1.1 The Structure of Matter

Figure A1.1: It is very important for competitors in any race to be properly hydrated.

The Sun seemed like a blast furnace, forcing all the competitors to contend with the oppressive heat. Despite the lightweight aluminium alloy frames of their bicycles and the ventilation holes in their plastic helmets, it was a challenge for the athletes to keep the pace when even the breeze felt hot. Knowing that harsh conditions would be facing the racers, the event's medical staff made sure that each competitor was properly hydrated before the race started. The fluids were carefully chosen to contain the salts and other substances racers would lose naturally during the race.

The "Observing Properties" activity on page 5 involved testing substances—aluminium, plastic, and rock salt—important to cyclists in a race. What gives these particular materials their unique properties? What is it about the **elements** making up these substances that make them desirable to cyclists?

To answer these questions, you first need to understand the structure of the basic unit of matter—the **atom**.

element: a pure substance that cannot be broken down into simpler substances by chemical means

atom: the smallest part of an element that has all the properties of that element

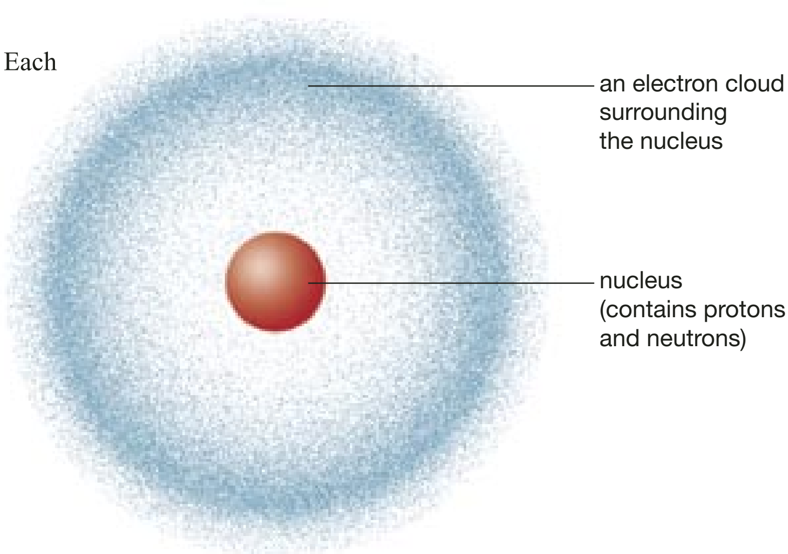
The Atom

Many different kinds of atoms exist in the universe. Each atom, however, is made up of the same three major particles: **protons**, **neutrons**, and **electrons**.

proton: a positively charged particle located in the nucleus of an atom

neutron: a neutral particle located in the nucleus of an atom

electron: a negatively charged particle located in the region surrounding the nucleus of an atom



The number of protons within the atom is so important it is given a special name—the **atomic number**. An atom with one proton, for example, is called a hydrogen atom. Hydrogen atoms have an atomic number of 1. An atom with six protons is called a carbon atom. Carbon atoms all have an atomic number of 6. It is the number of protons that makes the atom of one element differ from the atoms of all other elements.

Neutrons are also located in the nucleus of an atom. To determine the average number of neutrons in an atom, simply subtract the number of protons (the atomic number) from the atom's **atomic mass** and round to the nearest whole number. The sum of the number of neutrons and protons is called **mass number**. This value is always a whole number. For most elements, the difference between the atomic number and the mass number is the number of neutrons in the most common form of the atom.

atomic number: the number of protons in the nucleus of an atom

atomic mass: the average mass of the atoms of an element including all isotopes

mass number: the total number of protons and neutrons in an atom

Comparing Protons, Neutrons, and Electrons

Recall from previous science courses the modern model of the atom. This model has a number of features that are quite surprising. For example, the protons and neutrons make up most of the atom's mass, but these particles do not occupy much volume because they are located in a tiny space in the centre, called the nucleus. The electrons are particles with much less mass, but they move rapidly through the larger region surrounding the nucleus. This is why the space outside the nucleus is often described as "an electrons cloud."

Particle	Location	Mass (g/mol)	Charge
proton	nucleus	1.007 28	1+
neutron	nucleus	1.008 66	0
electron	surrounding nucleus	0.000 549	1–

The electrical characteristics of these particles explain why the fast-moving electrons are bound to the nucleus. Since oppositely charged objects are attracted to each other, the negatively charged electrons are attracted to the positively charged protons. In a neutral atom, the number of protons and electrons are equal, balancing the positive charges with the negative charges.

The electrical characteristics of protons and electrons can also explain why one atom will bond with another. When two atoms approach one another, the atoms may initially repel due to the interactions between the negatively charged outer electrons. However, it is the large concentration of positive charge in each nuclei that can exert greater attractive forces on all electrons in the vicinity.

DID YOU KNOW?

Protons and neutrons are made up of even smaller particles, called quarks.

All matter is made up of a large number of atoms associated with each other. The protons, neutrons, and electrons that make up each atom determine how that atom bonds with other atoms. These particles also determine the physical and chemical properties of each substance.

When you are wondering why a material shines, why it is soft or rigid, or why it has the ability to conduct electricity, you need to ask yourself these questions:

- How are the protons, neutrons, and electrons interacting within that substance?
- What is the structure of the atoms within that substance?

The answers to these questions will provide you with information about the properties of the atoms that make up a substance. They will also provide you with information about how the atoms within a substance interact with each other. You can use these two insights to explain the unique properties of a substance.

Practice

1. Outline the characteristics, location, and how each particle contributes to the properties of an atom.
   a. protons
   b. neutrons
   c. electrons
2. An atom has 6 protons, 6 neutrons, and 6 electrons.
   a. Determine the mass number of this atom. Support your answer.
   b. Determine the identity of this atom. Support your answer.
   c. Does this atom have a charge?
3. An atom has a mass number of 35. It has 18 neutrons and 18 electrons.
   a. Determine the number of protons in this atom. Support your answer.
   b. Determine the identity of this atom. Support your answer.
   c. Does the atom have a charge? Support your answer.
4. Explain why it is important to understand the structure of the atom in order to understand the behaviour of matter.

DID YOU KNOW?

Aluminium is a popular material for building high-quality bicycle frames. It is light and durable. Serious riders really appreciate an aluminium frame because it adds a stiffness that is very desirable when hill climbing.

Sketching Diagrams of Atoms

Once you have determined the number of protons, electrons, and neutrons that make up an atom, it is easy to put this information together to sketch a diagram of the atom of a particular element. The type of diagram often used in this course is called a Bohr diagram, named after the scientist Niels Bohr. Bohr developed the idea that only a certain number of electrons are able to occupy an **energy level**. Electrons in the energy levels closest to the nucleus have the lowest amount of energy.

energy level: a specific region surrounding the nucleus that is available for electrons

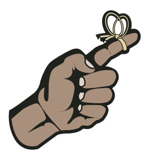
To sketch a Bohr diagram for an atom of a particular element, follow these steps:

step 1: Use the atomic number and atomic mass listed on the periodic table (on pages 554 and 555) to determine the number of protons, electrons, and neutrons (PEN) that make up the atom.

step 2: Draw the nucleus of the atom with the appropriate number of protons and neutrons within the nucleus.

step 3: Use dots to represent the electrons in each energy level that surrounds the nucleus. Each energy level holds a specific number of electrons. The number of electrons in a given energy level is shown by the number of elements in each period (row) on the periodic table. For example, the first energy level can hold two electrons. This is shown by the first period having only two elements: H and He. The second energy level of an atom can hold eight electrons. This is shown by the second period of the periodic table having eight elements: Li, Be, B, C, N, O, F, and Ne.

Remember: Energy levels closest to the nucleus (lower energy levels) are filled first, followed by energy levels farther from the nucleus (higher energy levels).

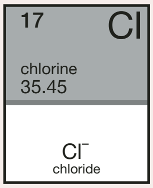


Example Problem 1.1

Sketch a Bohr diagram of the most common form of a chlorine atom.

Solution

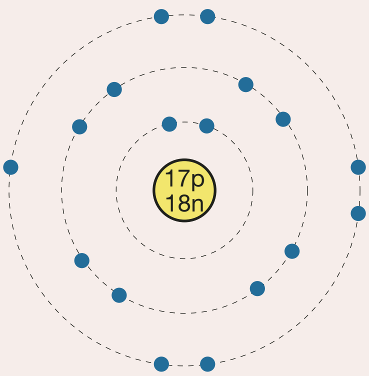
step 1: Determine the number of protons, electrons, and neutrons.



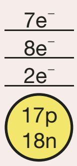
P: number of protons = atomic number
= 17
E: number of electrons = number of protons
= 17
N: number of neutrons = atomic mass – number of protons
= 35.45 – 17
= 18 ← rounded

step 2: Draw the nucleus of the atom. The nucleus of the atom contains the protons and neutrons.

step 3: Draw the electrons in their appropriate energy levels. Chlorine has 17 electrons. The first energy level can hold 2 electrons, leaving 15 more to place. The second energy level can hold 8 electrons, leaving 7 more to place. The third energy level can hold 8 electrons, but there are only 7 remaining. The final 7 will fit on the third energy level.

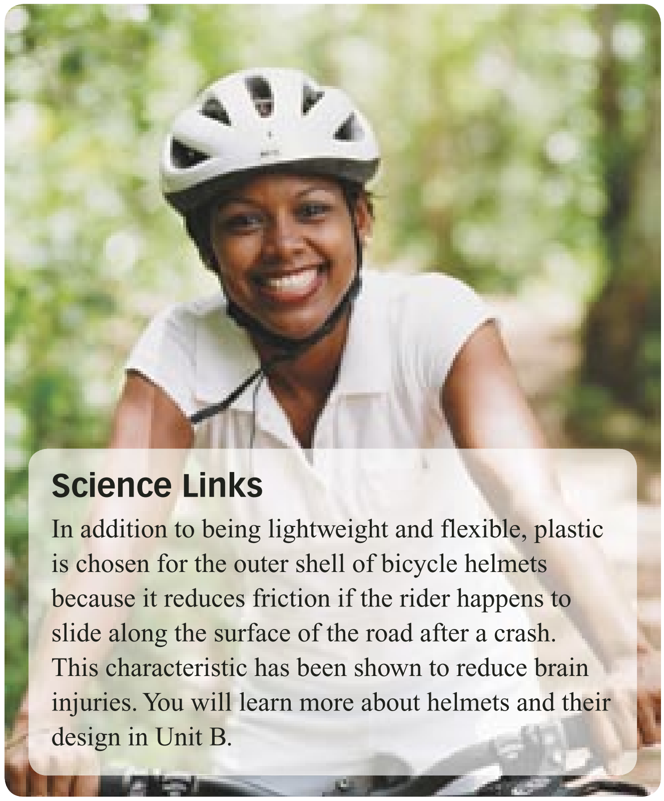


Here is a more concise way to represent the final Bohr diagram.



Practice

5. Draw Bohr diagrams to represent the atomic structure for the most common form of each element.
   - **a.** carbon
   - **b.** hydrogen
   - **c.** aluminium
   - **d.** lithium
   - **e.** sodium
   - **f.** fluorine
   - **g.** neon
   - **h.** helium



Science Links

In addition to being lightweight and flexible, plastic is chosen for the outer shell of bicycle helmets because it reduces friction if the rider happens to slide along the surface of the road after a crash. This characteristic has been shown to reduce brain injuries. You will learn more about helmets and their design in Unit B.

Lewis Dot Diagrams

Lewis dot diagram: a representation of an atom that shows only the valence electrons

The electrons in the outermost energy level become involved in chemical interactions. Therefore, chemists are most interested in these electrons. So, rather than draw Bohr diagrams, a more efficient way to represent atoms is to use **Lewis dot diagrams**.

Drawing a Lewis Dot Diagram of an Atom

step 1: Write the chemical symbol. This symbol will represent the inner electrons and the nucleus.

step 2: Determine the number of electrons in the outermost energy level.

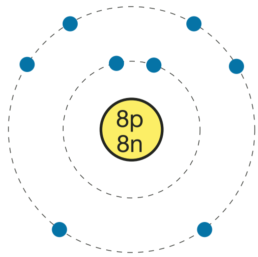
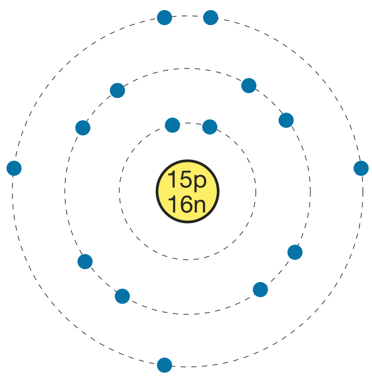
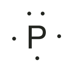
step 3: Use a dot to represent each electron in the outer energy level. The dots are placed on the north, east, south, or west sides of the symbol. Each position only has room for two electrons. Double up on electrons only after all the other positions contain at least one electron.

Example Problem 1.2

Draw the Bohr diagram and the Lewis dot diagram of the atoms for oxygen and phosphorus.

Solution

These diagrams are best organized in a table.

Atom	Bohr Diagram	Lewis Dot Diagram
oxygen		
phosphorus		

Practice

6. Draw the Lewis dot diagram of each of the following atoms.

a. carbon **b.** hydrogen **c.** aluminium **d.** lithium
e. sodium **f.** fluorine **g.** neon **h.** helium

Try This Activity

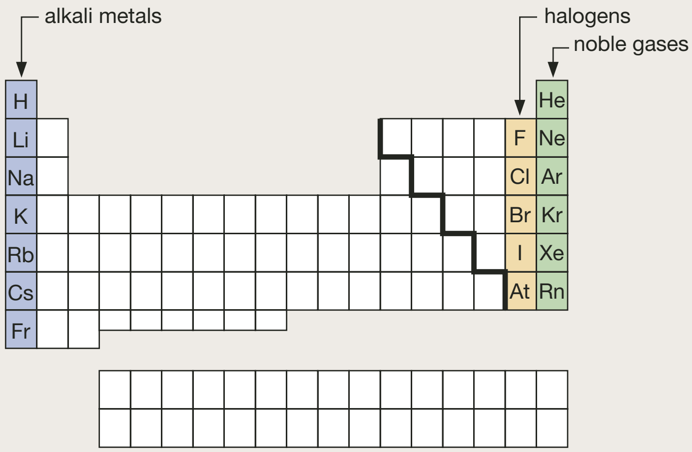
Diagrams of Atoms and the Periodic Table

Science Skills
✓ Analyzing and Interpreting

Background

In the opening to this chapter, you completed an activity in which you observed the properties of different substances. A more detailed version of this same process has occurred over many years as scientists studied the properties of the known elements. Once the results were organized by listing the elements from lowest atomic number to largest, it was noticed that many properties recurred periodically throughout the list. The periodic table is the result of these studies. The vertical columns (or groups) contain families of elements that have the same chemical properties.

The first vertical column (or group) of the periodic table contains a very reactive family of elements called alkali metals. Elements in this group have very similar properties. At the other end of the periodic table, the second-last group contains the halogens. This family of elements is also very reactive and has distinct properties compared to alkali metals. The last group on the right side of the periodic table contains the noble gases. These elements are not reactive and have other properties unique to that group.



Purpose

You will use diagrams of atoms to explore the connections between chemical properties, the periodic table, and the structure of atoms.

Procedure

1. Copy and complete the following table into your notebook. Be sure to leave enough room for your diagrams.

	Atom	Bohr Diagram	Lewis Dot Diagram
Alkali Metals	lithium		
	sodium		
Halogens	fluorine		
	chlorine		
Noble Gases	neon		
	argon		

Analysis

2. Sodium and lithium both come from the same family of elements—alkali metals. By comparing the structures you drew for these elements, write a hypothesis that explains why these two elements have similar properties.

3. Fluorine and chlorine are also from the same family of elements—halogens. By comparing the structures you drew for these elements, write a hypothesis that explains why these two elements have similar properties.

4. Neon and argon both come from the same family of elements—noble gases. By comparing the structures you drew for these elements, write a hypothesis that explains why these two elements have similar properties.

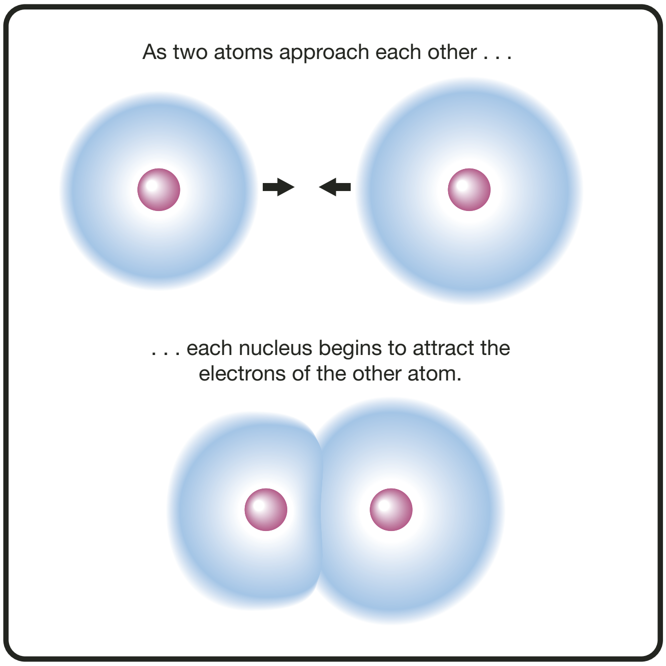
5. Alkali metals and halogens are very reactive elements. Write a hypothesis that explains why these elements are so reactive in comparison to noble gases.

Did You Know?

World-class cyclists competing in hot weather can lose 400 mg to 800 mg of sodium through perspiration every hour. They plan for this by drinking special fluids during the race to replace the sodium they lose. By comparison, the average person only needs between 200 mg and 500 mg of sodium in their daily diet. Unfortunately, people who eat excessive amounts of salty foods—like potato chips, corn chips, and pretzels—end up consuming many times the daily recommended amounts of sodium. This has been known to lead to high blood pressure and other health problems.

Atomic Bonding

When two atoms come into close proximity to one another, their electrons are attracted to both nuclei.



The electrons in the outer energy level are the most significant electrons in this process. These electrons are called **valence electrons**. Valence electrons are those that indicate the bonding properties of an atom.

valence electron: an electron that occupies the outermost energy level in an atom

If you, for example, look at the Lewis dot diagrams of lithium and sodium, you will notice that their Lewis dot diagrams are very similar—each atom has one valence electron. As a result of their similarity, these two atoms also have similar bonding properties.

lithium	sodium
Li·	Na·

The same is true if you compare the Lewis dot diagrams of fluorine and chlorine. In this case, both atoms have seven valence electrons. As a result of their similar electron arrangement, these two elements have similar characteristics when they form bonds with other atoms.

fluorine	chlorine
·F: (7 dots)	·Cl: (7 dots)

Why are these outer electrons so significant? What characteristic determines the bonding ability of an atom and how is it related to valence electrons? To answer these questions, you need to look at the Lewis dot diagrams of the elements that generally do not react or bond—the noble gases.

Lewis Dot Diagrams of the Noble Gases

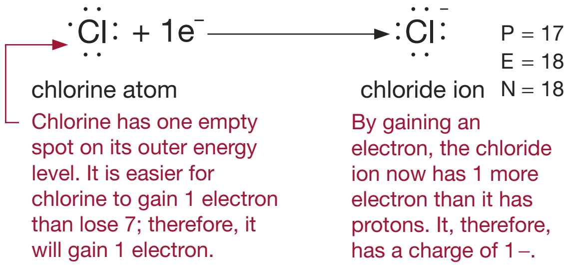
helium	neon	argon	krypton	xenon	radon
He (2 dots)	:Ne: (8 dots)	:Ar: (8 dots)	:Kr: (8 dots)	:Xe: (8 dots)	:Rn: (8 dots)

If you look at each Lewis dot diagram, you will notice that each atom—helium, neon, argon, krypton, xenon, and radon—has a full outer energy level. Stable atoms, such as these, rarely form bonds as a result of their filled outer energy levels. As you saw earlier, the arrangement of protons, neutrons, and electrons determines the properties of an atom. For noble gases, having their outer energy levels filled with the maximum number of electrons results in these atoms being unreactive.

Atoms can obtain a configuration to become more like a noble gas in one of three ways: by gaining electrons, by losing electrons, or by sharing electrons.

Gaining Electrons

An atom can gain electrons to fill empty spaces in its outermost energy level.

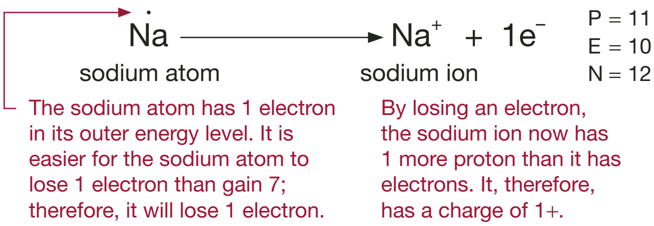


This results in the atom having more electrons than protons. The net charge for the atom changes to a negative charge. A charged atom is called an **ion**. A negatively charged ion is called an **anion**. Non-metallic atoms have a tendency to become negatively charged ions, or anions.

> **ion:** an electrically charged atom or group of atoms
>
> **anion:** a negatively charged ion

Losing Electrons

An atom can lose electrons from its outermost energy level to produce a positively charged ion.

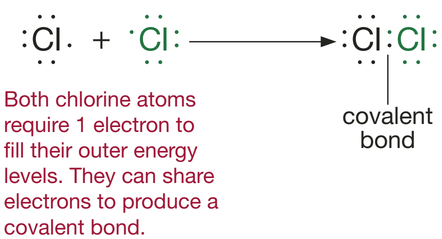


The net charge for the atom changes to a positive charge. A positively charged ion is called a **cation**. Metallic atoms have a tendency to form cations.

> **cation:** a positively charged ion

Sharing Electrons

An atom can share electrons with other atoms to produce a covalent bond.



Two or more non-metallic atoms tend to share electrons to complete their outer energy levels. You'll learn more about covalent bonds in Lesson 1.2.

Practice

7. Use Lewis dot diagrams to explain how the following atoms obtain a full outer energy level.

- **a.** oxygen
- **b.** fluorine
- **c.** phosphorus
- **d.** potassium
- **e.** calcium
- **f.** lithium
- **g.** carbon
- **h.** hydrogen
- **i.** neon

8. Compare your answers to question 7 with the ion charge for each of the atoms given on the periodic table. Describe any generalizations you can make from this comparison.

1.1 Summary

The variety of products that have become a part of everyday life are made from combinations of the elements listed in the periodic table. The smallest part of each element that still has the properties of that element is called an atom.

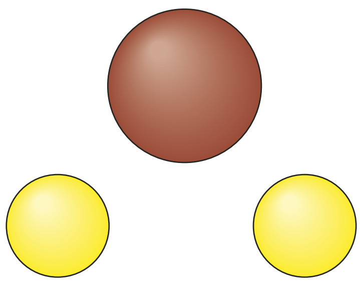


Figure A1.2: To build a model of a water molecule, you need two pieces to represent hydrogen atoms and one piece to represent an oxygen atom.

All the atoms of an element, like hydrogen, are identical and are distinct from the atoms of another element, like oxygen. Even though the atoms of different elements are distinct, they are made from the same basic parts: protons, neutrons, and electrons. You can use the information from the periodic table to sketch a diagram of an atom for a particular element to show how these parts are arranged.

The elements contained in the same vertical column on the periodic table, called groups or families, have the same number of valence electrons and similar properties. An atom is most stable when its outer energy level is filled with electrons. Atoms can gain, lose, or share electrons to obtain a full outer energy level.

1.1 Questions

Knowledge

1. Define the following terms.
   - **a.** atom
   - **b.** proton
   - **c.** neutron
   - **d.** electron
   - **e.** element
   - **f.** mass number
   - **g.** atomic number
   - **h.** energy level
   - **i.** Lewis dot diagram
   - **j.** valence electron
   - **k.** ion
   - **l.** anion
   - **m.** cation
2. Describe in terms of atomic structure how a chlorine atom differs from an oxygen atom.
3. Describe in terms of atomic structure how a sodium ion differs from a sodium atom.
4. Explain why an oxygen atom will tend to produce an ion with a charge of 2−.
5. Explain why a magnesium atom will tend to produce an ion with a charge of 2+.
6. Describe the similarities and differences between an anion and a cation.

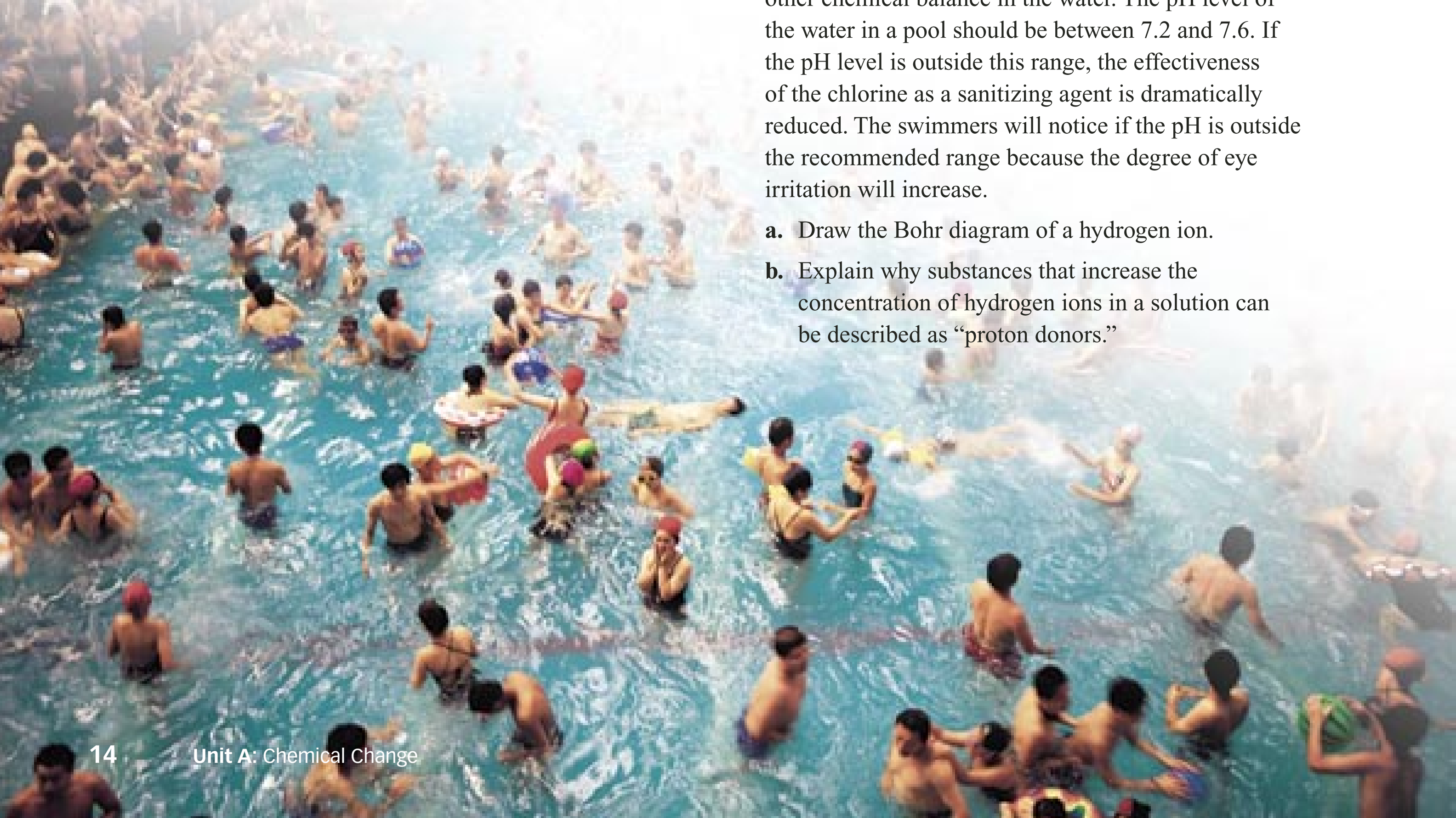
Applying Concepts

7. Create a cartoon that summarizes the characteristics of each particle that makes up an atom.
8. Use Lewis dot diagrams to explain why non-metallic atoms tend to gain electrons to form negative ions and metallic atoms tend to lose electrons to become positive ions.

Use the following information to answer questions 9 and 10.

> In the opening of this chapter, the need for wearing goggles and a bathing cap was linked to the chemistry of the pool water. One of the duties of lifeguards at local pools is to routinely test the water to ensure that key measures of the water's chemistry are within acceptable limits. Typical substances tested include the concentration of hydrogen ions—done as a pH test—and a test for the concentration of chlorine.

9. Chlorine is added to pool water to act as a disinfectant to kill harmful bacteria. The chlorine can be added as a gas or in combination with other substances in powdered form.
   - **a.** Draw the Lewis dot diagram of a chlorine atom.
   - **b.** Explain why chlorine is a very reactive element.
   - **c.** Chlorine's properties as a powerful disinfectant stem from its ability to react with molecules on the outer surfaces of bacteria and viruses. Provide a reason why chlorine is added to pool water from a special room through a pipe that re-circulates the pool water, and not at the side of the pool next to the swimmers.
10. The most important test in swimming-pool chemistry is the one that determines the pH of the pool water. This is because the pH of the pool water affects every other chemical balance in the water. The pH level of the water in a pool should be between 7.2 and 7.6. If the pH level is outside this range, the effectiveness of the chlorine as a sanitizing agent is dramatically reduced. The swimmers will notice if the pH is outside the recommended range because the degree of eye irritation will increase.
    - **a.** Draw the Bohr diagram of a hydrogen ion.
    - **b.** Explain why substances that increase the concentration of hydrogen ions in a solution can be described as "proton donors."



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Legend: t = top, m = middle, b = bottom, l = left, r = right

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