CONCEPT 3

An atom is made up of electrons, neutrons, and protons

Activity

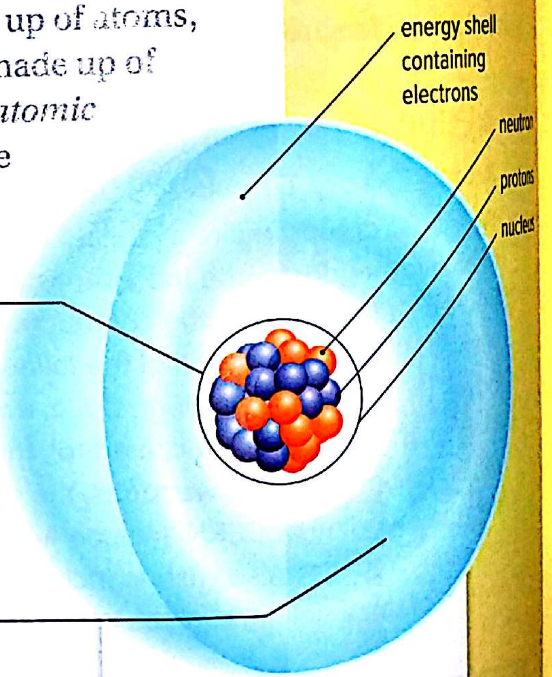
Cutting It Down to Size

Can you cut a piece of paper down to the size of an atom? Atoms vary in size, but a mid-sized atom is about 0.00000002 cm in diameter.

1. Take a strip of paper that is 25 cm long.
2. Predict how many times you would have to cut the strip in half to get a piece that is about 0.00000002 cm wide.
3. Start cutting. How many times were you able to cut your paper in half? How many more times would you have to cut to get your paper to the size of an atom?

atom the smallest particle of an element that retains the properties of that element

Today we know a lot about the nature and structure of atoms. An **atom** is defined as the smallest particle of an element that retains the properties of that element. All matter is made up of atoms, and atoms themselves are made up of smaller particles called *subatomic particles*. Key features of the atom are summarized in **Figure 2.31**.



nucleus

- The nucleus is the tiny region at the centre of the atom.
- The nucleus of most hydrogen atoms contains one proton.
- The nucleus of all other atoms contains both protons and neutrons.
- The number of protons in a nucleus determines the charge of the nucleus and the identity of an atom.

electron energy shell

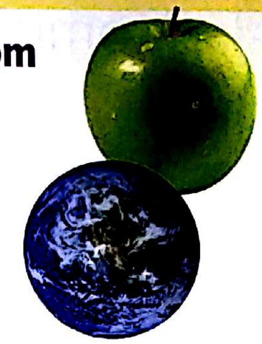
- The region that electrons occupy accounts for well over 99.99 percent of the volume of an atom.
- Electrons occupy specific regions called energy levels that surround the nucleus.
- An electron is not like a fast-moving particle racing around the nucleus. It is more like a spread-out cloud of negative charge that exists in the whole region all at once.

Figure 2.31 This model of the atom will help you explain the observations you make about matter in your study of chemistry.

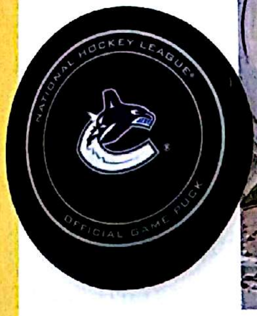
Electric Charge

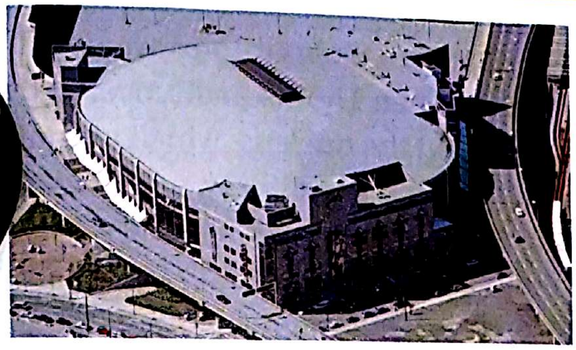
Electric charge comes in two types: positive and negative. Protons have a positive charge (1+ each), and electrons have a negative charge (1– each). The positive charge of the protons in the nucleus attracts the surrounding electrons. Neutrons have no charge. Atoms have equal numbers of protons and electrons, and so overall an atom is uncharged or neutral.

The Size of an Atom



Atoms are incredibly small. Suppose you enlarged everything on Earth so that an atom would become as big as a large apple. At this new scale, an apple would be as big as Earth!





The Size of the Nucleus Compared with an Atom

If a nucleus were the size of a hockey puck sitting at centre ice, the whole atom would include the entire rink, the seats, the building, and the surrounding streets and walkways or parking lot.

The Nuclear Force

Nuclei include multiple positively charged particles—protons—that are very close together. Normally, charged particles that have the same charge repel one another very strongly. But a force called the *nuclear force* (also called the *strong force*) acts within the nucleus to hold protons and neutrons together. It is very strong across very short distances—strong enough to counteract the repulsion between protons, keeping the nucleus from flying apart.

Connect to Investigation 2-I on pages 170–171

Subatomic Particles

Name	Symbol	Electric Charge	Relative Mass	Location in the Atom
proton	p^+	1+	1836	nucleus
neutron	n^0	0	1837	nucleus
electron	e^-	1–	1	surrounding the nucleus

Before you leave this page . . .

1. What are the three subatomic particles?
2. Compare and contrast the electron and the proton.
3. Use an analogy to describe the size or composition of an atom.
4. What does the existence of a nuclear force explain?

CONCEPT 4

Atomic theory continues to develop.

Activity

Atomic Theory in the Future

Do you think atomic theory is likely to change in the future? Write a brief blog post explaining your position. Support your ideas with examples.

According to Dalton's theory, atoms were indivisible and indestructible. Then Thomson discovered the electron and Rutherford discovered the nucleus, which was later found to be made up of neutrons and protons. The atom was not indivisible at all: it was made up of even smaller particles—*subatomic particles*. As scientists continued to study matter throughout the 20th century, they discovered that some of these subatomic particles were made up of still smaller particles.

Quarks

You may have heard the term "quark" before, perhaps in the title of CBC Radio's science program, Quirks and Quarks. According to current theories, quarks are *elementary particles*, meaning that they cannot be split apart into smaller particles. There are six different types, called *flavours* (really!) of quarks. They are classified based on their properties, which include mass and electric charge, and have the following creative names: *up*, *down*, *strange*, *charm*, *top*, and *bottom*.

Protons and neutrons are known as composite particles. As shown in **Figure 2.32**, they are both made up of quarks. Protons and neutrons also contain elementary particles called gluons. These act as a "glue" that binds quarks to one another.

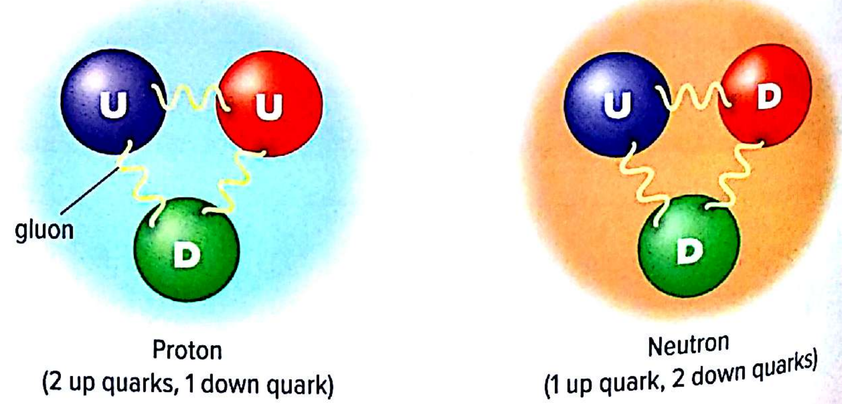


Figure 2.32 Protons and neutrons are made up of smaller elementary particles.

Leptons

Unlike protons and neutrons, electrons are themselves elementary particles. They are a type of elementary particle called *leptons*. Like quarks, leptons come in six flavours, as shown in **Table 2.4**. The key difference between quarks and leptons is that quarks experience the strong force, while leptons do not.

Table 2.4 Characteristics of Leptons

Lepton	Description
electron	• The electron is the lepton found in atoms. • Compared to the electron, muon and tau particles have the same charge (1−) but a much greater mass.
muon	
tau	
electron neutrinos	• Neutrinos are very difficult to detect. They have no charge and are nearly massless. • Trillions of them pass through our bodies each second. • Neutrinos are produced by high-energy processes such as nuclear reactions in the Sun.
muon neutrinos	
tau neutrinos	

Research Continues

Today, engineers and scientists continue to work together to probe the atom even further. One local example, the TRIUMF cyclotron, is shown in **Figure 2.33.** Located in Vancouver, the cyclotron was built to research the particles that make up matter. Electromagnets in the cyclotron accelerate protons to extraordinary speeds. The resulting proton beam is allowed to collide with various materials, and specialized detectors provide data about the products of the collisions.

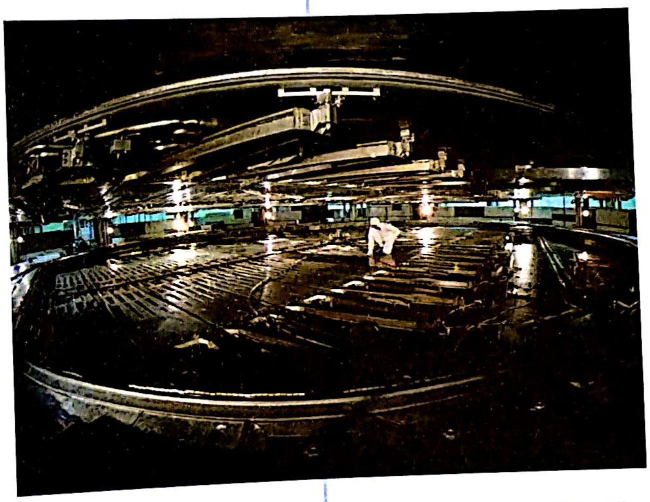


Figure 2.33 The TRIUMF cyclotron is a particle accelerator that produces a high-speed beam of protons. People come to Vancouver from all over the world to use it to run experiments.

Extending the Connections

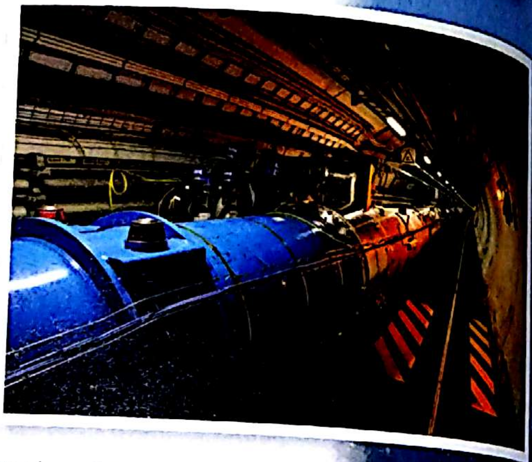
Beyond the Atom

Choose one of these terms or another of your choice to research: dark matter, antimatter, the Higgs boson, superstring theory, or quantum mechanics.

Before you leave this page . . .

1. Describe the structure of a proton.
2. Compare neutrinos and electrons.

AT ISSUE How do you smash subatomic particles—and why?



What's the Issue?

Strange but true: the job of the largest machine in the world is to study the smallest particles in existence. The machine is the Large Hadron Collider (LHC). It is a particle accelerator located on the border of France and Switzerland and operated by CERN, which stands for the French words for the European Organization for Nuclear Research.

The Large Hadron Collider consists of a ring 27 km in circumference buried underground. Inside the ring, two particle beams are sent in opposite directions through two pipes. Powerful electromagnets accelerate the particles until they are travelling close to light speed. The beams are then made to collide, and special detectors gather information about the particles produced by the collision. The LHC was used in experiments that resulted in the discovery of the Higgs boson particle. The existence of this particle was first proposed in the 1960s, but it took the LHC to create a collision with enough energy to produce one.

The Large Hadron Collider did not come cheap. The machine took decades of time and billions of dollars to plan and build. And it costs billions more to maintain and operate. The cost of finding the Higgs boson alone has been estimated at over $13 billion. Is the research worth the price tag?

CMS

ATLAS

Dig Deeper

Collaborate with your classmates to explore one or more of these questions—or generate your own questions of interest to explore.

1. What is the Higgs boson particle? Why is its discovery significant?
2. Other than the Higgs boson, what other discoveries have been made using the LHC? Will these discoveries result in useful applications? Should that matter?
3. There are different types of particle accelerators. What are they and what are some characteristics and examples of each?
4. Are there environmental risks to using the Large Hadron Collider and other particle research facilities? Are the risks worth the benefits?

Check Your Understanding of Topic 2.4

QP Questioning and Predicting PC Planning and Conducting PA Processing and Analyzing E Evaluating AI Applying and Innovating C Communicating

Understanding Key Ideas

1. Democritus's ideas about matter were amazingly close to modern atomic theory. Why did thousands of years pass before most people accepted his view? PA C

2. Use Dalton's model of the atom to explain the law of conservation of mass. PA C

3. Thomson's experiments with cathode rays resulted in a revised model of the atom. PA C
   a) What did Thomson discover about cathode rays?
   b) Why did this discovery mean that Dalton's model had to be changed?

4. Make a Venn diagram to compare Thomson's and Rutherford's models of the atom. PA C

5. What evidence supports Bohr's hypothesis that electrons can exist only in certain specified energy shells surrounding the atom? E C

6. Draw a labelled sketch to represent the atom as described in Concept 3. PA C

7. Compare and contrast protons and neutrons. PA C

8. Neutrons, protons, and electrons are all subatomic particles, but not all of them are elementary particles. PA C
   a) What is an elementary particle?
   b) Which particle in an atom is an elementary particle, and what type is it?
   c) Describe the structure of the other two particles in an atom.

Connecting Ideas

9. If Thomson's model of the atom had been correct, how would the results of Rutherford's experiment have been different? Use diagrams to illustrate your answer. E C

10. Of the three main subatomic particles that make up the atom (protons, neutrons, and electrons), why do you think the neutron was the last to be discovered? E C

Making New Connections

11. This giant sphere is a highly sensitive neutrino detector. It is located 2 km underground at the Sudbury Neutrino Observatory in northern Ontario. AI C
    a) Based on what you know about neutrinos, why do you think they are so difficult to detect?
    b) Neutrinos, along with many other high-energy particles, are constantly streaming at Earth's surface from space. Since this is the case, why do you think the neutrino detector is located so far underground?