's tube had a metal plate at each end. The plates were connected to a high-voltage electrical source that gave one of the plates—the anode—a positive charge and the other plate—the cathode—a negative charge. During his experiments, Thomson observed rays that traveled from the cathode to the anode. These cathode rays were bent by a magnet, as seen in **Figure 5,** showing that they were made up of particles that had mass and charge. Thomson knew that like charges repel each other and opposite charges attract each other. When he saw that the rays traveled toward a positively charged plate, he concluded that the cathode rays were made up of negatively charged particles. These invisible, negatively charged particles are called **electrons.**

Reading Check *Why were the cathode rays in Thomson's cathode ray tube bent by a magnet?*

Try to imagine Thomson's excitement at this discovery. He had shown that atoms are not too tiny to divide after all. Rather, they are made up of even smaller subatomic particles. Other scientists soon built upon Thomson's results and found that the electron had a small mass. In fact, an electron is 1/1,837 the mass of the lightest atom, the hydrogen atom. In 1906, Thomson received the Nobel Prize in Physics for his work on the discovery of the electron.

Matter that has an equal amount of positive and negative charge is said to be neutral—it has no net charge. Because most matter is neutral, Thomson pictured the atom as a ball of positive charge with electrons embedded in it. It was later determined that neutral atoms contained an equal number of positive and negative charges.

Science Online

Topic: Subatomic Particles

Visit red.msscience.com for Web links to information about particles that make up atoms.

Activity Can any of the particles be divided further? Display your data in a table.

Thomson's Model Thomson's model, shown in **Figure 6,** can be compared to chocolate chips spread throughout a ball of cookie dough. However, the model did not provide all the answers to the questions that puzzled scientists about atoms.

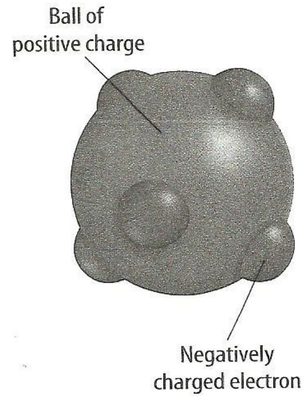


Figure 6 Thomson's model shows the atom as electrons embedded in a ball of positive charge.
Explain *how Thomson knew atoms contained positive and negative charges.*

Rutherford—The Nucleus Scientists still had questions about how the atom was arranged and about the presence of positively charged particles. In about 1910, a team of scientists led by Ernest Rutherford worked on these questions. In their experiment, they bombarded an extremely thin piece of gold foil with alpha particles. Alpha particles are tiny, high-energy, positively charged particles that he predicted would pass through the foil. Most of the particles passed straight through the foil as if it were not there at all. However, other particles changed direction, and some even bounced back. Rutherford thought the result was so remarkable that he later said, "It was almost as incredible as if you had fired a 15-inch shell at a piece of tissue paper, and it came back and hit you."

Positive Center Rutherford concluded that because so many of the alpha particles passed straight through the gold foil, the atoms must be made of mostly empty space. However, because some of the positively charged alpha particles bounced off something, the gold atoms must contain some positively charged object concentrated in the midst of this empty space. Rutherford called the positively charged, central part of the atom the **nucleus** (NEW klee us). He named the positively charged particles in the nucleus **protons.** He also suggested that electrons were scattered in the mostly empty space around the nucleus, as shown in **Figure 7.**

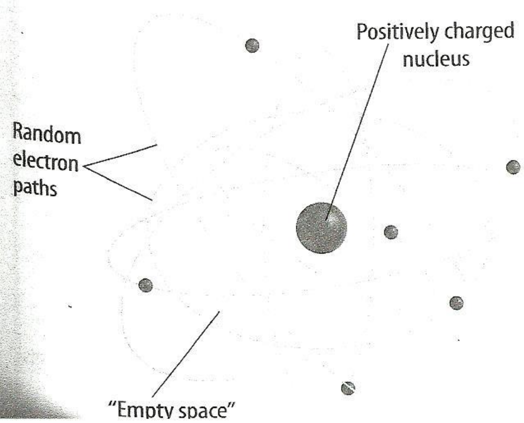


Figure 7 Rutherford concluded that the atom must be mostly empty space in which electrons travel in random paths around the nucleus. He also thought the nucleus of the atom must be small and positively charged.
Identify *where most of the mass of an atom is concentrated.*

Discovering the Neutron Rutherford had been puzzled by one observation from his experiments with nuclei. After the collisions, the nuclei seemed to be heavier. Where did this extra mass come from? James Chadwick, a student of Rutherford's, answered this question. The alpha particles themselves were not heavier. The atoms that had been bombarded had given off new particles. Chadwick experimented with these new particles and found that, unlike electrons, the paths of these particles were not affected by an electric field. To explain his observations, he said that these particles came from the nucleus and had no charge. Chadwick called these uncharged particles **neutrons** (NEW trahnz). His proton-neutron model of the atomic nucleus is still accepted today.

Improving the Atomic Model

Early in the twentieth century, a scientist named Niels Bohr found evidence that electrons in atoms are arranged according to energy levels. The lowest energy level is closest to the nucleus and can hold only two electrons. Higher energy levels are farther from the nucleus and can contain more electrons. To explain these energy levels, some scientists thought that the electrons might orbit an atom's nucleus in paths that are specific distances from the nucleus, as shown in **Figure 8.** This is similar to how the planets orbit the Sun.

The Modern Atomic Model As a result of continuing research, scientists now realize that because electrons have characteristics that are similar to waves and particles, their energy levels are not defined, planet-like orbits around the nucleus. Rather, it seems most likely that electrons move in what is called the atom's electron cloud, as shown in **Figure 9.**

INTEGRATE Career

Physicists and Chemists Physicists generally study the physical atom. The physical atom includes the inner components of an atom such as protons and neutrons, the forces that hold or change their positions in space and the bulk properties of elements such as melting point. Chemists, on the other hand, study the chemical atom. The chemical atom refers to the manner in which different elements relate to each other and the new substances formed by their union.

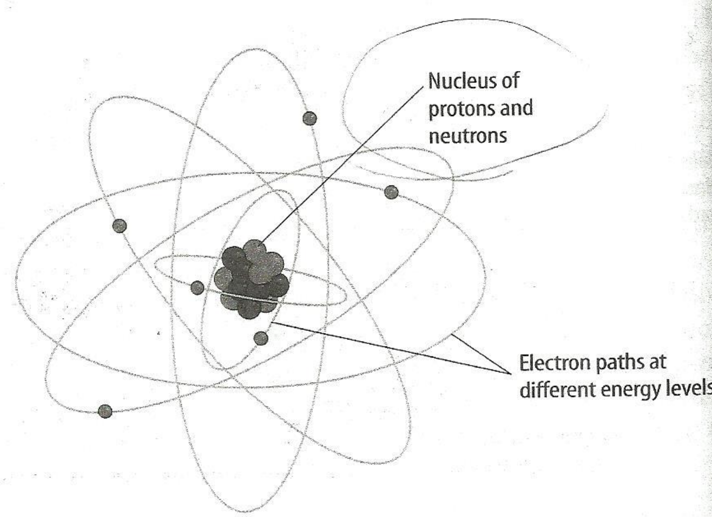


Figure 8 This simplified Bohr model shows a nucleus of protons and neutrons and electron paths based on energy levels.

The Electron Cloud The electron cloud is a spherical cloud of varying density surrounding the nucleus. The varying density shows where an electron is more or less likely to be. Atoms with electrons in higher energy levels have electron clouds of different shapes that also show where those electrons are likely to be. Generally, the electron cloud has a radius 10,000 times that of the nucleus.

Further Research By the 1930s, it was recognized that matter was made up of atoms, which were, in turn, made up of protons, neutrons, and electrons. But scientists, called physicists, continued to study the basic parts of this atom. Today, they have succeeded in breaking down protons and neutrons into even smaller particles called quarks. These particles can combine to make other kinds of tiny particles, too. The six types of quarks are *up, down, strange, charmed, top,* and *bottom.* Quarks have fractional electric charges of +2/3 or −1/3, unlike the +1 charge of a proton or the −1 charge of an electron. Research will continue as new discoveries are made about the structure of matter.

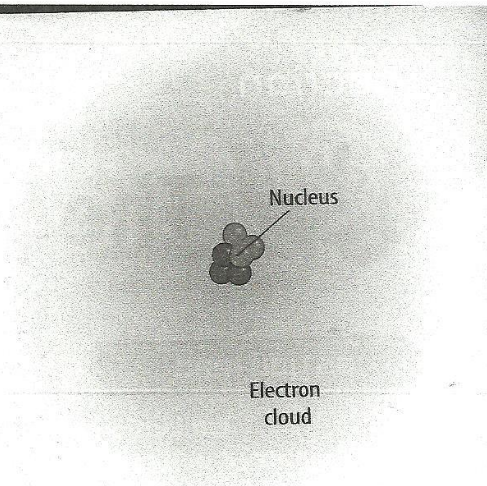


Figure 9 This model of the atom shows the electrons moving around the nucleus in a region called an electron cloud. The dark cloud of color represents the area where the electron is more likely to be found.
Infer *What does the intensity of color near the nucleus suggest?*

section 1 review

Summary

What is matter?

- Matter is anything that has mass and takes up space.
- Matter is composed of atoms.

Models of the Atom

- Democritus introduced the idea of an atom. Lavoisier showed matter is neither created nor destroyed, just changed.
- Dalton's ideas led to the atomic theory of matter.
- Thomson discovered the electron.
- Rutherford discovered protons exist in the nucleus.
- Chadwick discovered the neutron.

Improving the Atomic Model

- Niels Bohr suggested electrons move in energy levels.
- More recent physicists introduced the idea of the electron cloud and were able to break down protons and neutrons into smaller particles called quarks.

Self Check

1. **List** five examples of matter and five examples that are not matter. Explain your answers.
2. **Describe** and name the parts of the atom.
3. **Explain** why the word *atom* was an appropriate term for Democritus's idea.
4. **Think Critically** When neutrons were discovered, were these neutrons created in the experiment? How does Lavoisier's work help answer this question?
5. **Explain** the law of conservation of matter using your own examples.
6. **Think Critically** How is the electron cloud model different from Bohr's atomic model?

Applying Skills

7. **Classify** each scientist and his contribution according to the type of discovery each person made. Explain why you grouped certain scientists together.
8. **Evaluate Others' Data and Conclusions** Analyze, review, and critique the strengths and weaknesses of Thomson's "cookie dough" theory using the results of Rutherford's gold foil experiment.

section 2

The Simplest Matter

as you read

What You'll Learn

- **Describe** the relationship between elements and the periodic table.
- **Explain** the meaning of atomic mass and atomic number.
- **Identify** what makes an isotope.
- **Contrast** metals, metalloids, and nonmetals.

Why It's Important

Everything on Earth is made of the elements that are listed on the periodic table.

Review Vocabulary
mass: a measure of the amount of matter an object has

New Vocabulary
- element
- atomic number
- isotope
- mass number
- atomic mass
- metal
- nonmetal
- metalloid

The Elements

Have you watched television today? TV sets are common, yet each one is a complex system. The outer case is made mostly of plastic, and the screen is made of glass. Many of the parts that conduct electricity are metals or combinations of metals. Other parts in the interior of the set contain materials that barely conduct electricity. All of the different materials have one thing in common: they are made up of even simpler materials. In fact, if you had the proper equipment, you could separate the plastics, glass, and metals into these simpler materials.

One Kind of Atom Eventually, though, you would separate the materials into groups of atoms. At that point, you would have a collection of elements. An **element** is matter made of only one kind of atom. At least 110 elements are known and at least 90 of them occur naturally on Earth. These elements make up gases in the air, minerals in rocks, and liquids such as water. Examples of naturally occurring elements include the oxygen and nitrogen in the air you breathe and the metals gold, silver, aluminum, and iron. The other elements are known as synthetic elements. These elements have been made in nuclear reactions by scientists with machines called particle accelerators, like the one shown in **Figure 10.** Some synthetic elements have important uses in medical testing and are found in smoke detectors and heart pacemaker batteries.

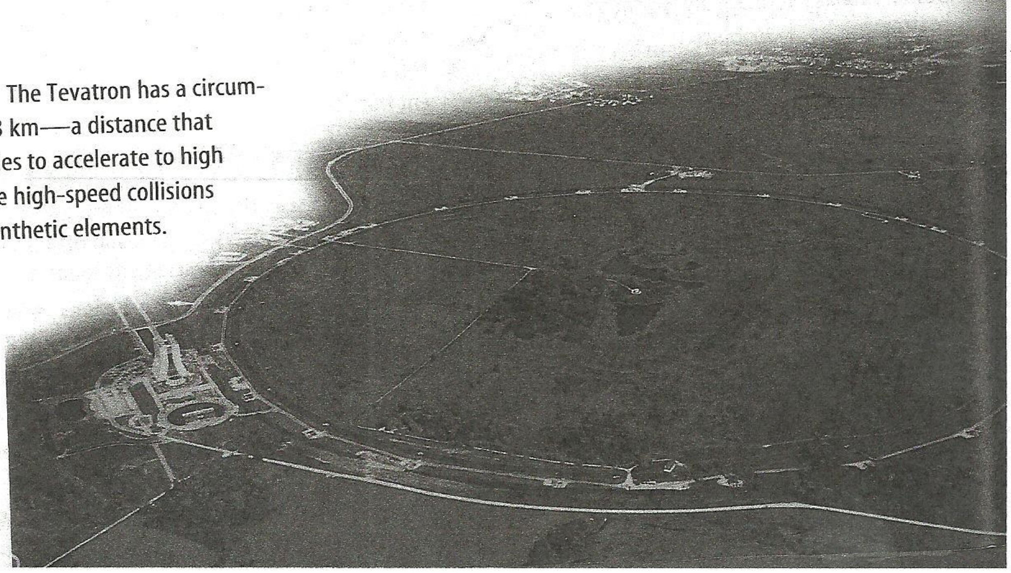


Figure 10 The Tevatron has a circumference of 6.3 km—a distance that allows particles to accelerate to high speeds. These high-speed collisions can create synthetic elements.