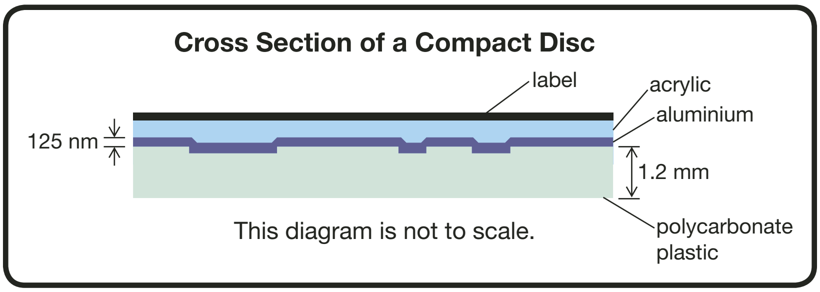
1.2 *Atomic Bonding and Properties*

Figure A1.3: Music CDs are made from a type of plastic called polycarbonate.

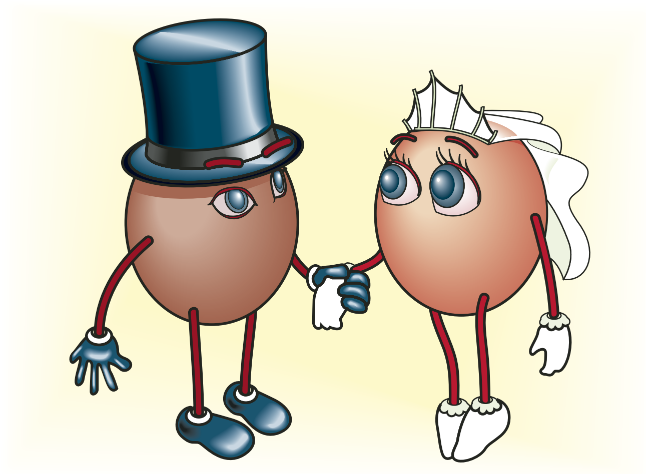
Are you the kind of a person who likes to take your music with you everywhere you go? If so, you probably own some sort of portable audio system. For some people, this involves a personal CD player with headphones. The heart of such a system is the music stored on the CD.



CDs themselves are made of a tough, transparent type of plastic called polycarbonate. A thin layer of aluminium under the label of the CD reflects the laser light from the CD player so it can read the musical information encoded in a microscopic series of pits and bumps. To protect the aluminium, a thin layer of acrylic is sprayed on top. The label for the CD is then printed onto the acrylic. It is amazing that commercially sold music CDs can be produced so inexpensively, given the intricate and incredibly small structure of the pits and bumps on the CDs. The costs are kept low by using a stamping process. The stampers themselves are produced by an electrochemical process that uses salt and other substances in a chemical bath to create the stampers from a glass master copy.

The same three substances you examined in the introduction to this chapter—aluminium, plastic, and salt—are all used in the process of manufacturing CDs. Clearly, the manufacturing process depends upon knowing the individual properties of each of these materials. In addition, it is critical to know how each of these bond with other materials.

Principles for Understanding Bonding



In Lesson 1.1 you were introduced to some important principles that play a key role in understanding the bonding behaviour of atoms. These principles are as follows:

- An atom is most stable when its outer energy level is full of electrons.
- Atoms can obtain full outer energy levels by gaining electrons, by losing electrons, or by sharing electrons with other atoms.
- If an atom gains electrons, it becomes negatively charged. If it loses electrons, it becomes positively charged.
- Negatively charged particles and positively charged particles attract each other, and similarly charged particles repel each other.

These principles will be used to sketch the atomic structure of a variety of substances. Once you have sketched diagrams of the atomic structures of rock salt, a piece of plastic, and a piece of metal, you will be better able to explain the properties of these different materials. Sketching the atomic structure of substances containing more than one atom has four basic steps.

Process for Sketching Atomic Structure

step 1: Draw the Lewis dot diagram of each atom that makes up the substance.

step 2: Determine which atom needs the most electrons to fill its outer energy level. Draw the Lewis dot diagram of this atom in the centre of your diagram.

step 3: Connect the atoms in a way so each atom's outer energy level is filled. Examine the finished diagram.

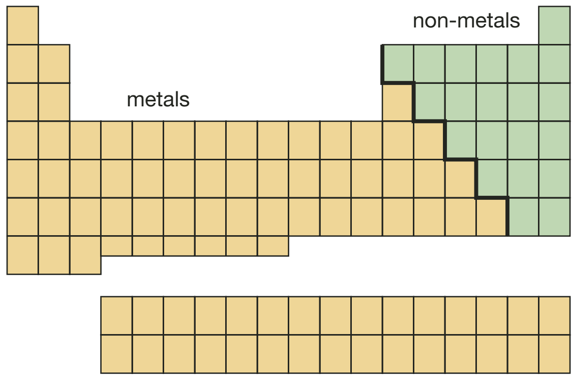
step 4: Make sure each atom has a completely filled outer energy level. If it doesn't, repeat step 3.

Aluminium

Aluminium is a **metal**. This means that aluminium has lustre and good heat and electrical conductivity. It also means that aluminium is malleable (can be hammered into different shapes without crumbling) and ductile (can be stretched to form long wires). Chemists classify all the elements that lie to the left of the staircase line on the periodic table as metals. The elements to the right of this line are classed as **non-metals**.

metal: a malleable and ductile element that has lustre, has good heat and electrical conductivity, and tends to form positive ions

non-metal: an element that is not flexible, does not conduct electricity, and tends to form negative ions



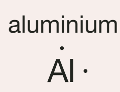
Metals tend to form positively charged ions or cations, whereas non-metals tend to form negatively charged ions or anions. So, if you are handling a piece of aluminium, you are holding a collection of positive ions. If the aluminium ions are all positively charged, why do these ions stay together? Shouldn't they repel one another? The answers to these questions are explained in Example Problem 1.3.

Example Problem 1.3

Following the process of sketching atomic structure, illustrate how atoms of aluminium bond together to form a solid piece of aluminium metal.

Solution

step 1: Draw the Lewis dot diagram of the atom.



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step 2: Determine how the atom can fill its outer energy level.

An aluminium atom can obtain a full outer energy level by

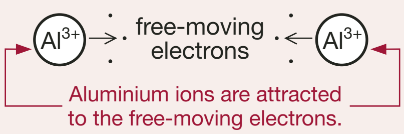
- gaining five electrons
- losing three electrons

It is much easier to lose three electrons than it is to gain five. So, an aluminium atom will tend to lose three electrons to become a stable aluminium ion.

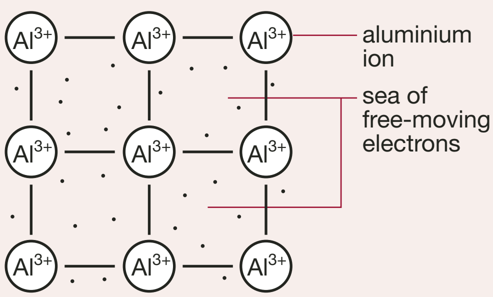
$$\dot{\underset{\cdot}{\text{Al}}}\cdot \longrightarrow \text{Al}^{3+} + 3e^-$$

step 3: Make a bond with aluminium ions.

Two aluminium ions are both positive ions. Why would they stick together if they naturally repel each other? The key to this answer is that both atoms lost electrons to become ions.



You can think of a strip of aluminium metal as aluminium ions remaining together because of their mutual attraction to free-moving electrons.



Note that there are an equal number of protons and electrons in this system. So, even though the electrons are free moving, overall, each atom is still neutral.

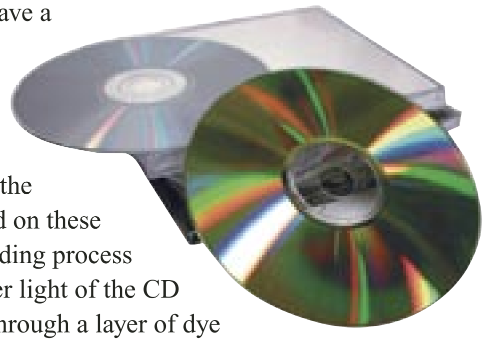
Practice

9. Sketch the atomic structure for each of the following. Follow the steps outlined in Example Problem 1.3.
   - **a.** beryllium
   - **b.** magnesium

Metal Coatings

It is the lustre of aluminium that makes it a good candidate for the prerecorded CDs you buy in a music store; it reflects the laser light very well. The other possible metals include gold, silver, and copper. Gold and silver are more reflective, but they are more expensive.

You may have noticed that many recordable compact discs, CD-Rs, have a different colour than the prerecorded CDs. That's because gold is the metal often used on these discs. The recording process requires the laser light of the CD burner to pass through a layer of dye in the recording process. So, the extra expense is warranted in this case because a more reflective metal is required.



Rock Salt

Rock salt is a **compound** called sodium chloride; it is made up of the elements sodium and chlorine. Since sodium is a metal and chlorine a non-metal, the resulting compound is called an **ionic compound**.

The ions in sodium chloride are held together by the force of attraction between the positive sodium ions and the negative chloride ions. This is called an **ionic bond**.

Example Problem 1.4 will show you how to apply the process to produce a sketch of the atomic structure of sodium chloride. This example will also shed light on why sodium chloride forms rectangular crystals.

compound: a pure substance formed from atoms of two or more elements with the different atoms joined in fixed ratios

ionic compound: a pure substance formed from a metal and a non-metal

ionic bond: a bond formed by the simultaneous attraction between positive and negative ions

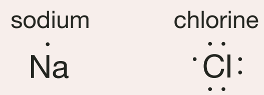
Figure A1.4: The special lighting of this photograph reveals the rectangular crystals of sodium chloride (or salt).

Example Problem 1.4

Sketch a diagram illustrating how the atoms of sodium and chlorine form ions and bond together to make sodium chloride—a common crystalline compound.

Solution

step 1: Draw the Lewis dot diagram of each atom.



step 2: Determine how each atom can obtain a full outer electron energy level.

A sodium atom can obtain a full outer energy level by

- gaining seven electrons
- losing one electron

Metals tend to have a weaker attraction for valence electrons; therefore, they tend to lose electrons. So, a sodium atom will tend to lose one electron to become a stable sodium ion.

$$Na \longrightarrow Na^{+} + 1e^{-}$$

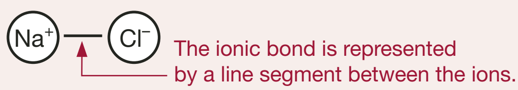
A chlorine atom can obtain a full outer energy level by

- gaining one electron
- losing seven electrons

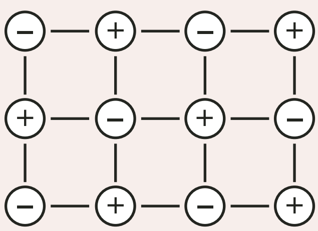
Non-metals tend to have a greater attraction for valence electrons; therefore, they tend to gain electrons. So, a chlorine atom will tend to gain one electron to become a stable chloride ion.

$$Cl + 1e^{-} \longrightarrow Cl^{-}$$

step 3: Make a bond with positive and negative ions.



Positively charged ions are attracted to negatively charged ions, and vice versa. This attraction holds the substance together to form a sodium chloride crystal.



Each ionic crystal results from the natural attraction of positive and negative ions.

Practice

10. Sketch the atomic structure for the following ionic crystals.

a. calcium oxide

b. potassium chloride

History and Salt

Throughout history, salt has been a highly prized commodity. Because of its ability to inhibit the growth of bacteria, it has been and still is used to preserve food.

DID YOU KNOW?

In ancient Rome, soldiers were paid in salt, called "salarium argentum." This is the origin of the modern word *salary*.

Figure A1.5: Fur is hung out by the building at the Hudson's Bay Company post at Lake Harbour, NWT.

Canada's First Nations peoples prized salt because it was used to cure meat and fish and to tan hides. Outcroppings of salt were often considered sacred places because of the deer, elk, bear, and bison that were attracted to these natural salt licks. The Dene Th'a people utilized the natural salt deposits found on the Salt Plains in Wood Buffalo National Park. These people used the salt at this site for their own needs and as a valuable commodity for trade.

Plastics

Although you will look at plastics in much greater detail in Chapter 3 of this unit, for now, the essential idea is that plastics are primarily made up of carbon and hydrogen atoms. Since both carbon and hydrogen are non-metals, the resulting combination is called a **molecular compound**.

Molecular compounds do not involve ions. So, the carbon and hydrogen atoms are held together because the nucleus of a carbon atom is simultaneously attracted to the same electrons as the nucleus of a hydrogen atom. This simultaneous attraction is called a **covalent bond**.

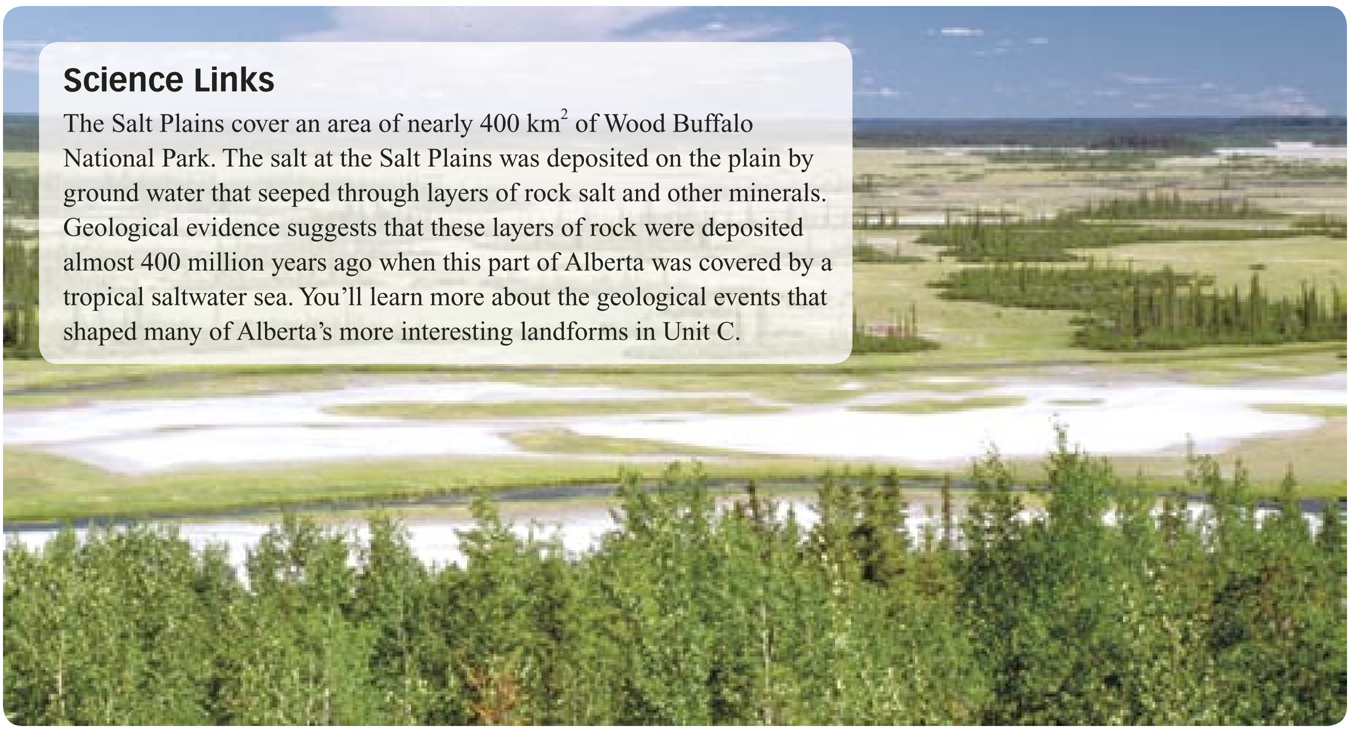
The resulting combination of carbon and hydrogen atoms is called a **molecule**.

- **molecular compound:** a pure substance formed from non-metals
- **covalent bond:** a bond formed by the simultaneous attraction of two nuclei for a shared pair of electrons
- **molecule:** a particle containing a fixed number of covalently bonded, non-metal atoms

The basics of sketching a diagram of a molecule consisting of carbon and hydrogen atoms is illustrated in Example Problem 1.5. You'll do this in more detail in Chapter 3.

Science Links

The Salt Plains cover an area of nearly 400 km^2 of Wood Buffalo National Park. The salt at the Salt Plains was deposited on the plain by ground water that seeped through layers of rock salt and other minerals. Geological evidence suggests that these layers of rock were deposited almost 400 million years ago when this part of Alberta was covered by a tropical saltwater sea. You'll learn more about the geological events that shaped many of Alberta's more interesting landforms in Unit C.

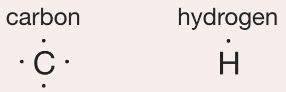


Example Problem 1.5

Sketch a diagram illustrating how atoms of carbon and hydrogen bond together to form a long, chain-like molecule.

Solution

step 1: Draw the Lewis dot diagram of each atom.



step 2: Determine how the atoms can obtain a full outer energy level.

A carbon atom can obtain a full outer energy level by

- gaining four electrons
- losing four electrons

In a case like this, an atom will often share electrons.

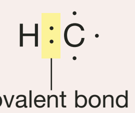
A hydrogen atom can obtain a full outer energy level by

- gaining one electron
- losing one electron

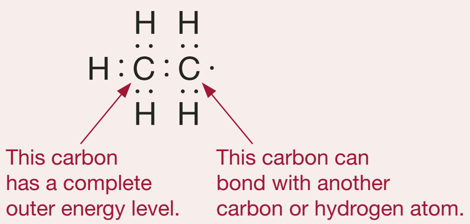
In a case like this, an atom will often share electrons.

step 3: Make bonds with two non-metal atoms.

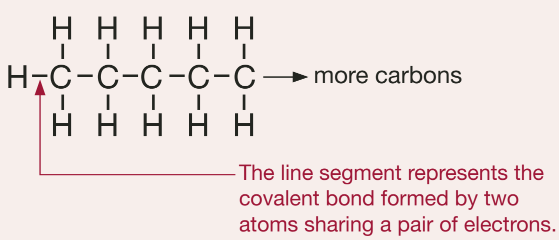
Non-metal atoms, like carbon and hydrogen, tend to require electrons to fill their outer energy levels. When this situation occurs, both atoms share electrons to form a covalent bond.



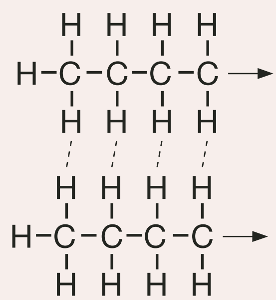
In this diagram, the carbon atom still does not have a full outer energy level. So, it will either bond with more hydrogen atoms or more carbon atoms.



A plastic strip is made up of long strands of carbon atoms sharing electrons with one another and with hydrogen atoms. Each long strand is a molecule.



Adjacent strands will have a slight attraction toward each other, forming the piece of plastic.



Plastics All Around You

Polycarbonate, a type of plastic used to make CDs, consists of long molecules—each molecule built around a backbone of over a thousand carbon atoms. The recipe can be varied to produce products that are incredibly resilient, like bulletproof window glazing. Future applications might include a plastic coating for automobiles that is scratchproof. This will eliminate the need to paint vehicles.

The same properties that make plastics like polycarbonates highly desirable become a significant liability when it comes to disposal. The fact that these materials are strong, durable, and resistant to the effects of heat, cold, water, weather, and even ultraviolet light means that recycling plastics has become very important, given the limited space available for landfills.

Figure A3.6: Polycarbonates are used to make a variety of consumer goods.

The thin metal coating on CDs makes it even more difficult to recycle the polycarbonate in these products. Given the widespread use and popularity of CDs, special recycling centres have been developed to reclaim the polycarbonate for the manufacture of automobile parts.

Categories of Matter

Earlier, you sketched diagrams of the atomic structure of commonly found categories of matter: an ionic compound, a molecular compound, and a metal.

Common Name	Atoms That Make Up This Substance	Category of Matter	Properties
rock salt	sodium and chlorine	ionic compound	• brittle • high melting point • soluble in water
hard plastic	carbon and hydrogen	molecular compound	• flexible • low melting point • insoluble in water • does not conduct electricity
aluminium foil	aluminium	metallic element	• malleable • high melting point • insoluble in water • a good conductor of heat and electricity

Everything you own, see, and interact with is comprised of substances that are made from atoms. If you want to understand the properties of a substance, a good place to begin is by identifying the category of matter. The next step is to link the diagrams of the atomic structures you sketched for that category of matter to the properties of these materials.

Practice

11. Draw a representation of the structure of the following substances. Identify the substance that contains ionic, covalent, or metallic bonds.

a. magnesium oxide, MgO

b. a sample of calcium

c. a water molecule, H_2O

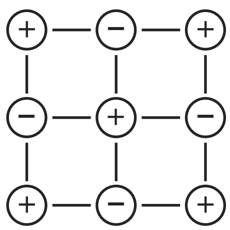
Explaining the Properties of Categories of Matter (Extension)

Thus far, you have looked at the structure and composition of three types of matter: an ionic compound, a molecular compound, and a metal. You can use these three models to explain the unique properties you noted in the "Observing Properties" activity in the chapter introduction on page 5.

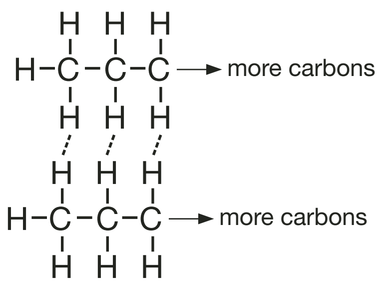
Why are molecular compounds more likely to melt if heated?

When subjected to high temperatures, the three tested substances responded differently. The rock salt (an ionic compound) and the aluminium foil (a metal) change little when heated compared to the plastic (a molecular compound). The attractive forces between particles in metals and in ionic compounds must be stronger, since these substances changed little when exposed to high temperatures.

Strong Ionic Bonds



The bonds within an ionic compound are very strong because you have full negative and positive charges attracting each other.



There is only a slight attraction between molecules within a molecular compound.

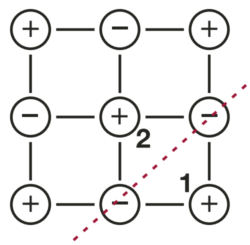
The plastic quickly melting next to a heat source suggests that the bonds between atoms in this molecular compound must be weaker in comparison to ionic bonds. Generally speaking, the compounds composed of atoms with covalent bonds will melt at lower temperatures than ionic compounds.

Figure A1.7: Plastic food containers will start to melt if they are left too close to a heat source.

Why do ionic crystals snap if you try bending them?

If you attempt to bend an ionic crystal, you may bring like charges next to each other. Like charges repel each other, and the crystal will break.

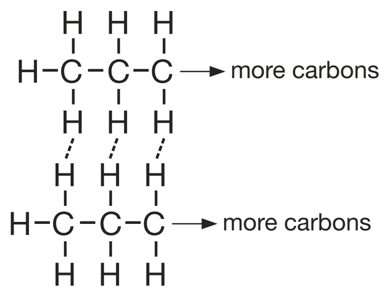
Bending an Ionic Compound



If you bend the crystal along the dotted line, positive ion **1** will come closer to positive ion **2**. They will repel each other, causing a break in the crystal structure.

The atoms of molecular compounds are not charged. Therefore, when bent, the atoms do not repel one another.

Bending a Molecular Compound

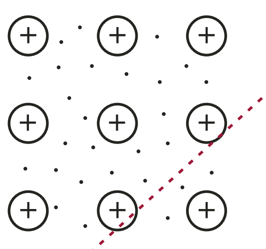


There are no positive or negative charges in molecular compounds. (If there are, they are very weak.) If you fold them, no like charges will come close to each other.

The electrons within a collection of metal atoms are held less tightly to any individual atom than the electrons involved in either an ionic or molecular compound. It is the free electrons that give a metal its ability to bend.

The nuclei of the metal atoms within the structure of a metal are all positively charged, so you would think the metal would snap if you bend it. However, the electrons of all the metal atoms act as a cushion between the repulsive force if two metal ions come too close to each other. Metals can be bent because of the movement of free electrons.

Bending a Metal

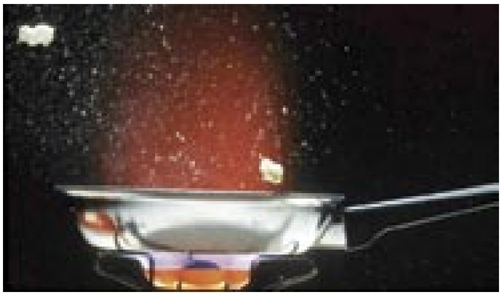


If you bend the metal along the dotted line, the positive ions do come closer to each other; however, the free electrons will move to cushion the repulsive force.

Why did metal effectively conduct heat and electricity?

In the “Observing Properties” activity on page 5, the aluminium (metal) foil was the only substance to conduct electricity. Since an electric current involves the movement of charges along a path or circuit, can you think of a reason why the metal was the best conductor of electricity?

Think back to your diagram of metallic bonding. In the metal, the valence electrons are held less tightly by the bonding between atoms. Since the electrons have the ability to move throughout the metal, some people describe the electrons as behaving like an “electron gas”—able to drift and flow among the positive metal ions. An external circuit takes advantage of this arrangement and introduces a stream of moving electrons—an electric current—that can move through the electron gas quite easily. In an ionic crystal or molecular compound, the electrons are held so tightly that there is no path for the external electric current to flow.



You might be surprised to know that the free electrons are also responsible for metals being good conductors of heat. If the end of a piece of metal is exposed to a source of heat, the positive ions within the metal closest to the heat source begin to vibrate more. Although some energy is transferred to the neighbouring metal ions, most of the energy is transferred to the nearby free electrons. These free electrons can then move to the cold end of the metal and transfer this energy to another positive metal ion, causing it to vibrate more. Again, in an ionic crystal or molecular compound, there are no free electrons available. In these materials the heat is passed from one vibrating ion or atom to its neighbour, which is a much slower process.

Why did the rock salt start dissolving in the water?

Only rock salt—the ionic compound—responded to the addition of water. Water is able to dissolve many ionic compounds; and, as you will see later in this chapter, diagrams that show the bonds in matter can help explain why this occurs.

Looking at matter in terms of atoms and atomic structure is a powerful tool. Understanding the atomic structure of a substance helps explain the observations you make about matter every day. You will be referring to these diagrams throughout this unit; so, make sure you have a good understanding of them.

Practice

12. a. Draw diagrams of the atomic structure of the ionic compound potassium chloride, KCl, the molecular compound methane, CH_4, and the metal magnesium, Mg. Use these models to explain the observations in 12.b. to 12.e.

b. Insulators prevent electrical conduction. Molecular compounds make excellent electrical insulators, whereas metals make excellent electrical conductors.

c. Many minerals in rocks are composed of ionic compounds. If you try bending a rock, it will snap.

d. Heat travels along a metal coat hanger as you use it to roast a marshmallow over an open fire.

e. The end of a coat hanger is black after you take it out of an open fire.

1.2 Summary

Atoms bond with each other to form a variety of substances. The properties of a particular substance can be explained by sketching diagrams of the atomic structure of the atoms, ions, and molecules it is composed of. Ionic, covalent, and metallic bonds result in matter having unique properties.

1.2 Questions

Knowledge

1. Define the following terms.

a. compound
b. metal
c. ionic compound
d. ionic bond
e. covalent bond
f. molecule
g. molecular compound

2. Identify the difference between each pair of terms.

a. a chlorine atom and a chloride ion
b. a sodium ion and a chloride ion
c. an ionic bond and a covalent bond
d. an ionic compound and a molecular compound

Applying Concepts

3. Explain why using sketches of the atomic structure of a substance improves the ability to explain the physical properties of a substance.

4. Refer to valence electrons. Explain why non-metal atoms tend to gain electrons to form negative ions and metal atoms tend to lose electrons to become positive ions.

5. Metallic substances have “free” electrons moving around positive ions. List three metallic properties that result from these “free” electrons.

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

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