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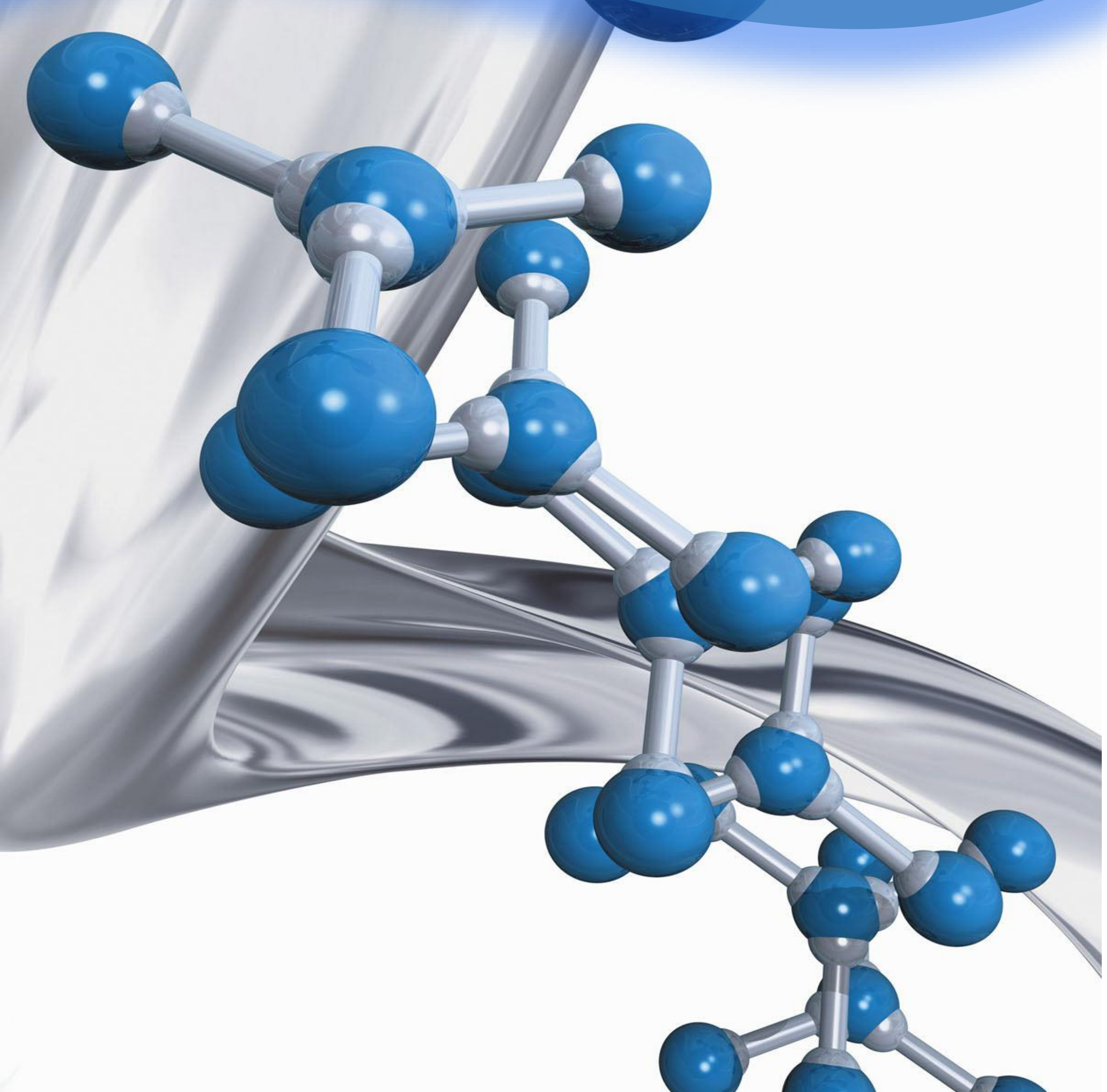
The Science Called Chemistry



Preface

The Science Called Chemistry has two basic aims: to introduce students to the fundamental principles of chemistry and to show them how chemistry affects their lives. Studying **The Science Called Chemistry**, students will gain an understanding and appreciation of the nature of chemistry and the methods by which chemical knowledge is acquired. It develops an understanding of basic principles and continues to build on these in a logical manner.

The word science is derived from the Latin word *scientia*, which means knowledge. Science is a human activity which is directed toward increasing our knowledge about the composition and behavior of matter, both living and nonliving. Matter is the material which makes up the universe.

To live in the modern world is to be surrounded by the products of chemistry. We all make use of these products. Synthetic fibres for clothing, carpeting, and many other useful items. Grooming products such as deodorants, soaps, and hair sprays are products of chemistry. In fact, the list of chemicals found in our homes seems endless.

Occasionally, a basic knowledge of chemistry can prevent people from making a tragic mistakes. A knowledge of chemistry will probably not alter the course of your life, but it may help you to avoid making a bad mistake. At the very least, a knowledge of chemistry will teach you to be cautious when you use any of the chemical products available to you.

Contents

1. ATOMS AND BONDING

1.1 What Is Chemical Bonding?

Look around you for a moment and describe what you see. Do you see the pages of this textbook? A window? Perhaps trees or buildings? Your friends and classmates? The air you breathe? All these objects—and many others not even mentioned—have one important property in common. They are all forms of matter. And all matter—regardless of its size, shape, colour, or phase—is made of tiny particles called **atoms.** Atoms are the basic building blocks of all the substances in the universe. As you can imagine, there are hundreds of thousands of different substances in nature.

There are only 109 different elements. Elements are the simplest type of substance. Elements are made of only one kind of atom.

The 109 elements are each made of specific types of atoms. Atoms of elements combine with one another to produce new and different substances called compounds. You already know several compounds: water, sodium chloride (table salt), sugar, carbon dioxide, vinegar, lye, and ammonia. Compounds contain more than one kind of atom chemically joined together.

The combining of atoms of elements to form new substances is called chemical bonding. Chemical bonds are formed in very definite ways. The atoms combine according to certain rules. The rules of **chemical bonding** are determined by the structure of the atom.

Electrons and Energy Levels

The atom contains a positively charged center called the nucleus. Found inside the nucleus are two types of subatomic (smaller than the atom) particles: protons and neutrons. Protons have a positive charge, and neutrons have no charge. Neutrons are neutral particles. Thus the nucleus as a whole has a positive charge.

Located outside the nucleus are negatively charged particles called electrons. The negative charge of the electrons balances the positive charge of the nucleus. The atom as a whole is neutral. It has no net charge.

The negatively charged electrons of an atom are attracted by the positively charged nucleus of that atom. This electron-nucleus attraction holds the atom together. The electrons, however, are not pulled into the nucleus. They remain in a region outside the nucleus called the electron cloud.

The electron cloud is made up of a number of different energy levels. Electrons within an atom are arranged in energy levels. Each energy level can hold only a certain number of electrons. The first, or innermost, energy level can hold only 2 electrons. The second and third energy levels can each hold 8 electrons. The electrons in the outermost energy level of an atom are called **valence electrons.** It is the valence electrons that play the most significant role in determining how atoms combine.

When the outermost energy level of an atom contains the maximum number of electrons, the level is full, or complete. Atoms that have complete (filled) outermost energy levels are very stable. They usually do not combine with other atoms to form compounds. They do not form chemical bonds.

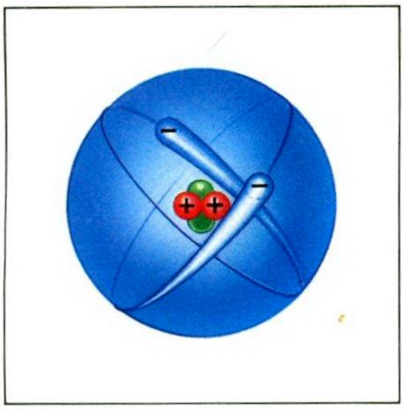


Fig. 1.1 The structure of an atom

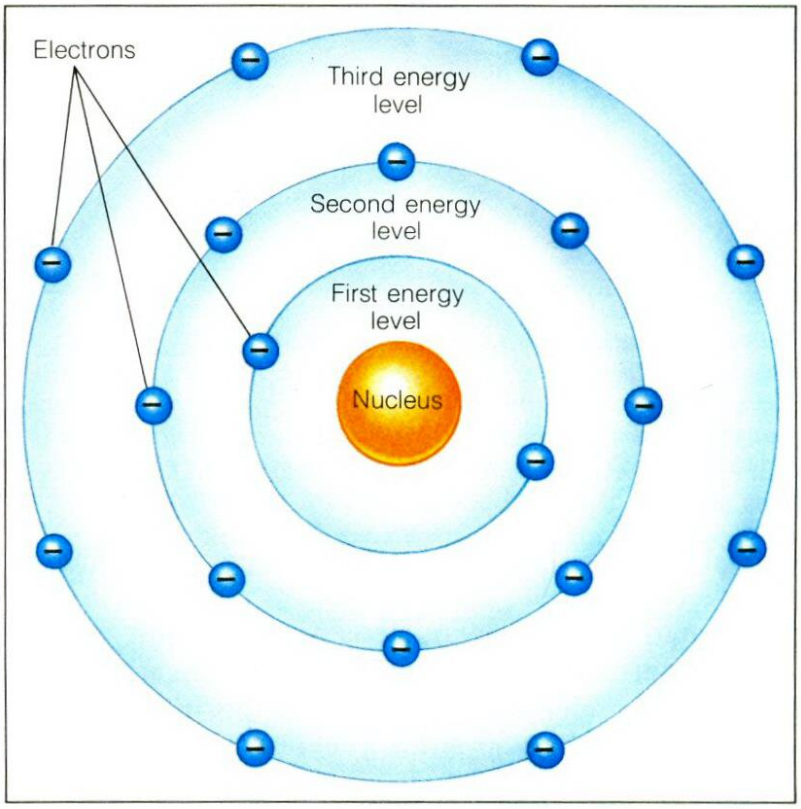


Fig. 1.2 The formation of an atom.

Turn to Appendix and study it carefully. You are looking at the periodic table of the elements—one of the most important "tools" of a physical scientist. All the known elements (109) are listed in this table in a specific way. Every element belongs to a family, which is a numbered, vertical column. There are 18 families of elements. Every element also belongs to a period, which is a numbered, horizontal row. Elements in the same family have similar properties, the most important of which is the number of electrons in the outermost energy level, or the number of valence electrons.

Look at Family 18 in the periodic table. It contains the elements helium, neon, argon, krypton, xenon, and radon. The atoms of these elements do not form chemical bonds under normal conditions. This is because all the atoms of elements in Family 18 have filled outermost energy levels. Remember, if the first energy level is also the outermost, it needs only 2 electrons to make it complete.

Fig. 1.3 The elements which are members of Family 18.

Electrons and bonding

The electron arrangement of the outermost energy level of an atom determines whether or not the atom will form chemical bonds. In Family 18 atoms of elements have complete outermost energy level. These atoms generally do not form chemical bonds.

Atoms of elements other than those in Family 18 do not have filled outermost energy levels. Their outermost energy level lacks one or more electrons to be complete. Some of these atoms tend to gain electrons in order to fill the outermost energy level. Fluorine (F), which has 7 valence electrons, gains 1 electron to fill its outermost energy level. Other atoms tend to lose the valence electron and are left with only filled energy levels. Sodium (Na), which has 1 valence electron, loses 1 electron.

In order to achieve stability, an atom will either gain or lose electrons. In other words, an atom will bond with another atom if the bonding gives both atoms complete outermost energy levels.

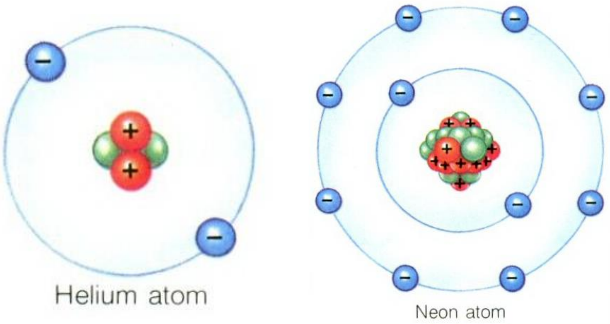


Fig. 1.4 The outermost energy levels of a helium and a neon atoms.

Vocabulary notes:

property in common – спільна риса,
matter – матерія,
forms of matter – форми матерії,
particle – частка,
to combine – об’єднувати(ся),
ammonia – аміак,
to determine – визначати ,
to investigate – досліджувати,
electron – електрон,
energy level – енергетичний рівень,
to contain – вміщувати,
positively charged – позитивно заряджений,
nucleus – ядро,
subatomic – субатомний,
proton – протон,
neutron – нейтрон,
neutral – нейтральний,
negatively charged – негативно заряджений,
net charge – повний (загальний) заряд,
to attract – притягувати,
electron cloud – електронна хмара,
compound – речовина, сполука, суміш, склад,
carbon dioxide – вуглекислий газ,
vinegar – оцет,
lye – луг,
innermost energy level – внутрішній енергетичний рівень,
outermost energy level – зовнішній енергетичний рівень,
the periodic table of the elements – періодична таблиця елементів,
helium – гелій,
neon – неон,
argon – аргон,
krypton – криптон,
xenon – ксенон,
radon – радон,
electron arrangement – розміщення електронів,
to gain electrons – приєднувати електрони,
fluorine – фтор.

1.2 Ionic Bonds

As you have just learned, an atom will bond with another atom in order to achieve stability, which means in order for both atoms to get complete outermost energy levels. One way a complete outermost energy level can be achieved is by the transfer of electrons from one atom to another. Bonding that involves a transfer of electrons is called **ionic bonding.** Ionic bonding, or electron-transfer bonding, gets its name from the word **ion.** An ion is a charged atom. Remember, an atom is neutral. But if there is a transfer of electrons, a neutral atom will become a charged atom.

Because ionic bonding involves the transfer of electrons, one atom gains electrons and the other atom loses electrons. Within each atom the negative and positive charges no longer balance. The atom that has gained electrons has gained a negative charge.

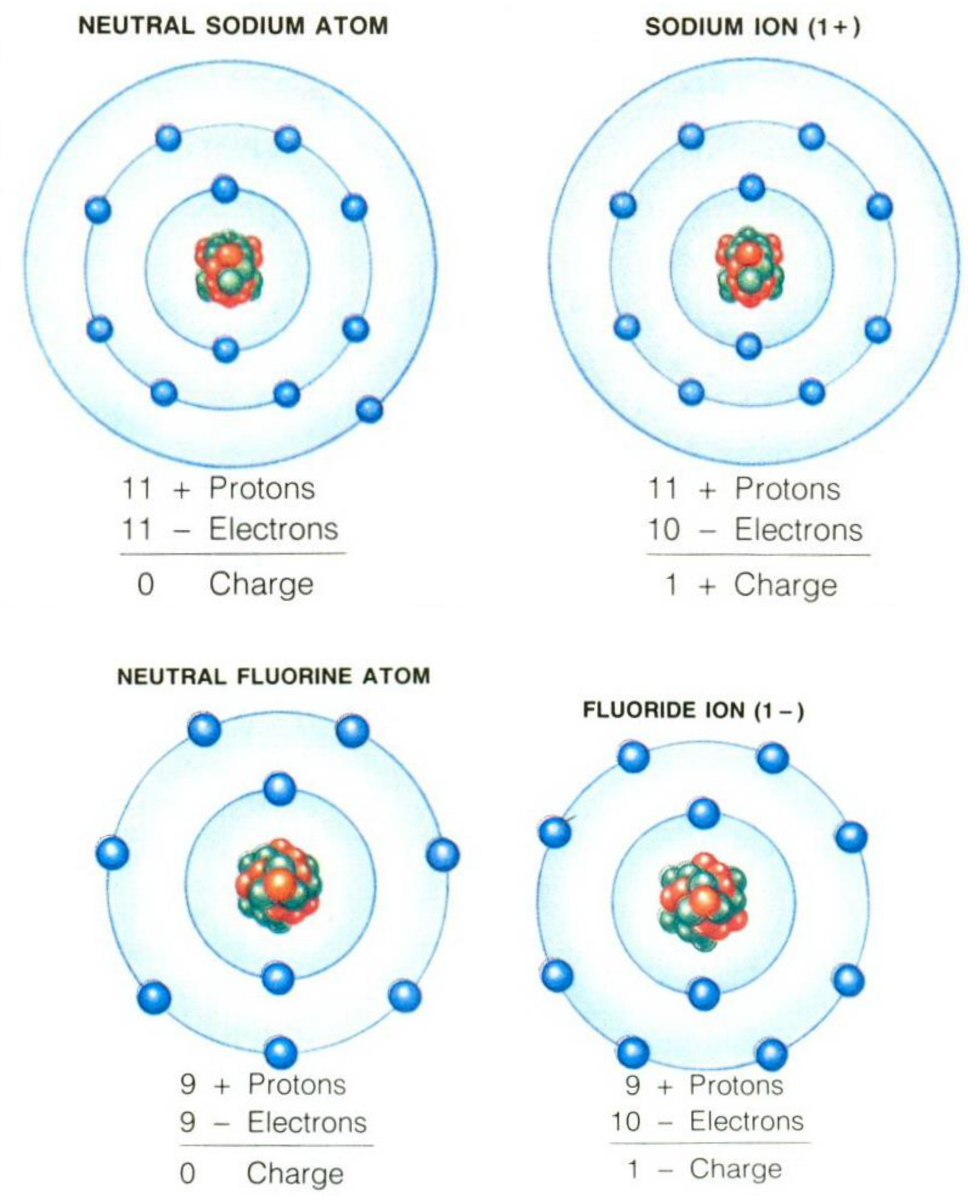


Fig. 1.5 The formation of a negative fluoride ion and positive sodium ion.

It is a negative ion. For example, fluorine (F) has 7 valence electrons. To complete its outermost energy level, the fluorine atom gains 1 electron. In gaining 1 negatively charged electron, the fluorine atom becomes a negative ion. The symbol for the fluoride ion is F^{1-}. (For certain elements, the name of the ion is slightly different from the name of the atom. The difference is usually in the ending of the name—as with the fluorine atom and the fluoride ion.)

The sodium atom (Na) has 1 valence electron. When a sodium atom loses this valence electron, it is left with an outermost energy level containing 8 electrons. In losing 1 negatively charged electron, the sodium atom becomes a positive ion. The symbol for the sodium ion is Na^{1+}. Figure 1-4 shows the formation of the fluoride ion and the sodium ion.

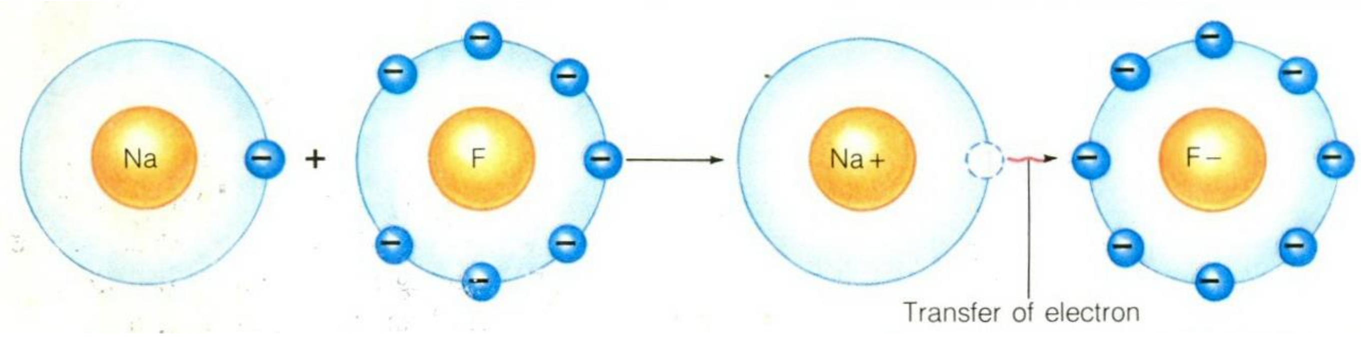


Fig.1.6 The transfer of an electron during the ionic bonding.

In nature, it is a general rule that opposites attract. Since the two ions Na^{1+} and F^{1-} have opposite charges, they attract each other. The strong attraction holds the ions together in an ionic bond. The formation of the ionic bond results in the formation of the compound sodium fluoride, NaF. See *Fig. 1.6.*

Energy for Ion Formation

In order for the outermost electron to be removed from an atom, the attraction between the negatively charged electron and the positively charged nucleus must be overcome. The process of removing electrons and forming ions is called **ionization.** Energy is needed for ionization. This energy is called **ionization energy.**

The ionization energy for atoms that have few valence electrons is low. Do you know why? Only a small amount of energy is needed to remove electrons from the outermost energy level. As a result, these atoms tend to lose electrons easily and to become positive ions. What elements would you expect would have low ionization energies?

The ionization energy for atoms with many valence electrons is very high. These atoms do not lose electrons easily. As a matter of fact, these atoms usually gain electrons. It is much easier to gain 1 or 2 electrons than to lose 7 or 6 electrons! The tendency of an atom to attract electrons is called **electron affinity.** Atoms such as fluorine are said to have a high electron affinity because they attract electrons easily.

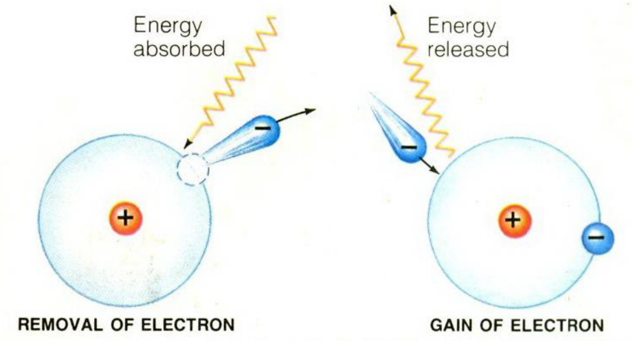


Fig. 1.7 Ion formation energy.

Arrangement of Ions in Ionic Compounds

Ions of opposite charge strongly attract each other. Ions of like charge strongly repel each other. As a result, ions in an ionic compound are arranged in a specific way. Positive ions tend to be near negative ions and farther from other positive ions.

The placement of ions in an ionic compound results in a regular, repeating arrangement called a **crystal lattice.** A crystal lattice is made of huge numbers of ions. A crystal lattice gives the compound great stability. It also accounts for certain physical properties. For example, ionic solids tend to have high melting points. *Fig. 1.8* shows the crystal lattice structure of sodium chloride.

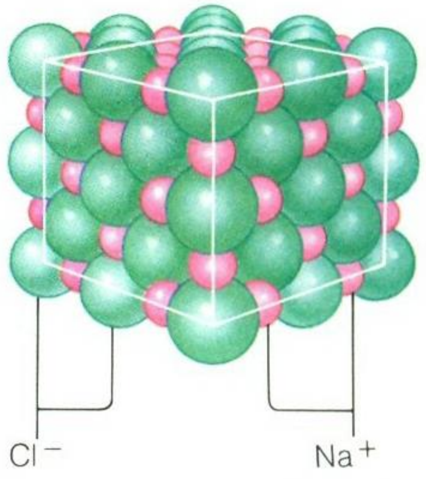


Fig.1 .8 A crystal lattice.

Ionic compounds are made of nearly endless arrays of ions. A chemical formula for an ionic compound shows the ratio of ions present in the crystal lattice. It does not show the actual number of ions.

Each ionic compound has a characteristic crystal lattice arrangement. This lattice arrangement gives a particular shape to the crystals of the compound. For example, sodium chloride forms cubic crystals.

The crystal shape of an ionic compound is of great importance to geologists in identifying minerals. There are more than 2000 different kinds of minerals, and many of them look alike! One of the properties by which minerals are classified is crystal shape. There are six basic crystal shapes, or systems, and each of the thousands of minerals belongs to one of these systems.

Vocabulary notes:

transfer of electrons – переміщення електронів,
opposite – протилежність,
to overcome – долати,
to repel – відштовхувати(ся),
ionic compound – іонна сполука,
crystal lattice – кристалічна решітка,
to account for – нести відповідальність,
ionic solid – іонне тверде тіло,
melting point – температура плавлення,
endless arrays of ions – безкінечна кількість іонів,
chemical formula – хімічна формула,
ratio – співвідношення, пропорція, коефіцієнт.

1.3 Covalent Bonds

Bonding often occurs between atoms that have high ionization energies and high electron affinities. In other words, neither atom loses electrons easily, but both atoms attract electrons. In such cases, there can be no transfer of electrons between atoms. What there can be is a sharing of electrons. Bonding in which electrons are shared rather than transferred is called **covalent bonding.** Look at the word covalent. Do you see a form of a word you have just learned? Do you know what the prefix *co*- means? Why is covalent an appropriate name for such a bond?

By sharing electrons, each atom fills up its outermost energy level. So the shared electrons are in the outermost energy level of both atoms at the same time.

Nature of the Covalent Bond

In covalent bonding, the positively charged nucleus of each atom simultaneously attracts the negatively charged electrons that are being shared. The electrons spend most of their time between the atoms. The attraction between the nucleus and the shared electrons holds the atoms together.

The simplest kind of covalent bond is formed between two hydrogen atoms. Each hydrogen atom has 1 valence electron. By sharing their valence electrons, both hydrogen atoms fill their outermost energy level. Remember, the outermost energy level of a hydrogen atom is complete with 2 electrons. The two atoms are now joined in a covalent bond. See Figure 1.8.

Chemists represent the electron sharing that takes place in a covalent bond by an **electron-dot diagram.** In such a diagram, the chemical symbol for an element represents the nucleus and all the inner energy levels of the atom—that is, all the energy levels except the outermost energy level, which is the energy level with the valence electrons. Dots surrounding the symbol represent the valence electrons.

A hydrogen atom has only 1 valence electron. An electron-dot diagram of a hydrogen atom would look like this:

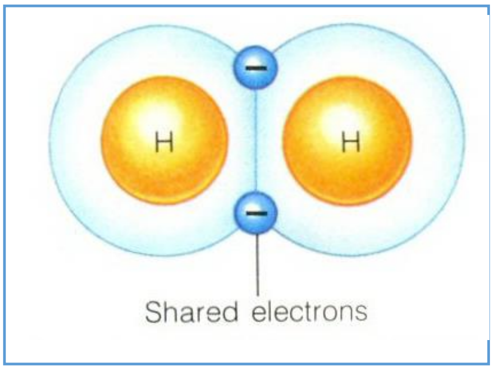


Fig. 1.9 The covalent bond between 2 atoms of hydrogen.

The covalent bond between the two hydrogen atoms shown in *Fig.1.9* can be represented in an electron-dot diagram like this:

The two hydrogen atoms are sharing a pair of electrons. Each hydrogen atom achieves a complete outermost energy level (an energy level containing 2 electrons).

Chlorine has 7 valence electrons. An electron-dot diagram of a chlorine atom looks like this:

The chlorine atom needs one more electron to complete its outermost energy level. If it bonds with another chlorine atom, the two atoms could share a pair of electrons. Each atom would then have 8 electrons in its outermost energy level. The electron-dot diagram for this covalent bond would look like this:

Covalent bonding often takes place between atoms of the same element. In addition to hydrogen and chlorine, the elements oxygen, fluorine, bromine, iodine, and nitrogen bond in this way. These elements are called **diatomic elements.** When found in nature, diatomic elements always exist as two atoms covalently bonded.

The chlorine atom, with its 7 valence electrons, can also bond covalently with an unlike atom. For example, a hydrogen atom can combine with a chlorine atom to form the compound hydrogen chloride. See *Fig.1.10.* The electron-dot diagram for this covalent bond isYou can see from this electron-dot diagram that by sharing electrons, each atom completes its outermost energy level.

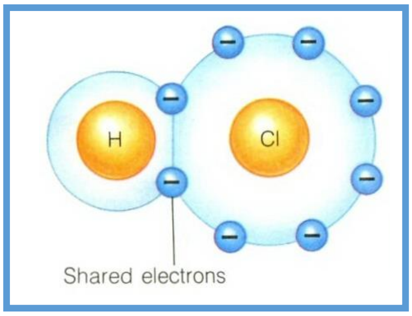


Fig. 1.10 The compound hydrogen chloride molecule formation.

Formation of Molecules

In a covalent bond, a relatively small number of atoms are involved in the sharing of electrons. The combination of atoms that results forms a separate unit rather than the large crystal lattices characteristic of ionic compounds.

The combination of atoms formed by a covalent bond is called a **molecule**. A molecule is the smallest particle of a covalently bonded substance that has all the properties of that substance. This means that 1 molecule of water, for example, has all the characteristics of a glass of water, a bucket of water, or a pool of water. But if a molecule of water were broken down into atoms of its elements, the atoms would not have the same properties as the molecule.

Molecules are represented by chemical formulas. Like a chemical formula for an ionic crystal, the chemical formula for a covalent molecule contains the symbol of each element involved in the bond. Unlike a chemical formula for an ionic crystal, however, the chemical formula for a molecule shows the exact number of atoms of each element involved in the bond. The subscripts, or small numbers placed to the lower right of the symbols, show the number of atoms of each element. When there is only 1 atom of an element, the subscript 1 is not written. It is understood to be 1. Thus, a hydrogen chloride molecule has the formula HCl. What would be the formula for a molecule that has 1 carbon (C) atom and 4 chlorine (Cl) atoms?

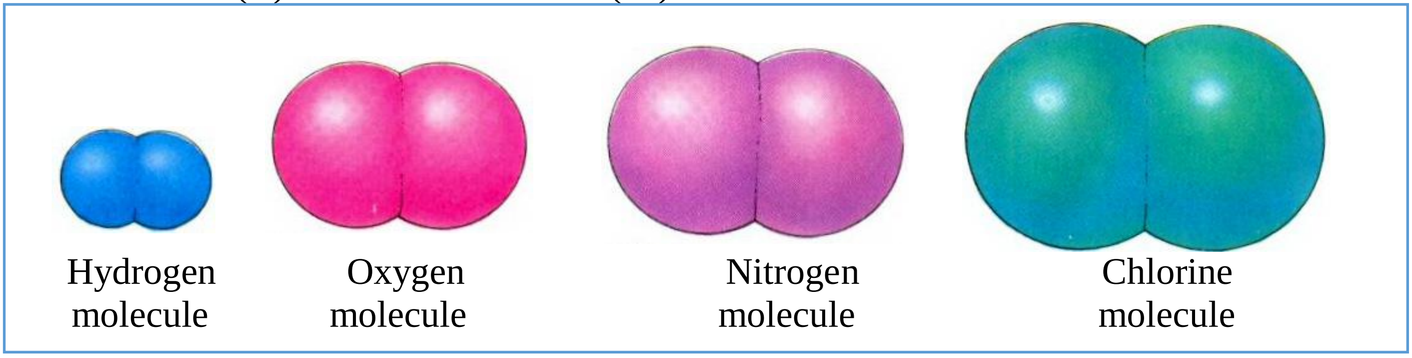
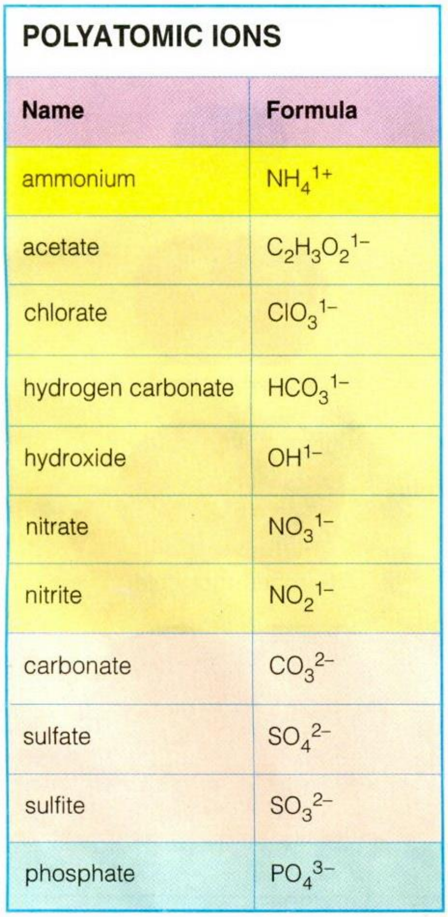


Fig. 1.11 Diatomic elements.

Covalently bonded solids tend to have low melting points. Some covalent substances, however, do not have low melting points. They have rather high melting points. This is because molecules of these substances are very large. The molecules are large because the atoms involved continue to bond to one another. These substances are called **network solids.** Carbon in the form of graphite is an example of a network solid. So too is silicon dioxide, the main ingredient in sand. Certain glues also form networks of atoms whose bonds are difficult to break. This accounts for the holding properties of such glues.

Polyatomic Ions

Certain ions are made of covalently bonded atoms that tend to stay together as if they were a single atom. A group of covalently bonded atoms that acts like a single atom when combining with other atoms is called a **polyatomic ion.** Although the bonds within the polyatomic ion are covalent, the polyatomic ion usually forms ionic bonds with other atoms.



POLYATOMIC IONS

Name	Formula
ammonium	NH_4^{1+}
acetate	$C_2H_3O_2^{1-}$
chlorate	ClO_3^{1-}
hydrogen carbonate	HCO_3^{1-}
hydroxide	OH^{1-}
nitrate	NO_3^{1-}
nitrite	NO_2^{1-}
carbonate	CO_3^{2-}
sulfate	SO_4^{2-}
sulfite	SO_3^{2-}
phosphate	PO_4^{3-}

Fig. 1.12 Polyatomic Ions.

Fig.1.12 is a list of some of the more common polyatomic ions, and *Fig.1.13* shows the atomic structure of several polyatomic ions. Some of these ions may sound familiar to you. For example, the polyatomic ion hydrogen carbonate (HCO_3^{1-}) bonded to sodium produces sodium hydrogen carbonate ($NaHCO_3$), better known as baking soda. Magnesium hydroxide ($MgOH_2$) is milk of magnesia. And ammonium nitrate (NH_4NO_3—two polyatomic ions bonded together) is an important fertilizer.

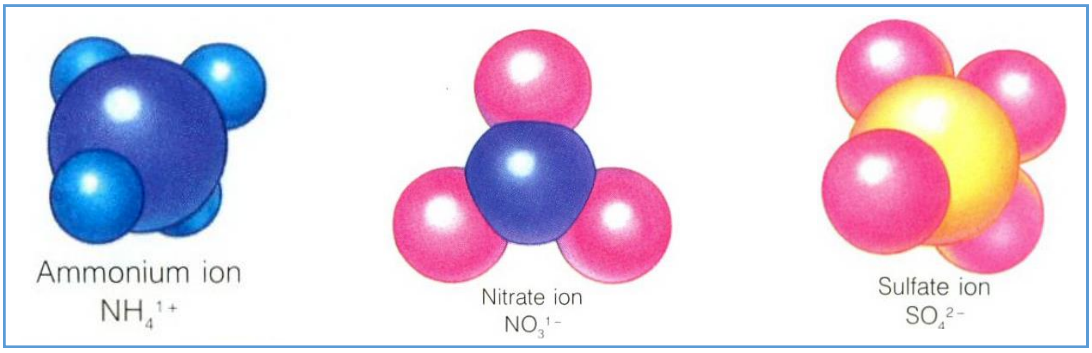


Fig.1.13 The atomic structure of several polyatomic ions.

Vocabulary notes:

sharing of electrons – формування спільних електронів,
hydrogen – водень,
oxygen – кисень,
chlorine – хлор,
bromine – бром,
iodine – йод,
nitrogen – азот,
diatomic element – двоатомний елемент,
subscript – індекс,
hydrogen chloride – хлоргідрат,
carbon – вуглець,
graphite – графіт,
silicon dioxide – двоокис кремнію,
ingredient – компонент,
glue – клей,
polyatomic ion – багатоатомний іон,
hydrogen carbonate – вуглеводень,
sodium – натрій,
magnesium hydroxide – гідроксид магнію,
ammonium nitrate – азотнокислий амоній,
fertilizer – добриво.

1.4 Metallic Bonds

You are probably familiar with metals such as copper, silver, gold, iron, tin, and zinc. And perhaps you even know that cadmium, nickel, chromium, and manganese are metals too. But do you know what makes an element a metal? Metals are elements that give up electrons easily.

In a metallic solid, or a solid made entirely of one metal element, only atoms of that particular metal are present. There are no other atoms to accept the electron(s) the metal easily gives up. How, then, do the atoms of a metal bond?

The atoms of metals form **metallic bonds.** In a metallic bond, the outer electrons of the atoms form a common electron cloud. This common distribution of electrons occurs throughout a metallic crystal. In a sense, the electrons become the property of all the atoms. These electrons are often described as a "sea of electrons." **The positive nuclei of atoms of metals are surrounded by free-moving, or mobile, electrons that are all attracted by the nuclei at the same time.**

The sea of mobile electrons in a metallic crystal accounts for many properties of metals. Metals are malleable, which means they can be hammered into thin sheets without breaking. Metals are also ductile: They can be drawn into thin wire. The flexibility of metals results from the fact that the metal ions can slide by one another and the electrons are free to flow. Yet the attractions between the ions and the electrons hold the metal together even when it is being hammered or drawn into wire.

The ability of the electrons to flow freely makes metals excellent conductors of both heat and electricity. Metallic bonding also accounts for the high melting point of most metals. For example, the melting point of silver is 961.9°C and of gold, 1064.4°C.

Vocabulary notes:

copper – мідь,
silver – срібло,
gold – золото,
iron – залізо,
tin – олово,
zinc – цинк,
cadmium – кадмій,
nickel – нікель,
chromium – хром,
manganese – марганець,
metallic bonds – металічний зв'язок,
a sea of electrons – море електронів,
positive nuclei – позитивне ядро,
free-moving – такий, що вільно рухається,
mobile – рухомий,
malleable – ковкий,
ductile – еластичний,
flexibility – піддатливість.

1.5 Predicting Types of Bonds

You have just learned about three different types of bonds formed between atoms of elements: ionic bonds, covalent bonds, and metallic bonds. By knowing some of the properties of an element, is there a way of predicting which type of bond it will form? Fortunately, the answer is yes. And the property most important for predicting bond type is the electron arrangement in the atoms of the element—more specifically, the number of valence electrons.

The placement of the elements involved in bonding in the periodic table often indicates whether the bond will be ionic, covalent, or metallic. Look again at the periodic table. Elements at the left and in the center of the periodic table are metals. These elements have metallic bonds.

Compounds formed between elements that lose electrons easily and those that gain electrons easily will have ionic bonds. Elements at the left and in the center of the periodic table tend to lose valence electrons easily. These elements are metals. Elements at the right tend to gain electrons readily. These elements are nonmetals. A compound formed between a metal and a nonmetal will thus have ionic bonds.

Compounds formed between elements that have similar tendencies to gain electrons will have covalent bonds. Bonds between nonmetals, which are at the right of the periodic table, will be covalent.

Combining Capacity of Atoms

The number of electrons in the outermost energy level of an atom, the valence electrons, determines how an atom will combine with other atoms. If you know the number of valence electrons in an atom, you can calculate the number of electrons that atom needs to gain, lose, or share when it forms a compound. **The number of electrons an atom gains, loses, or shares when it forms chemical bonds is called its oxidation number.** The **oxidation number** of an atom describes its combining capacity.

An atom of sodium has 1 valence electron. It loses this electron when it combines with another atom. In so doing, it forms an ion with a 1+ charge, Na^{1+}. The oxidation number of sodium is 1+. A magnesium atom has 2 valence electrons, which it will lose when it forms a chemical bond. The magnesium ion is Mg^{2+}.The oxidation number of magnesium is 2+.

An atom of chlorine has 7 valence electrons. It will gain 1 electron when it bonds with another atom. The ion formed will have a 1- charge, Cl^{1-}. The oxidation number of chlorine is 1-. Oxygen has 6 valence electrons.

Using Oxidation Numbers

You can use the oxidation numbers of atoms to predict how atoms will combine and what the formula for the resulting compound will be. In order to do this, you must follow one important rule: *The sum of the oxidation numbers of the atoms in a compound must be zero.*

Sodium has an oxidation number of 1+. Chlorine has an oxidation number of 1-. One atom of sodium will bond with 1 atom of chlorine to form NaCl. Magnesium has an oxidation number of 2+. When magnesium bonds with chlorine, 1 atom of magnesium must combine with 2 atoms of chlorine, since each chlorine atom has an oxidation number of 1-. In other words, 2 atoms of chlorine are needed to gain the electrons lost by 1 atom of magnesium. The compound formed, magnesium chloride, contains 2 atoms of chlorine for each atom of magnesium. Its formula is $MgCl_2$.

Vocabulary notes:

magnesium – магній,
fluorine – фтор,
sample – зразок, взірець,
capacity – здатність,
calcium bromide - бромід кальцію,
sodium oxide – окис натрію.

TASKS

I. Key terms. Read, translate and memorize the following definitions:

Atom – *атом* – the smallest part of any element that retains all the properties of that element.

Chemical bonding – *хімічний зв'язок* – combining of atoms of elements to form new substances.

Valence electron – *валентний електрон* – electron in the outermost energy level of an atom.

Ion – *іон* – an atom that has become charged due to the loss or gain of electrons.

Ionic bonding – *іонний зв'язок* – bonding that involves the transfer of electrons.

Ionization – *іонізація* – process of removing electrons and forming ions.

Ionization energy – *енергія іонізації* **-** energy required for ionization.

Electron affinity – *спорідненість електронів* – tendency of an atom to attract electrons.

Crystal lattice – *кристалічна решітка* – regular, repeating arrangement of atoms.

Covalent bonding – *ковалентний зв'язок* – bonding that involves the sharing of electrons.

Electron-dot diagram - *електронно-точкова діаграма* **-** diagram that uses the chemical symbol for an element surrounded by a series of dots to represent the electron sharing that takes place in a covalent bond.

Diatomic element – *двоатомний елемент* – element whose atoms can form covalent bonds with another atom of the same element.

Molecule – *молекула* – combination of atoms formed by a covalent bond.

Polyatomic ion – *багатоатомний іон* – group of covalently bonded atoms that acts like a single atom when combining with other atoms.

Metallic bond – *металічний зв'язок* **-** bond formed by atoms of metals, in which the outer electrons of the atoms form a common electron cloud.

Oxidation number – *ступінь окислення* **-** number of electrons an atom gains, loses or shares when it forms chemical bonds.

II. Match the chemical terms on the left with their correct definitions on the right.

atom	number of electrons an atom gains, loses or shares when it forms chemical bonds;
ion	combination of atoms formed by a covalent bond;
valence electron	bonding that involves the sharing of electrons;
ionic bonding	tendency of an atom to attract electrons;
chemical bonding	energy required for ionization;
ionization	combining of atoms of elements to form new substances;
ionization energy	process of removing electrons and forming ions;
electron affinity	bonding that involves the transfer of electrons;
covalent bonding	electron in the outermost energy level of an atom;
molecule	an atom that has become charged due to the loss or gain of electrons;
oxidation number	the smallest part of any element that retains all the properties of that element.

III. Fill in the blanks from the words below. Translate the sentences into Ukrainian:

Atoms, compound, protons, neutrons, electrons, valence electrons, chemical bonds, gain, lose, ion, molecule, polyatomic ion.

1. … are the basic building blocks of all the substances in the universe.
2. Atoms of elements combine with one another to produce new and different substances called ….
3. Inside the nucleus are two types of subatomic particles: … and ….
4. Outside the nucleus are negatively charged particles called ….
5. The electrons in the outermost energy level of an atom are called … ….
6. The electron arrangement of the outermost energy level of an atom determines whether or not the atom will form … ….
7. In order to achieve stability, an atom will either … or … electrons.
8. Ionic bonding, or electron-transfer bonding, gets its name from the word ….
9. A … is the smallest particle of a covalently bonded substance that has all the properties that substance.
10. A group of covalently bonded atoms that acts like a single atom when combining with other atoms is called a ….

IV. Answer the following questions:

1. What is chemical bonding?
2. What are valence electrons?
3. Describe the ionic bond. How does it differ from a covalent bond? A metallic bond?
4. What is the difference between an atom and an ion?
5. What physical form do ionic compounds usually have? Why?
6. Give definitions or descriptions of the following:
   a) ionic compound;
   b) crystal lattice;
   c) electron-dot diagram.
7. What is a molecule?
8. How can the oxidation number of an atom be used?

V. Make written translation into Ukrainian of the text "Covalent Bonds".

VI. Translate into English:

1. Атом містить позитивно заряджений центр, який називається ядром.

2. У середині ядра є два види субатомних часточок: протони й нейтрони.

3. Протони мають позитивний заряд, а нейтрони є нейтральними часточками.

4. Для того, щоб досягнути стабільності, атоми або приєднують, або віддають електрони.

5. Зв'язок, що передбачає переміщення електронів, називається іонним.

6. При ковалентному зв'язку позитивно заряджене ядро атома одночасно притягує негативно заряджені електрони, які перебувають у спільному користуванні.

7. Атоми металів утворюють металічні зв'язки.

8. Кількість електронів, яку атом приєднує, віддає чи поділяє, називається ступенем окислення.

Chemical Reactions

2.1 Nature of Chemical Reactions

You have probably never given much thought to an ordinary book of matches. But stop for a minute and consider the fact that a single match in a book of matches can remain unchanged indefinitely. Yet if someone strikes that match, it bursts into a brilliant flame. And when that flame goes out, the appearance of the match will have changed forever. It can never be lighted again. The match has undergone a **chemical reaction.** What does this mean? **A chemical reaction is a process in which the physical and chemical properties of the original substances change as new substances with different physical and chemical properties are formed.** The burning of gasoline, the rusting of iron, and the baking of bread are all examples of chemical reactions.

Characteristics of Chemical Reactions

All chemical reactions share certain characteristics. One of these characteristics is that a chemical reaction always results in the formation of a new substance. The dark material on a burned match is a new substance. It is not the same substance that was originally on the match.

Another chemical reaction that you can easily observe occurs when a flashbulb lights. Because modern cameras have built-in flashes powered by a battery, you may not be familiar with traditional flashbulbs. At one time, however, all cameras used flashbulbs to provide the light necessary to take a photograph. Such flashbulbs can be used only once.

Inside a flashbulb is a small coil of shiny gray metal. This metal is magnesium. The bulb is filled with the invisible gas oxygen. When the flashbulb is set off, the magnesium combines with the oxygen in a chemical reaction. During the reaction, energy is released in the form of light, and a fine white powder is produced. You can see this powder on the inside of the bulb. The powder is magnesium oxide, a compound with physical and chemical properties unlike those of the elements that were originally present—magnesium and oxygen. During the chemical reaction, the original substances are changed into a new substance. Now you can understand why traditional flashbulbs can be used only once.

The substances present before the change and the substances formed by the change are the two kinds of substances involved in a chemical reaction. A substance that enters into a chemical reaction is called a **reactant**. A substance that is produced by a chemical reaction is called a **product.** So a general description of a chemical reaction can be stated as reactants changing into products.

In addition to changes in chemical and physical properties, chemical reactions always involve a change in energy. Energy is either absorbed or released during a chemical reaction. For example, heat energy is absorbed when sugar changes into caramel. When gasoline burns, hear energy is released.

Capacity to React

In order for a chemical reaction to occur, the reactants must have the ability to combine with other substances to form products. What accounts for the ability of different substances to undergo certain chemical reactions? In order to answer this question, you must think back to what you learned about atoms and bonding.

Atoms contain electrons, or negatively charged particles. Electrons are located in energy levels surrounding the nucleus, or center of the atom. The electrons in the outermost energy level are called the valence electrons. It is the valence electrons that are involved in chemical bonding. An atom forms chemical bonds with other atoms in order to complete its outermost energy level. As you learned in Chapter 1, having a complete outermost energy level is the most stable condition for an atom. An atom will try to fill its outermost energy level by gaining or losing electrons, or by sharing electrons. A chemical bond formed by the gain or loss of electrons is an ionic bond. A chemical bond formed by the sharing of electrons is a covalent bond.

The arrangement of electrons in an atom determines the ease with which the atom will form chemical bonds. An atom whose outermost energy level is full will not bond with other atoms.

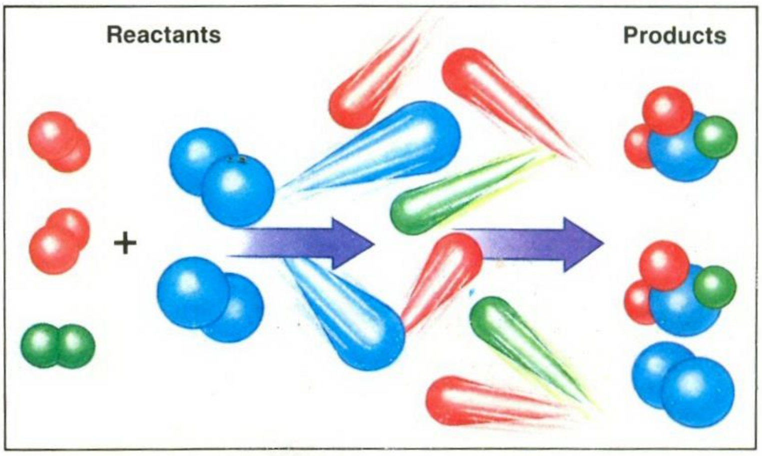


Fig. 2.1 Formation of new bonds in products.

But an atom with an incomplete outermost energy level will bond readily. The ease with which an atom will form chemical bonds is known as the bonding capacity of an atom. The bonding capacity of an atom determines its ability to undergo chemical reactions. And the ability to undergo chemical reactions is an important chemical property.

During a chemical reaction, atoms can form molecules, molecules can break apart to form atoms, or molecules can react with other molecules. In any case, new substances are produced as existing bonds are broken, atoms are rearranged, and new bonds are formed.

Vocabulary notes:

indefinitely – необмежено,
gasoline – газолін,
rusting of iron – ржавіння заліза,
flame – полум’я,
flashbulb – лампа-спалах,
coil – спіраль,
magnesium – магній,
to enter – вступати,
reactant – реагент,
product – продукт хім. реакції,
to absorb – поглинати,
to release – виділяти,
heat energy – теплова енергія,
caramel – карамель,
ease – легкість.

2.2 Chemical Equations

It is important to be able to describe the details of a chemical reaction—how the reactants changed into the products. This involves indicating all the individual atoms involved in the reaction. One way of doing this is to use words. But describing a chemical reaction with words can be awkward. Many atoms may be involved, and the changes may be complicated.

For example, consider the flashbulb reaction described earlier. A word equation for this reaction would be: Magnesium combines with oxygen to form magnesium oxide and give off energy in the form of light. You could shorten this sentence by saying: Magnesium and oxygen form magnesium oxide and light energy.

Chemists have developed a more convenient way to represent a chemical reaction. Using symbols to represent elements and formulas to represent compounds, a chemical reaction can be described by a **chemical equation.** A chemical equation is an expression in which symbols and formulas are used to represent a chemical reaction.

In order to write a chemical equation, you must first write the correct chemical symbols or formulas for the reactants and products. Then you need to show that certain substances combine. This is done with the use of a + sign, which replaces the word and. Between the reactants and the products, you need to draw an arrow to show that the reactants have changed into the products. The arrow, which is read "yields," takes the place of an equal sign. It also shows the direction of the chemical change. The chemical equation for the flashbulb reaction can now be written:

$$\mathbf{Mg + O_2 \longrightarrow MgO + Energy}$$

$$\textbf{Magnesium + Oxygen} \longrightarrow \textbf{Magnesium oxide + Energy}$$

Conservation of Mass

Chemists have long known that atoms can be neither created nor destroyed during a chemical reaction. In other words, the number of atoms of each element must be the same before and after the chemical reaction (that is, the number of atoms remains the same on both sides of the arrow in a chemical equation). The changes that occur during any chemical reaction involve only the rearrangement of atoms, not their production or destruction.

Every atom has a particular mass. Because the number of atoms of each element remains the same, mass can never change in a chemical reaction. The total mass of the reactants must equal the total mass of the products. No mass is lost or gained. **The observation that mass remains constant in a chemical reaction is known as the law of conservation of mass.**

Balancing Chemical Equations

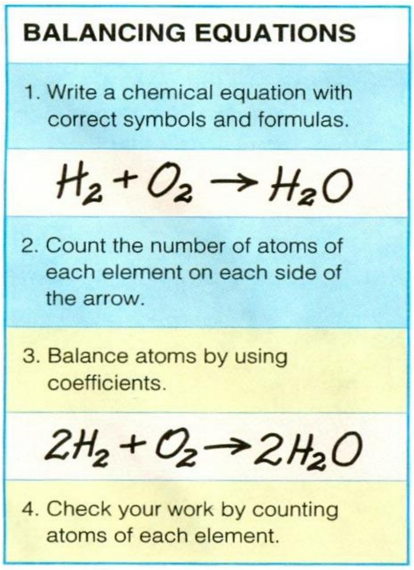
The law of conservation of mass must be taken into account when writing a chemical equation for a chemical reaction. A chemical equation must show that atoms are neither created nor destroyed. The number of atoms of each element must be the same on both sides of the equation.

An equation in which the number of atoms of each element is the same on both sides of the equation is called a balanced chemical equation. Let's go back to the chemical equation for the flashbulb reaction:

$$\mathbf{Mg + O_2 \longrightarrow MgO + Energy}$$

There are 2 oxygen atoms on the left but only 1 on the right. This cannot be correct because atoms can be neither created nor destroyed during a chemical reaction. How, then, can you make the number of atoms of each element the same on both sides of the equation?

One thing you cannot do to balance an equation is change a subscript. Changing the subscript would mean changing the substance. You can, however, change the number of atoms or molecules of each substance involved in the chemical reaction. You can do this by placing a number known as a coefficient in front of the appropriate symbols and formulas. Suppose the coefficient 3 is placed in front of a molecule of oxygen. It would be written as $3O_2$, and it would mean that there are 6 atoms of oxygen (3 molecules of 2 atoms each).



BALANCING EQUATIONS

1. Write a chemical equation with correct symbols and formulas.

$H_2 + O_2 \rightarrow H_2O$

2. Count the number of atoms of each element on each side of the arrow.
3. Balance atoms by using coefficients.

$2H_2 + O_2 \rightarrow 2H_2O$

4. Check your work by counting atoms of each element.

Fig. 2.2 The steps in balancing a chemical equation.

Now let's return to the flashbulb equation. To balance this equation, you must represent more than 1 atom of oxygen on the product side of the equation. If you place a coefficient of 2 in front of the formula for magnesium oxide, you will have 2 molecules of MgO. So you will have 2 atoms of oxygen. But you will also have 2 atoms of magnesium on the product side and only 1 atom of magnesium on the reactant side. So you must add a coefficient of 2 to the magnesium on the reactant side of the equation. There—the equation is balanced:

$$\mathbf{2Mg + O_2 \longrightarrow 2MgO + Energy}$$

If you count atoms again, you will find 2 magnesium atoms on each side of the equation, as well as 2 oxygen atoms. The equation can be read: 2 atoms of magnesium combine with 1 molecule of oxygen to yield 2 molecules of magnesium oxide. Notice that when no coefficient is written, such as in front of the molecule of oxygen, the number is understood to be 1. Remember that to balance a chemical equation, you can change coefficients but never symbols or formulas.

Chemical equations are actually easy to write and balance. Follow the rules in *Fig. 2.2* and those listed here.

1. Write a word equation and then a chemical equation for the reaction. Make sure the symbols and formulas for reactants and products are correct.

2. Count the number of atoms of each element on each side of the arrow. If the numbers are the same, the equation is balanced.

3. If the number of atoms of each element is not the same on both sides of the arrow, you must balance the equation by using coefficients. Put a coefficient in front of a symbol or formula so that the number of atoms of that substance is the same on both sides of the arrow. Continue this procedure until you have balanced all the atoms.

4. Check your work by counting the atoms of each element to make sure they are the same on both sides of the equation.

Vocabulary notes:

awkward – незручний,
chemical equation – хімічне рівняння,
to yield – давати,
rearrangement – перестановка,
conservation of mass – збереження маси,
balance chemical equation – збереження рівноваги,
coefficient – коефіцієнт,
procedure – процедура.

2.3 Types of Chemical Reactions

There are billions of different chemical reactions. In some reactions, elements combine to form compounds. In other reactions, compounds break down into elements. And in still other reactions, one element replaces another.

Chemists have identified four general types of reactions: synthesis, decomposition, single replacement, and double replacement. In each type of reaction, atoms are being rearranged and substances are being changed in a specific way.

Synthesis Reaction

In a **synthesis reaction,** two or more simple substances combine to form a new, more complex substance. So that you can easily identify synthesis reactions, it may be helpful for you to remember the form these reactions always take:

$$\mathbf{A + B \longrightarrow C}$$

For example, the reaction between sodium and chlorine to form sodium chloride is a synthesis reaction:

$$\mathbf{2Na + Cl_2 \longrightarrow 2NaCl}$$

$$\textbf{Sodium + Chlorine} \longrightarrow \textbf{Sodium chloride}$$

Reactions involving the corrosion of metals are synthesis reactions. The rusting of iron involves the chemical combination of iron with oxygen to form iron oxide. Reactions in which a substance burns in oxygen are often synthesis reactions. Think back to the in that occurs in a flashbulb.

Decomposition Reaction

In a **decomposition reaction,** a complex substance breaks down into two or more simpler substances. Decomposition reactions are the reverse of synthesis reactions. Decomposition reactions take the form:

$$\mathbf{C \longrightarrow A+B}$$

When you take the cap off a bottle of soda, bubbles rise quickly to the top. Why? Carbonated beverages such as soda contain the compound carbonic acid, H_2CO_3. This compound decomposes into water (H_2O) and carbon dioxide gas (CO_2). The CO_2, gas makes up the bubbles that are released. The balanced equation for the decomposition of carbonic acid is

$$\mathbf{H_2CO_3 \longrightarrow H_2O + CO_2}$$

$$\textbf{Carbonic acid} \longrightarrow \textbf{Water +Carbon dioxide}$$

Single-Replacement Reaction

In a **single-replacement reaction,** an uncombined element replaces an element that is part of a compound. These reactions take the form :

$$\mathbf{A+ BX \longrightarrow AX+B}$$

Notice that the atom represented by the letter X switches its partner from B to A.

An example of a single-replacement reaction is the reaction between sodium and water. The very active metal sodium must be stored in oil, not water. When it comes in contact with water, it reacts explosively. The sodium replaces the hydrogen in the water and releases lots of energy. The balanced equation for the reaction of sodium with water is:

$$2Na + 2H_2O \longrightarrow 2NaOH + H_2$$

Sodium + Water ⟶ Sodium hydroxide + Hydrogen

Most single-replacement reactions, however, do not cause explosions.

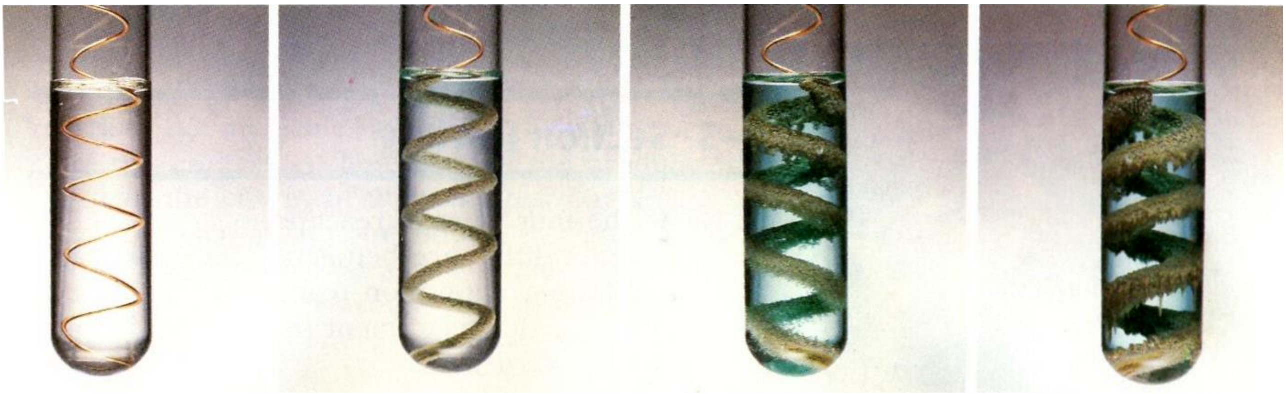


Fig. 2.3 The gradual buildup of silver metal on the coil.

Double-Replacement Reaction

In a **double-replacement reaction,** different atoms in two different compounds replace each other. In other words, two compounds react to form two new compounds. These reactions take the form:

$$AX+BY \longrightarrow AY+BX$$

Notice that in this reaction the atoms represented by both the letters X and Y switch partners.

If you have ever had an upset stomach, you may have taken a medicine that contained the compound magnesium carbonate. This compound reacts with the hydrochloric acid in your stomach in the following way:

$$MgCO_3 + 2\,HCl \longrightarrow MgCl_2 + H_2CO_3$$

Magnesium chloride +Hydrochloric acid ⟶ Magnesium carbonate + Carbonic acid

In this double-replacement reaction, the magnesium and hydrogen replace each other, or switch partners. One product is magnesium chloride, a harmless compound. The other product is carbonic acid. Do you remember what happens to carbonic acid? It decomposes into water and carbon dioxide. Your stomachache goes away because instead of too much acid, there is now water and carbon dioxide. You owe your relief to this double-replacement reaction:

$$MgCO_3 + 2\,HCl \longrightarrow MgCl_2 + H_2O + CO_2$$

Magnesium carbonate Magnesium chloride+

+Hydrochloric acid ⟶ Water + Carbon dioxide

Vocabulary notes:

billion – більйон,
to break down – розпадатися,
to replace – заміняти, заміщати,
to identify – визначати,
synthesis – синтез,
decomposition – розпад, розчеплення,
single replacement reaction – реакція заміщення,
double replacement reaction – реакція обміну,
to involve – спричиняти,
corrosion of metal – корозія металу,
reverse – зворотній,
carbonated beverage – газований напій,
carbonic acid – вугільна кислота,
uncombined element – вільний елемент,
to switch – змінювати,
hydrogen – гідроген, водень,
magnesium carbonate – карбонат магнію,
hydrochloric acid – соляна кислота,
magnesium chloride – хлорид магнію,
to owe – завдячувати.

2.4 Energy of Chemical Reactions

Energy is always involved in a chemical reaction. Sometimes energy is released, or given off, as the reaction takes place. Sometimes energy is absorbed. **Based on the type of energy change involved, chemical reactions are classified as either exothermic or endothermic reactions.**

In either type of reaction, energy is neither created nor destroyed. It merely changes position or form. The energy released or absorbed usually takes the form of heat or visible light.

Exothermic Reactions

A chemical reaction in which energy is released is an **exothermic reaction.** The word exothermic comes from the root *-thermic,* which refers to heat, and the prefix *exo-*, which means out of. Heat comes out of, or is released from, a reacting substance during an exothermic reaction. A reaction that involves burning, or a combustion reaction, is an example of an exothermic reaction. The combustion of methane gas, which occurs in a gas stove, releases a large amount of heat energy.

The energy that is released in an exothermic reaction was originally stored in the molecules of the reactants. Because the energy is released during the reaction, the molecules of the products do not receive this energy. So the energy of the products is less than the energy of the reactants. Energy diagrams, such as the ones shown in

Fig.2.4, can be used to show the energy change in a reaction. Note that in an exothermic reaction, the reactants are higher in energy than the products are.

Endothermic Reactions

A chemical reaction in which energy is absorbed is an **endothermic reaction.** The prefix *endo*- means into. During an endothermic reaction, energy is taken into a reacting substance. The energy absorbed during an endothermic reaction is usually in the form of heat or light. The decomposition of sodium chloride, or table salt, is an endothermic reaction. It requires the absorption of electric energy.

The energy that is absorbed in an endothermic reaction is now stored in the molecules of the products. So the energy of the products is more than the energy of the reactants. See *Fig. 2.4* again.

Activation Energy

The total energy released or absorbed by a chemical reaction does not tell the whole story about the energy changes involved in the reaction. In order for the reactants to form products, the molecules of the reactants must combine to form a short-lived, high-energy, extremely unstable molecule. The atoms of this molecule are then rearranged to form products. This process requires energy. The molecules of the reactants must "climb" to the top of an "energy hill" before they can form products.

The energy needed to "climb" to the top of the "energy hill" is called **activation energy.** After the reactants have absorbed this activation energy, they can "slide down" the energy hill to form products.

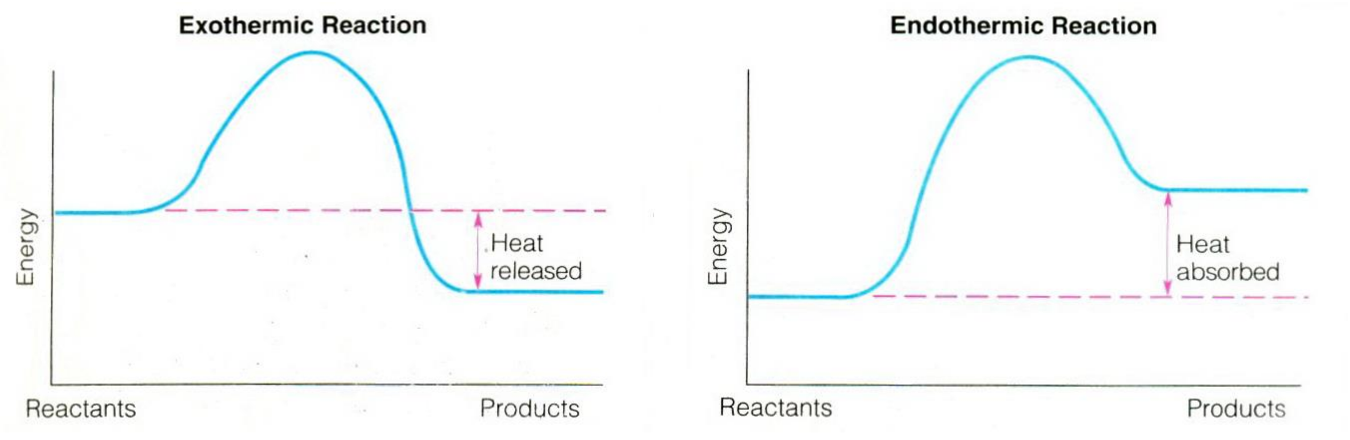


Fig.2.4 Energy diagram for an exothermic and endothermic reactions.

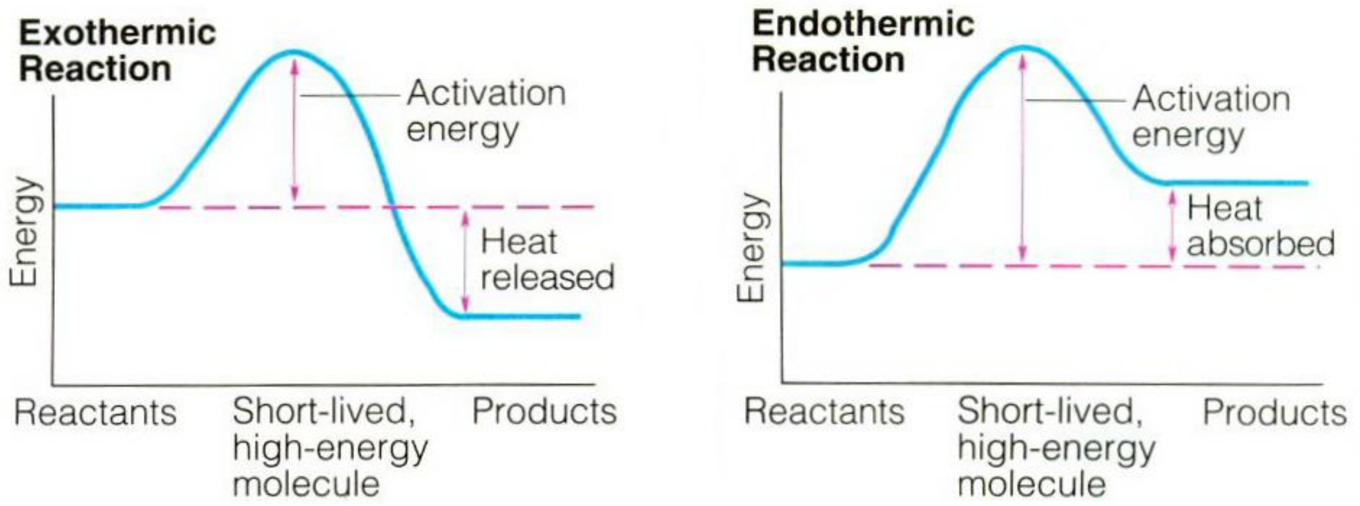


Fig.2.5 Activation energy of an exothermic and an endothermic reactions.

An energy diagram indicates more than whether a reaction is exothermic or endothermic. An energy diagram shows the activation energy of the reaction. *Fig. 2.5* shows an energy diagram for both an exothermic reaction and an endothermic reaction.

All chemical reactions require activation energy. Even an exothermic reaction such as the burning of a match requires activation energy. In order to light a match, it must first be struck. The friction of the match against the striking pad provides the necessary activation energy.

Vocabulary notes:

exothermic reaction – екзотермічна реакція,
endothermic reaction – ендотермічна реакція,
combustion reaction – реакція горіння,
methane – метан,
sodium chloride – хлорид натрію,
activation energy – енергія активації,
friction – тертя,
to provide – забезпечувати

2.5 Rates of Chemical Reactions

The complete burning of a thick log can take many hours. Yet if the log is ground into fine sawdust, the burning can take place at dangerously high speeds. In fact, if the dust is spread through the air, the burning can produce an explosion! In both these processes, the same reaction is taking place. The various substances in the wood are combining with oxygen. One reaction, however, proceeds at a faster speed than the other one does. What causes the differences in reaction times?

In order to explain differences in reaction time, chemists must study **kinetics.** Kinetics is the study of **reaction rates.** The rate of a reaction is a measure of how quickly reactants turn into products. Reaction rates depend on a number of factors, which you will now read about.

Collision Theory

You learned that chemical reactions occur when bonds between atoms are broken, the atoms are rearranged, and new bonds are formed. In order for this process to occur, particles must collide. As two particles approach each other, they begin to interact. During this interaction, old bonds may be broken and new bonds formed. For a reaction to occur, however, particles must collide at precisely the correct angle with the proper amount of energy. The more collisions that occur under these conditions, the faster the rate of the chemical reaction.

A theory known as the **collision theory** relates particle collisions to reaction rate. **According to the collision theory, the rate of a reaction is affected by four factors: concentration, surface area, temperature, and catalysts.**

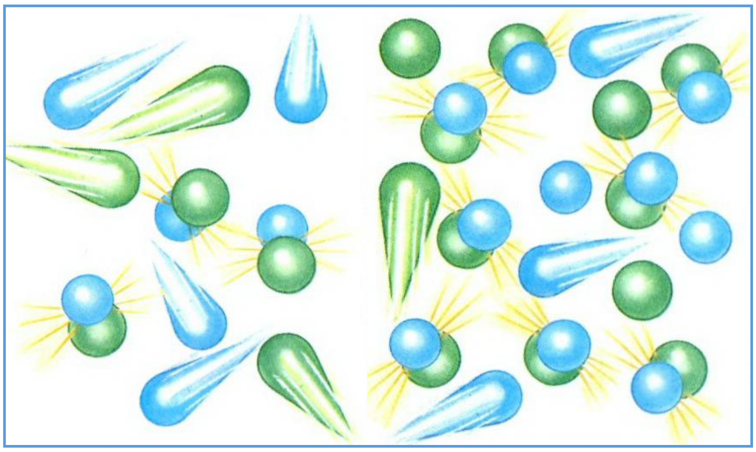


Fig.2.6 Collisions of molecule.

Concentration

The concentration of a substance is a measure of the amount of that substance in a given unit of volume. A high concentration of reactants means there are a great many particles per unit volume. So there are more particles of reactants available for collisions. More collisions occur and more products are formed in a certain amount of time.

Generally, most chemical reactions proceed at a faster rate if the concentration of the reactants is increased. A decrease in the concentration of the reactants decreases the rate of reaction. For example, a highly concentrated solution of sodium hydroxide

(NaOH), or lye, will react more quickly to clear a clogged drain than will a less concentrated lye solution.

Surface Area

When one of the reactants in a chemical reaction is a solid, the rate of reaction can be increased by breaking the solid into smaller pieces. This increases the surface area of the reactant. Surface area refers to how much of a material is exposed. An increase in surface area increases the collisions between reacting particles.

A given quantity of wood burns faster as sawdust than it does as logs. Sawdust has a much greater surface area exposed to air than do the logs. So oxygen particles from the air can collide with more wood particles per second. The reaction rate is increased.

Many medicines are produced in the form of a fine powder or many small crystals. Medicine in this form is often more effective than the same medicine in tablet form. Tablets dissolve in the stomach and enter the bloodstream at a slower rate.

Temperature

An increase in temperature generally increases the rate of a reaction. Here again the collision theory provides an explanation for this fact. Particles are constantly in motion. Temperature is a measure of the energy of their motion. Particles at a high temperature have more energy of motion than do particles at a low temperature. Particles at a high temperature move faster than do particles at a low temperature. So particles at a high temperature collide more frequently. They also collide with greater energy. This increase in the rate and energy of collisions affects the reaction rate. More particles of reactants are able to gain the activation energy needed to form products. So reaction rate is increased.

At room temperature, the rates of many chemical reactions roughly double or triple with a rise in temperature of 10°C.

Catalysts

Some chemical reactions take place very slowly. The reactions involved with digesting a cookie are examples. In fact, if these reactions proceeded at their normal rate, it could take weeks to digest one cookie! Fortunately, certain substances speed up the rate of a chemical reaction. These substances are catalysts. A catalyst is a substance that increases the rate of a reaction but is not itself changed by the reaction. Although a catalyst alters the reaction, it can be recovered at the end of the reaction.

How does a catalyst change the rate of a reaction if it is not changed by the reaction? Again, the explanation is based on the collision theory. Reactions often involve a series of steps. A catalyst changes one or more of the steps.

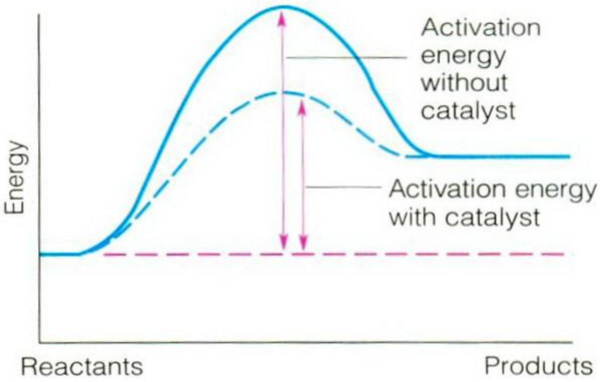


Fig. 2.7 A catalyst changes the rate of a chemical reaction.

A catalyst produces a different, lower energy path for the reaction. In other words, it lowers the "energy hill," or activation energy. A decrease in the activation energy needed for the reaction allows more reactant particles to form products. Collisions need not be so energetic. Therefore, more collisions are successful at producing products.

A catalyst is usually involved in one or more of the early steps in a reaction. The catalyst is, however, re-formed during a later step. This explains why a catalyst can be recovered at the end of the reaction.

Catalysts are used in many chemical processes. Certain automobiles contain devices called catalytic converters. A catalytic converter speeds up the reaction that changes the harmful gases produced by automobile engines into harmless ones. Some of the most important catalysts are those found in your body. Catalysts in the body are called enzymes. Each enzyme increases the rate of a specific reaction involved in the body's metabolism.

Vocabulary notes:

rate of chemical reaction – швидкість хімічної реакції,
to be ground – бути перемеленим,
sawdust – тирса,
to proceed – продовжувати,
kinetics – кінетика,
to collide – зіткнутися,
precisely – точно,
collision theory – теорія зіткнення.
volume – об’єм,

sodium hydroxide – гідроксид натрію,
clogged drain – каналізаційна труба,
charcoal – деревне вугілля,
solid – тверда речовина,
to expose – піддавати,
bloodstream – потік крові,
catalyst – каталізатор,
digesting – травлення,
catalytic converter – каталітичний конвертер,
enzyme – фермент,
metabolism – метаболізм.

TASKS

Chemical reaction – *хімічна реакція –* process in which substances undergo physical and chemical changes that result in the formation of new substances with different properties.

Reactant – *реагент –* substance that enters into a chemical reaction.

Product – *продукт –* substance produced by a chemical reaction.

Chemical equation – *хімічне рівняння –* description of a chemical reaction using symbols to represent elements and formulas to represent equations.

Synthesis reaction – *реакція синтезу –* chemical reaction in which two or more simple substances combine to form a new, more complex substance.

Decomposition reaction – *реакція розчеплення* **-** chemical reaction in which a complex substance breaks down into two or more simpler substances.

Single-replacement reaction – *реакція заміщення –* chemical reaction in which an uncombined element replaces an element that is part of a compound.

Double-replacement reaction – *реакція обміну –* chemical reaction in which different atoms in two different compounds replace each other.

Exothermic reaction – *екзотермічна реакція –* chemical reaction in which energy is released.

Endothermic reaction – *ендотермічна реакція –* chemical reaction in which energy is absorbed.

Activation energy – *енергія активізації* **-** energy required for a chemical reaction to occur.

Kinetics – *кінетика –* study of the rates of chemical reactions.

Reaction rate – *швидкість реакції –* measure of how quickly reactants change into products.

Collision theory – *теорія зіткнення* – theory that relates collisions among particles to reaction rate; reaction rate depends on such factors as concentration, surface area, temperature, and catalysts.

Catalyst – *каталізатор* – substance that increases the rate of a chemical reaction without being changed by the reaction.

II. Match the chemical terms on the left with their correct definitions on the right.

reactant	substance that increases the rate of a chemical reaction without being changed by reaction
product	measure of how quickly reactants change into products
exothermic reaction	energy required for a chemical reaction to occur
endothermic reaction	study of the rates of chemical reactions
activation energy	chemical reaction in which energy is absorbed
kinetics	chemical reaction in which energy is released
reaction rate	substance produced by a chemical reaction
catalyst	substance that enters into a chemical reaction

III. Fill in the blanks from the words below. Translate the sentences into Ukrainian:

Chemical reactions, reactants, products, bonding capacity, chemical equations, conservation of mass, synthesis, decomposition, single replacement, double replacement, exothermic, endothermic, reaction rate, concentration, surface area, temperature, catalysts, enzymes.

1. The burning of gasoline, the rusting of iron and the baking of bread are all examples of … ….
2. A general description of a chemical reaction can be stated as … changing into ….
3. The … … of an atom determines its ability to undergo chemical reaction.
4. A … … is an expression in which symbols and formulas are used to represent a chemical reaction.
5. The observation that mass remains constant in a chemical is known as the law of … … ….
6. There are four general types of chemical reactions: …, …, … … and … ….

7. Based on the type of energy change involved, chemical reactions are classified as … and … reactions.
8. … … is a measure of how quickly reactants turn into products.
9. According to the collision theory, the rate of a reaction is affected by four factors: …, … …, …, ….
10. Catalysts in the body are called ….

IV. Answer the following questions:

1. Describe some factors that serve as evidence for chemical reactions.
2. Give some examples of chemical reactions.
3. Imagine a burning candle. Describe any evidence for chemical reactions that occur when a candle burns.
4. What is meant by the rate of a chemical reaction?
5. What is a reactant? A product?
6. Tell how each of the following can alter the rate of a chemical reaction:
   a) temperature;
   b) state of subdivision;
   c) concentration.
7. Suppose you want to burn some coal in air quickly. Explain how each of the following factors can be changed to increase the rate of the combustion of coal:

a) temperature;
b) state of subdivision;
c) concentration.

8. What is a catalyst and how does a catalyst alter the rate of a chemical reaction?
9. What types of chemical reactions do you know?

What is the difference between exothermic and endothermic reactions?

V. Make written translation into Ukrainian of the text "Energy of Chemical Reactions".

VI. Translate into English:

1. Хімічна реакція – це процес, в результаті якого фізичні та хімічні властивості первинної речовини змінюються, так як утворюються нові речовини з відмінними фізичними та хімічними властивостями.

2. Речовина, яка вступає в хімічну реакцію, називається реагентом.

3. Речовина, яка виробляється внаслідок хімічної реакції, називається продуктом.

4. Вчені визначили чотири основні типи хімічних реакцій: заміщення, обміну, розчеплення, синтезу.

5. Хімічна реакція, в якій енергія виділяється, є екзотермічною.

6. Через те, що енергія виділяється під час реакції, молекули продукту не отримують цю енергію.

7. Таким чином енергія продукту є меншою, ніж енергія реагента.

8. Хімічна реакція, в якій енергія поглинається, є ендотермічною.

9. Відповідно до теорії зіткнення, на швидкість реакції впливають чотири фактори: концентрація, площа поверхні, температура та каталізатори.

Families of Chemical Compounds

3.1 Solution Chemistry

In this chapter you will discover how scientists have attempted to bring order to the incredible number of different types of chemical compounds that exist. In other words, you will learn about a system of classifying compounds into families based on their physical and chemical properties.

One of the most important and abundant families of chemical compounds is the family of acids, bases, and salts. This family may already be familiar to you. Have you ever heard of acetic acid in vinegar? Magnesium hydroxide in milk of magnesia? Or sodium hydrogen carbonate in baking soda? Acetic acid is an acid; magnesium hydroxide is a base; and sodium hydrogen carbonate is a salt. See—you do know something about this family!

In order to better understand acids, bases, and salts, it will be helpful to take a few steps back and look at an important process that produces these compounds. The process involves making solutions.

What Is a Solution?

What happens when a lump of sugar is dropped into a glass of lemonade? What takes place when carbon dioxide gas is bubbled through water? And where do mothballs go when they disappear? The answer to these questions is the same: The sugar, gaseous carbon dioxide, and mothballs all dissolve in the substances in which they are mixed.

Careful examination of each of these mixtures— even under a microscope—will not reveal molecules of sugar in lemonade, carbon dioxide in water, or naphthalene in the air. But the sweet taste of lemonade tells you the sugar is there. The "fizziness" of soda water indicates the presence of carbon dioxide. And the smell of mothballs is evidence of naphthalene. In each of these mixtures, the molecules of one substance have become evenly distributed among the molecules of the other substance. The mixtures are uniform (the same) throughout. Each mixture is a **solution.**

A solution is a mixture in which one substance is dissolved in another substance. Different parts of a solution are identical. That is what is meant by the words uniform throughout. The molecules making up a solution are too small to be seen and do not settle when the solution is allowed to stand. A solution, then, is a "well-mixed" mixture.

All solutions have several basic properties. Let's go back to the glass of sweetened lemonade to discover just what these properties are. **A solution consists of two parts: One part is the substance being dissolved, and the other part is the substance doing the dissolving.**

The substance that is dissolved is called the **solute**. The substance that does the dissolving is called the **solvent**. The solvent is sometimes called the dissolving medium. In the sweetened lemonade, the solute is the sugar and the solvent is the lemonade. Even without the sugar, the lemonade is a solution. It is made of water and lemon juice.

The most common solutions are those in which the solvent is a liquid. The solute can be a solid, a liquid, or a gas. The most common solvent is water.

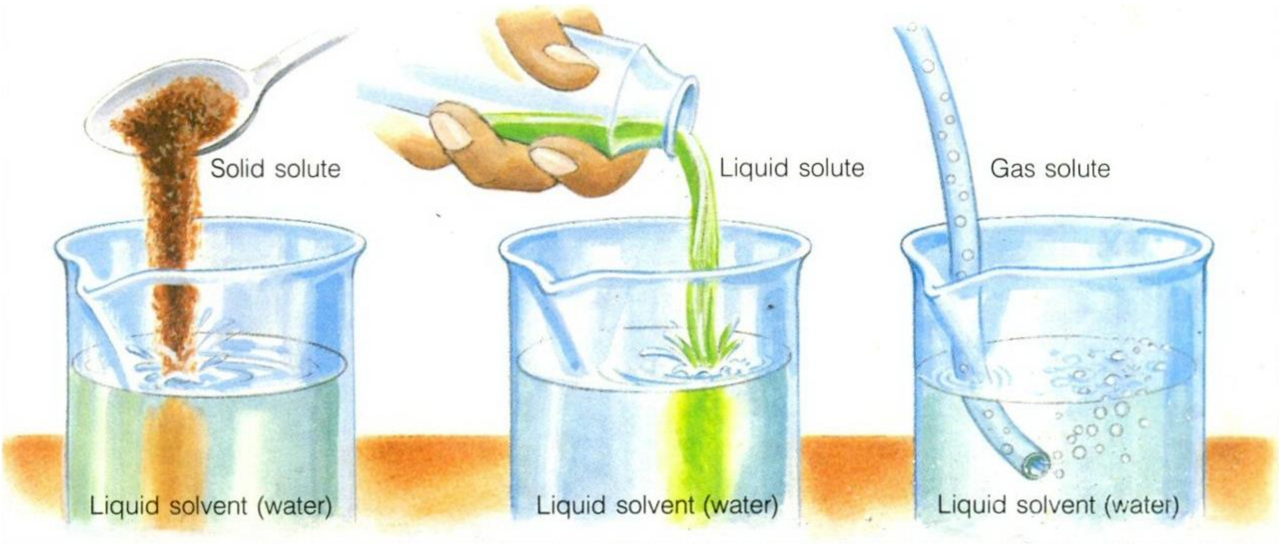


Fig.3.1 Three types of solution.

When alcohol is the solvent, the solution is called a tincture. Have you ever heard of tincture of iodine? It is an antiseptic used to treat minor cuts and scratches. What is the solute in this solution?

The particles in a solution are individual atoms, ions, or molecules. Because the particles are so small, they do not scatter light that passes through the solution. A liquid solution appears clear.

Most solutions cannot easily be separated by simple physical means such as filtering. However, a physical change such as evaporation or boiling can separate the parts of many solutions. If salt water is boiled, the water will change from a liquid to a gas, leaving behind particles of salt.

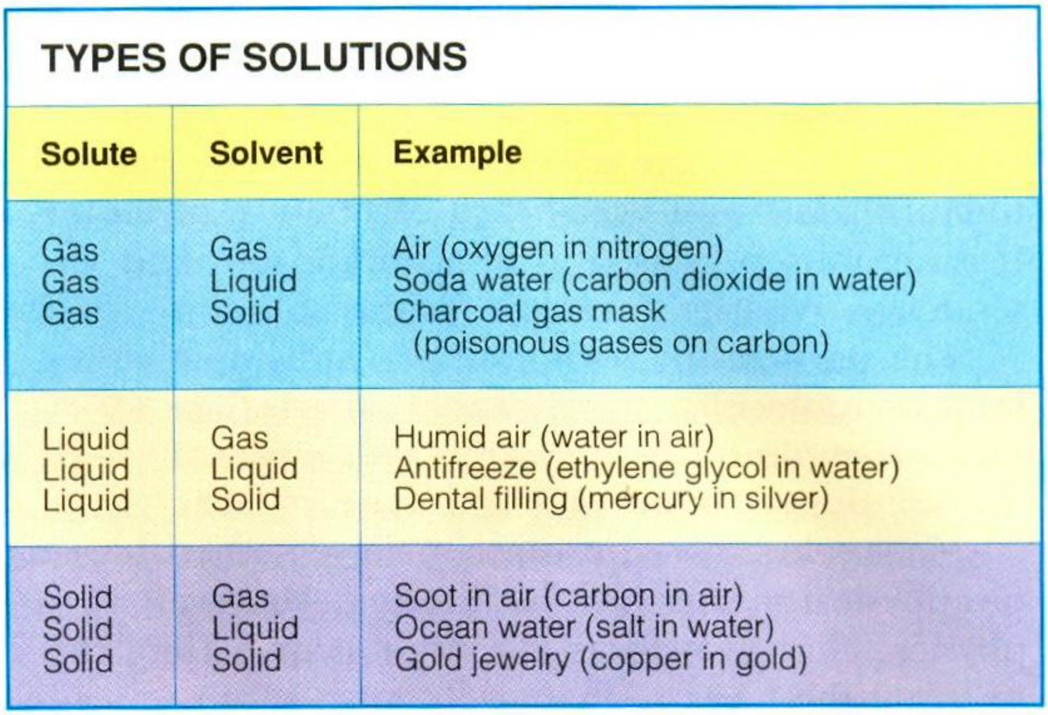
Another important property of a solution is its ability or inability to conduct an electric current. An electric current is a flow of electrons. In order for electrons to flow through a solution, ions must be present. As you learned, ions are charged atoms. A solution that contains ions is a good conductor of electricity. A solution that does not contain ions is a nonconductor.

Pure water is a poor conductor of electric current because it does not contain ions. If a solute such as potassium chloride is added to the water, however, the resulting solution is a good conductor. Substances which water solutions conduct an electric current are called **electrolytes**. Potassium chloride, sodium chloride, and silver nitrate are examples of electrolytes. Most electrolytes are ionic compounds.

Substances which water solutions do not conduct an electric current are called **nonelectrolytes.** A solution of sugar and water does not conduct an electric current. Sugar is a nonelectrolyte, as are alcohol and benzene. Many covalent compounds are nonelectrolytes because they do not form ions in solution.

Making Solutions

Solutions abound in nature. The oceans, the atmosphere, even Earth's interior are solutions. Your body contains a number of vital solutions. Every solution has a particular solute and solvent.



TYPES OF SOLUTIONS

Solute	Solvent	Example
Gas	Gas	Air (oxygen in nitrogen)
Gas	Liquid	Soda water (carbon dioxide in water)
Gas	Solid	Charcoal gas mask (poisonous gases on carbon)
Liquid	Gas	Humid air (water in air)
Liquid	Liquid	Antifreeze (ethylene glycol in water)
Liquid	Solid	Dental filling (mercury in silver)
Solid	Gas	Soot in air (carbon in air)
Solid	Liquid	Ocean water (salt in water)
Solid	Solid	Gold jewelry (copper in gold)

Fig.3.2 Types of solutions.

TYPES OF SOLUTIONS Matter can exist as a solid, a liquid, or a gas. From these three phases of matter, nine different types of solutions can be made. *Fig. 3.2* shows these types of solutions.

The most common solutions are liquid solutions, or solutions in which the solvent is a liquid. The solute can be a solid, a liquid, or a gas. Two liquids that dissolve in each other are said to be miscible. Water and alcohol are miscible. Do you think oil and water are miscible? Solutions of solids dissolved in solids are called alloys. Most alloys are made of metals. Some common alloys include brass, bronze, solder, stainless steel, and wrought iron. You might want to find out exactly what the solute and solvent are in each of these alloys.

RATE OF SOLUTION Suppose you wanted to dissolve some sugar in a glass of water as quickly as possible. What might you do? If your answer included stirring the solution, using granulated sugar, or heating the water, you are on the right track.

Normally, the movement of solute molecules away from the solid solute and throughout the solvent occurs rather slowly. Stirring or shaking the solution helps to move solute particles away from the solid solute faster. More molecules of the solute are brought in contact with the solvent sooner, so the solute dissolves at a faster rate.

Solution action occurs only at the surface of the solid solute. So if the surface area of the solute is increased, the rate of solution is increased. When the solid solute is ground into a fine powder, more solute molecules are in contact with the solvent. Finely powdered solids dissolve much faster than do large lumps or crystals of the same substance.

If heat is applied to a solution, the molecules move faster and farther apart. As a result, the dissolving action is speeded up.

SOLUBILITY From experience, you know that table salt and sugar readily dissolve in water. These compounds are described as being very soluble or having a high degree of **solubility** in water. The solubility of a solute is a measure of how much of that solute can be dissolved in a given amount of solvent under certain conditions. Although a large amount of table salt dissolves in water, only a small amount of table salt dissolves in alcohol. So although the solubility of salt in water is high, the solubility of salt in alcohol is rather low. The solubility of a solute depends on the nature of the solute and of the solvent. Solubility is usually described in terms of the mass of the solute that can be dissolved in a definite amount of solvent at a specific temperature.

Two main factors affect the solubility of a solute. These factors are temperature and pressure. Usually, an increase in the temperature of a solution increases the solubility of a solid in a liquid. Just think how much more sugar dissolves in hot tea than in cold

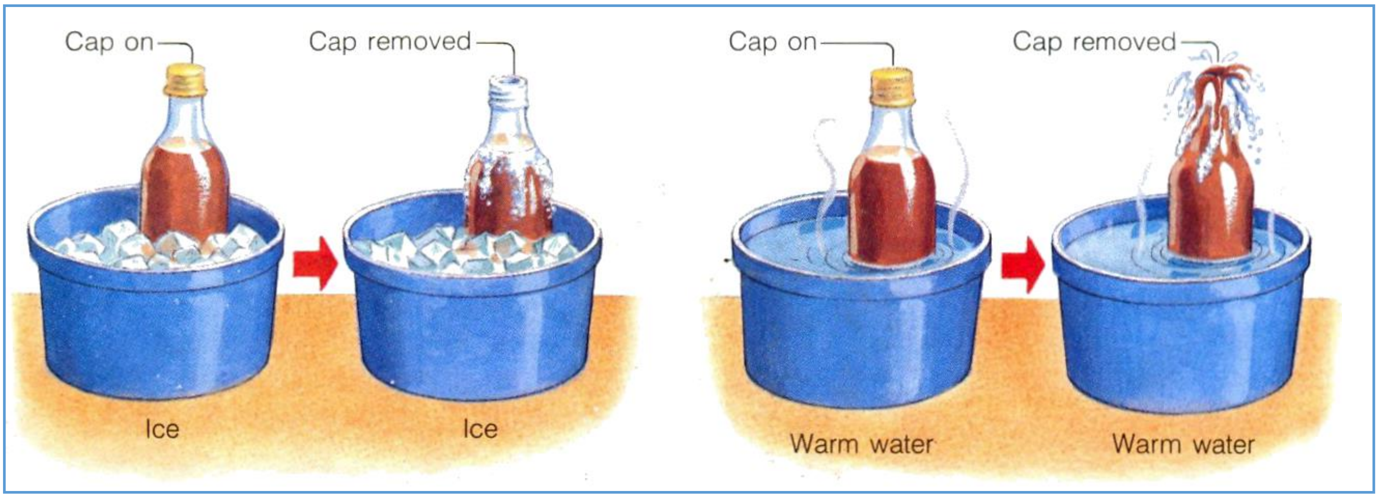


Fig.3.3 The influence of the pressure and the temperature on the solubility of a gas solute.

The situation for a gas dissolved in a liquid is just the opposite. Raising the temperature of a solution decreases the solubility of a gas in a liquid. Perhaps you have observed this fact without actually realizing it. The soda goes flat, or loses its fizz. The fizz in soda is carbon dioxide gas dissolved in soda water. As the temperature of the solution increases, the solubility of the carbon dioxide decreases. The gas comes out of solution, leaving the soda flat.

For both solids and liquids dissolved in liquids, increases and decreases in pressure have practically no effect on solubility. For gases dissolved in liquids, however, an increase in pressure increases solubility, and a decrease in pressure decreases solubility. A bottle of soda fizzes when the cap is removed because molecules of carbon dioxide gas escape from solution as the pressure is decreased. The solubility of the carbon dioxide gas has been decreased by a decrease in pressure.

CONCENTRATION The **concentration** of a solution refers to the amount of solute dissolved in a certain amount of solvent. A solution in which a lot of solute is dissolved in a solvent is called a **concentrated solution.** A solution in which there is little solute dissolved in a solvent is called a **dilute solution**. The terms concentrated and dilute are not precise, however. They do not indicate exactly how much solute and solvent are present.

Using the concept of solubility, the concentration of a solution can be expressed in another way. A solution can be described as saturated, unsaturated, or supersaturated. To understand these descriptions, remember that solubility measures the maximum amount of solute that can be dissolved in a given amount of solvent.

A **saturated solution** is a solution that contains all the solute it can possibly hold at a given temperature. In a saturated solution, no more solute can be dissolved at that temperature. If more solute is added to a saturated solution, it will settle undissolved to the bottom of the solution. In describing a saturated solution, the temperature must always be given.

An **unsaturated solution** is a solution that contains less solute than it can possibly hold at a given temperature. In an unsaturated solution, more solute can be dissolved.

Under special conditions, a solution can be made to hold more solute than is normal for that temperature. Such a solution is a **supersaturated solution**. A supersaturated solution is unstable. If a single crystal of solute is added to a supersaturated solution, the excess solute comes out of solution and settles to the bottom. Only enough solute to make the solution saturated remains dissolved.

SPECIAL PROPERTIES Why is salt spread on roads and walkways that are icy? Why is salt added to cooking water? Why is a substance known as ethylene glycol added to the cooling systems of cars? The answers to these questions have to do with two special properties of solutions.

Experiments show that when a solute is dissolved in a liquid solvent, the freezing point of the solvent is lowered. The lowering of the freezing point is called freezing point depression. The addition of solute molecules interferes with the phase change of solvent molecules. So the solution can exist in the liquid phase at a lower temperature than can the pure solvent. Ethylene glycol, commonly known as antifreeze, is added to automobile cooling systems to lower the freezing point of water.

The addition of a solute to a pure liquid solvent also raises the boiling point of the solvent. This increase is called boiling point elevation. In this case, the addition of solute molecules interferes with the rapid evaporation, or boiling, of the solvent molecules. So the solution can exist in the liquid phase at a higher temperature than can the pure solvent. When salt is added to cooking water, the water boils at a higher temperature. Although it takes a longer time to heat the water to boiling, it takes a shorter time to cook food in that water.

Vocabulary notes:

a lump of sugar – грудка цукру,
to bubble – пузиритися,
mothball – нафталінова кулька,
gaseous – газований,
microscope – мікроскоп,
naphthalene – нафталін,
fizziness – шипіння,
evenly – рівномірно,
solute – розчинна речовина,
solvent – розчинник,
dissolving medium – розчинюючий засіб,
solid – тверде тіло,
liquid – рідина,
gas – газ,
tincture – настоянка,
iodine – йод,
antiseptic – антисептик,
to scatter light – розсіювати світло,
filtering – фільтрування,
evaporation – випаровування,
boiling – кипіння,
to conduct – проводити,
electric current – електричний струм,
conductor – провідник,
nonconductor – непровідник,
potassium chloride - хлористий калій,
electrolyte – електроліт,
silver nitrate – нітрат срібла,
nonelectrolyte – неелектроліт,
benzene – бензол.
to abound – бути (перебувати) у великій кількості,
Earth's interior – внутрішня частина Землі,
miscible liquid – сумісні рідини,
alloys – сплав,
brass – латунь,
solder - спайка, припій,
stainless steel – нержавіюча сталь,
wrought iron – коване залізо,
solubility – розчинність,
dilute solution – розбавлений розчин,
saturated solution – насичений розчин,
unsaturated solution – ненасичений розчин,
ethylene glycol - етиленгліколь,
freezing point depression - зниження температури замерзання,
boiling point elevation - підвищення температури кипіння.

3.2 Acids and Bases

If you look in your medicine cabinet and refrigerator and on your kitchen shelves, you will find examples of groups of compounds known as **acids** and **bases.** Acids are found in aspirin, vitamin C, and eyewash. Fruits such as oranges, grapes, lemons, grapefruits, and apples contain acids. Milk and tea contain acids, as do pickles, vinegar, and carbonated drinks. Bases are found in products such as lye, milk of magnesia, deodorants, ammonia, and soaps.

Acids and bases also play an important role in the life processes that take place in your body. Many industrial processes use acids and bases. The manufacture of a wide variety of products involves the use of acids and bases.

Properties of Acids

As a class of compounds, all acids have certain physical and chemical properties when dissolved in water. One of the physical properties all acids share is sour taste. Lemons taste sour because they contain citric acid. Vinegar contains acetic acid. However, you should never use taste to identify a chemical substance. You should use other, safer properties.

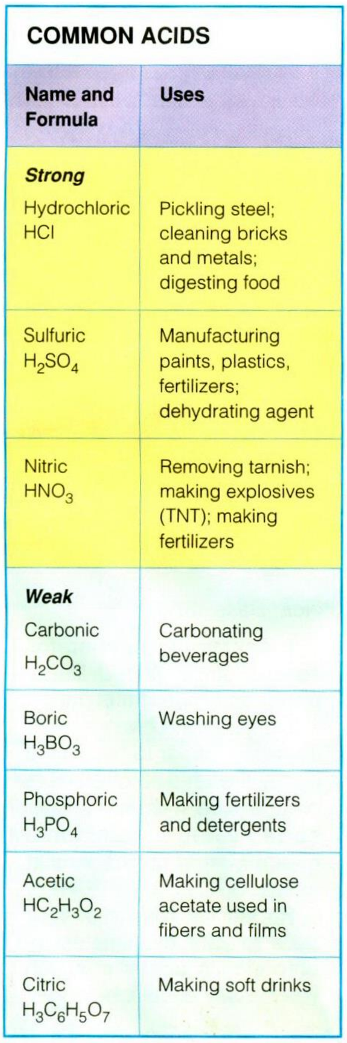
Acids affect the colour of indicators. Indicators are compounds that show a definite colour change when mixed with an acid or a base. Litmus paper, a common indicator, changes from blue to red in an acid solution. Another indicator, phenolphthalein, is colourless in an acid solution.

Acids react with active metals to form hydrogen gas and a metal compound. This reaction wears away, or corrodes, the metal and produces a residue. For example, sulfuric acid in a car battery often corrodes the terminals and leaves a residue.

Another property of acids can be identified by looking at the list of common acids in *Fig. 3.4.* What do all these acids have in common? Acids contain hydrogen. When dissolved in water, acids ionize to produce positive hydrogen ions (H^+). A hydrogen ion is a proton. So acids are often defined as proton donors.

The hydrogen ion, or proton, produced by an acid is quickly surrounded by a water molecule. The attraction between the hydrogen ion (H^+) and the water molecule (H_2O) results in the formation of a hydronium ion, H_3O^+.

The definition of an acid as a proton donor helps to explain why all hydrogen-containing compounds are not acids.



COMMON ACIDS

Name and Formula	Uses
Strong	
Hydrochloric HCl	Pickling steel; cleaning bricks and metals; digesting food
Sulfuric H_2SO_4	Manufacturing paints, plastics, fertilizers; dehydrating agent
Nitric HNO_3	Removing tarnish; making explosives (TNT); making fertilizers
Weak	
Carbonic H_2CO_3	Carbonating beverages
Boric H_3BO_3	Washing eyes
Phosphoric H_3PO_4	Making fertilizers and detergents
Acetic $HC_2H_3O_2$	Making cellulose acetate used in fibers and films
Citric $H_3C_6H_5O_7$	Making soft drinks

Fig. 3.4 Common acids.

Table sugar contains 22 hydrogen atoms, but it is not an acid. When dissolved in water, table sugar does not produce H^+ ions. Table sugar is not a proton donor. So it does not turn litmus paper red or phenolphthalein colourless.

Common Acids

The three most common acids in industry and in the laboratory are sulfuric acid (H_2SO_4), nitric acid (HNO_3), and hydrochloric acid (HCl). These three acids are strong acids. That means they ionize to a high degree in water and produce hydrogen ions. The presence of hydrogen ions makes strong acids good electrolytes. (Remember, electrolytes are good conductors of electricity.)

Acetic acid ($HC_2H_3O_2$), carbonic acid (H_2CO_3), and boric acid (H_3BO_3) are weak acids. They do not ionize to a high degree in water, so they produce few hydrogen ions. Weak acids are poor electrolytes. *Fig. 3.4* lists the name, formula, and uses of some common acids. Remember, handle any acid—weak or strong—with care!

Properties of Bases

When dissolved in water, all bases share certain physical and chemical properties. Bases usually taste bitter and are slippery to the touch. However, bases can be poisonous and corrosive. So you should never use taste or touch to identify bases.

Bases turn litmus paper from red to blue and phenolphthalein to bright pink. Bases emulsify, or dissolve, fats and oils. They do this by reacting with the fat or oil to form a soap. The base ammonium hydroxide is used as a household cleaner because it "cuts" grease. The strong base sodium hydroxide, or lye, is used to clean clogged drains.

COMMON BASES

Name and Formula	Uses
Strong	
Sodium hydroxide NaOH	Making soap; drain cleaner
Potassium hydroxide KOH	Making soft soap; battery electrolyte
Calcium hydroxide $Ca(OH)_2$	Leather production; making plaster
Magnesium hydroxide $Mg(OH)_2$	Laxative; antacid
Weak	
Ammonium hydroxide NH_4OH	Household cleaner
Aluminum hydroxide $Al(OH)_3$	Antacid; deodorant

Fig. 3.5 Common bases.

All bases contain the hydroxide ion, OH^-. When dissolved in water, bases produce this ion.

Because a hydroxide ion (OH^-) can combine with a hydrogen ion (H^+) and form water, a base is often defined as a proton (H^+) acceptor.

Common Bases

Strong bases dissolve readily in water to produce large numbers of ions. So strong bases are good electrolytes. Examples of strong bases include potassium hydroxide (KOH), sodium hydroxide ($NaOH$), and calcium hydroxide ($Ca(OH)_2$).

Weak bases do not produce large numbers of ions when dissolved in water. So weak bases are poor electrolytes. Ammonium hydroxide (NH_4OH) and aluminum hydroxide ($Al(OH)_3$) are weak bases. *See Fig. 3.5.*

Vocabulary notes:

pickle – соління,
deodorant – дезодорант,
citric acid – лимонна кислота,
indicator – індикатор,
litmus paper – лакмусовий папір,
phenolphthalein – фенолфталеїн,
to corrode – ржавіти,
residue – осад,
proton – протон,
proton donor - донор протонів,
hydronium ion - іон гідроксонію,
sulfuric acid – сірчана кислота,
nitric acid – азотна кислота,
hydrochloric acid – хлороводнева, соляна кислота,
borin acid – борна кислота,
to emulsify – перетворювати на емульсію,
grease – жир,
potassium hydroxide -– гідроксид калію,
sodium hydroxide - гідроксид натрію,
calcium hydroxide - гідроксид кальцію,
ammonium hydroxide - гідроксид амонію,
aluminum hydroxide - гідроксид алюмінію.

3.3 Acids and Bases in Solution: Salts

As you have just learned, solutions can be acidic or basic. Solutions can also be neutral. To measure the acidity of a solution, the **pH** scale is used. **The pH of a solution is a measure of the hydronium ion** (H_3O^+) **concentration**. Remember, the hydronium ion is formed by the attraction between a hydrogen ion (H^+) from an acid and a water molecule (H_2O). So the pH of a solution indicates how acidic the solution is.

The pH scale is a series of numbers from 0 to 14. The middle of the scale—7—is the neutral point. A neutral solution has a pH of 7. It is neither an acid nor a base. Water is a neutral liquid. **A solution with a pH below 7 is an acid.** Strong acids have low pH numbers. A solution with a pH above 7 is a base. Strong bases have high pH numbers.

Determining Solution pH

The pH of a solution can be determined by using an indicator. You already know about two indicators: litmus paper and phenolphthalein. Other indictors include pH paper, methyl orange, and bromthymol blue. Each indicator shows a specific colour change as the pH of a solution changes.

Common household materials can be used as indicators. Red-cabbage juice covers the entire pH range. Grape juice is bright pink in the presence of an acid and bright yellow in the presence of a base. Even tea can be an indicator. Have you ever noticed the colour of tea change when you add lemon juice? For accurate pH measurements, a pH meter is used.

Formation of Salts

When acids react chemically with bases, they form a class of compounds called salts. A salt is a compound formed from the positive ion of a base and the negative ion of an acid. A salt is a neutral substance.

The reaction of an acid with a base produces a salt and water. The reaction is called **neutralization**. In neutralization, the properties of the acid and the base are lost as two neutral substances—a salt and water—are formed.

The reaction of HCl with NaOH is a neutralization reaction. The positive hydrogen ion from the acid combines with the negative hydroxide ion from the base. This produces water. The remaining positive ion of the base combines with the remaining negative ion of the acid to form a salt.

$$\mathbf{H^{+}C1^{-} + Na^{+}OH^{-} \longrightarrow H_{2}O + NaCl}$$

Many of the salts formed by a neutralization reaction are insoluble in water—that is, they do not dissolve in water. They crystallize out of solution and remain in the solid phase. An insoluble substance that crystallizes out of solution is called a precipitate. The process by which a precipitate forms is called precipitation. An example of a precipitate is magnesium carbonate. Snow, rain, sleet, and hail are considered forms of precipitation because they fall out of solution.

A neutralization reaction is a double-replacement reaction—and a very important one, too! For a dangerous acid can be combined with a dangerous base to form a harmless salt and neutral water

Vocabulary notes:

acidity – кислотність,
hydronium ion - іон гідроксонію,
hydrochloric – соляний,
determining – визначення,
methyl orange – метиловий оранжевий,
bromthymol blue - бромтімоловий синій,
neutralization reaction – реакція нейтралізації,
insoluble – нерозчинний,
precipitate – осад,
precipitation – випадання в осад.

3.4 Carbon and Its Compounds

Do you know what such familiar substances as sugar, plastic, paper, and gasoline have in common? They all contain the element carbon. Carbon is present in more than 2 million known compounds, and this number is rapidly increasing. Approximately 100,000 new carbon compounds are being isolated or synthesized every year. In fact, more than 90 percent of all known compounds contain carbon!

Carbon compounds form an important family of chemical compounds known as organic compounds. The word organic means coming from life. Because carbon-containing compounds are present in all living things, scientists once believed that **organic compounds** could be produced only by living organisms. Living things were thought to have a mysterious "vital force" that was responsible for creating carbon compounds. It was believed that the force could not be duplicated in the laboratory.

In 1828, the German chemist Friedrich Wohler produced an organic compound called urea from two inorganic substances. Urea is a waste product produced by the human body. It was not long before chemists accepted the idea that organic compounds could be prepared from materials that were never part of a living organism. What is common to all organic compounds is not that they originated in living things but that they all contain the element carbon. Today, the majority of organic compounds are synthesized in laboratories.

There are some carbon compounds that are not considered organic compounds. Calcium carbonate, carbon dioxide, and carbon monoxide are considered inorganic (not organic) compounds.

The Bonding of Carbon

Carbon's ability to combine with itself and with other elements explains why there are so many carbon compounds. Carbon atoms form covalent bonds with other carbon atoms.

The simplest bond involves 2 carbon atoms. The most complex involves thousands of carbon atoms. The carbon atoms can form long straight chains, branched chains, single rings, or rings joined together.

The bonds between carbon atoms can be single covalent bonds, double covalentbonds, or triple covalent bonds. In a single bond, one pair of electrons is shared between 2 carbon atoms. In a double bond, two pairs of electrons are shared between 2 carbon atoms.

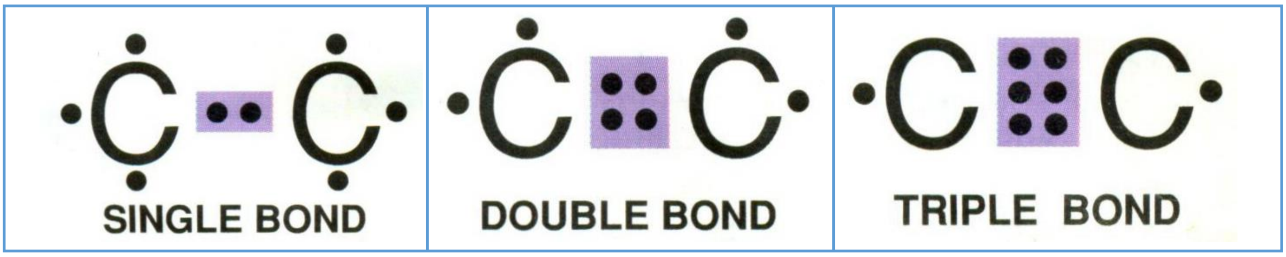


Fig.3.6 Sharing of electrons.

Carbon atoms also bond with many other elements. These elements include oxygen, hydrogen, members of the nitrogen family, and members of Family 17. The simplest organic compounds contain just carbon and hydrogen. Because there are so many compounds of carbon and hydrogen, they form a class of organic compounds all their own.

A great variety of organic compounds exists because the same atoms that bond together to form one compound may be arranged in several other ways in several other compounds. Each different arrangement of atoms represents a separate organic compound.

Properties of Organic Compounds

Organic compounds usually exist as gases, liquids, or low-melting-point solids. Organic liquids generally have strong odors and low boiling points. Organic liquids do not conduct an electric current. What is the name for a substance whose solution does not conduct electricity? Organic compounds generally do not dissolve in water.

Oil, which is a mixture of organic compounds, floats on water because the two liquids are insoluble.

Structural Formulas

A molecular formula for a compound indicates what elements make up that compound and how many atoms of each element are present in a molecule. For example, the molecular formula for the organic compound ethane is C_2H_6. In every molecule of ethane, there are 2 carbon atoms and 6 hydrogen atoms.

What a molecular formula does not indicate about a molecule of a compound is how the different atoms are arranged. To do this, a **structural formula** is used. A structural formula shows the kind, number, and arrangement of atoms in a molecule. You can think of a structural formula as being a model of a molecule.

Fig.3.7 shows the structural formula for ethane and two other organic compounds: methane and propane. Note that in a structural formula, a dash (-) is used to represent the pair of shared electrons forming a covalent bond. In writing structural formulas, it is important that you remember the electron arrangement in a carbon atom.

Carbon has 4 valence electrons, or 4 electrons in its outermost energy level. Each electron will form a covalent bond with an electron of another atom to produce a stable outermost level containing 8 electrons. So when structural formulas are written, there can be no dangling bonds—no dangling dashes.

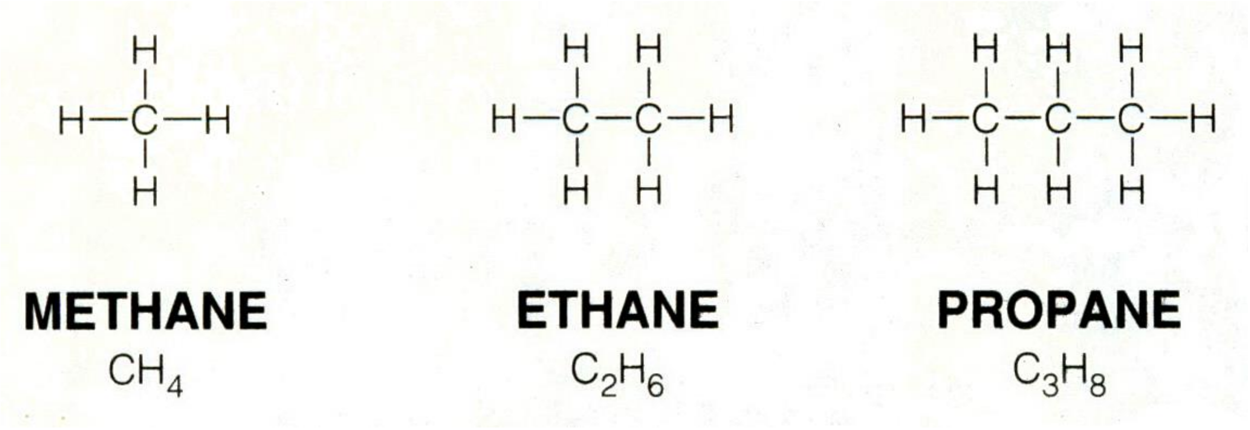


Fig.3.7 The structural formula for ethane, methane and propane.

Isomers

Compounds with the same molecular formula but different structures are called **isomers.** *Fig. 3.8* shows two isomers of butane, C_4H_{10}. Notice that one isomer is a straight chain and the other isomer is a branched chain. In a branched chain, all the carbon atoms are not in a straight line. This difference in structure will account for any differences in the physical and chemical properties of these two compounds.

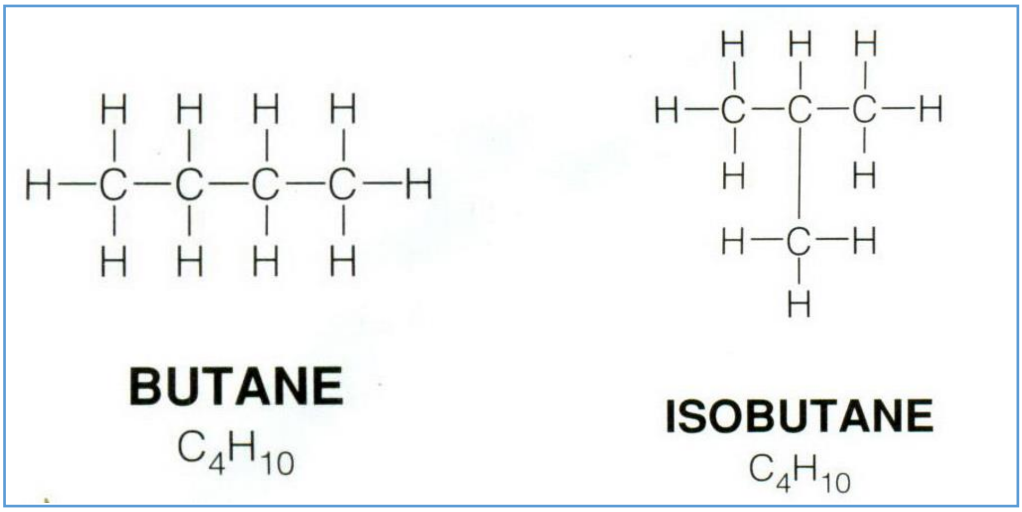


Fig.3.8 Two isomers of butane.

Fig. 3.9 shows three isomers of pentane, C_5H_{12}. This time there is one straight chain and two branched chains. To see the difference between the two branched chains, count the number of carbon atoms in the straight-chain portion of each molecule. How many are there in each branched isomer? What do you think happens to the number of possible isomers as the number of carbon atoms in a molecule increases? The compound whose formula is $C_{15}H_{32}$ could have more than 400 isomers!

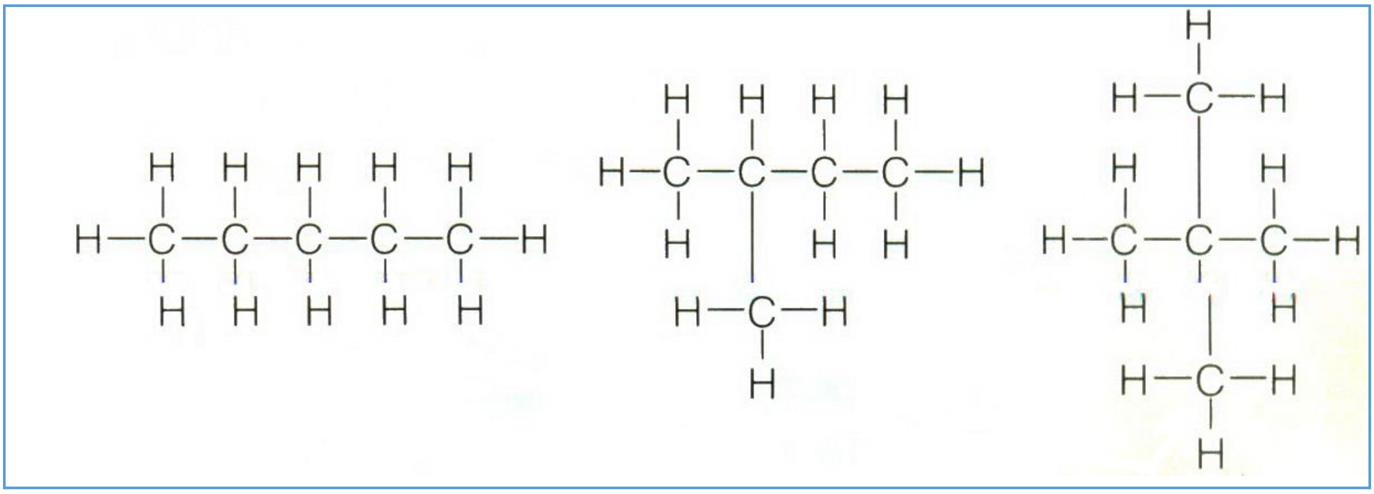


Fig.3.9 Three isomers of pentane.

Vocabulary notes:

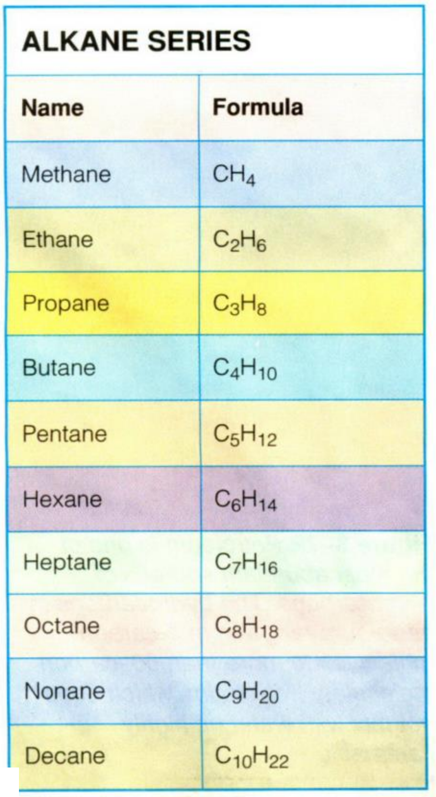
organic compound – органічна речовина,
to duplicate – дублювати,
urea – сеча,
single rings – поодинокі кільця,
rings joined together – кільця з’єднані разом,
odor – запах,
to float – триматися на поверхні води,
ethane – етан,
structural formula – структурна формула,
methane – метан,
propane – пропан,
dangling – відокремлений,
isomer – ізомер,
butane – бутан,
pentane – пентан.

3.5 Hydrocarbons

Have you ever heard of a butane lighter, seen a propane torch, or noticed a sign at a service station advertising "high octane" gasoline? Butane, propane, and octane are members of a large group of organic compounds known as **hydrocarbons.** A hydrocarbon contains only hydrogen and carbon.

Hydrocarbons can be classified as saturated or unsaturated depending on the type of bonds between carbon atoms. In saturated hydrocarbons, all the bonds between carbon atoms are single covalent bonds. **In unsaturated hydrocarbons,** one or more of the bonds between carbon atoms is a double covalent or triple covalent bond.

Alkanes



ALKANE SERIES	
Name	**Formula**
Methane	CH_4
Ethane	C_2H_6
Propane	C_3H_8
Butane	C_4H_{10}
Pentane	C_5H_{12}
Hexane	C_6H_{14}
Heptane	C_7H_{16}
Octane	C_8H_{18}
Nonane	C_9H_{20}
Decane	$C_{10}H_{22}$

Fig.3.10 Alkane series

The **alkanes** are straight-chain or branched-chain hydrocarbons in which all the bonds between carbon atoms are single covalent bonds. Alkanes are saturated hydrocarbons. All the hydrocarbons that are alkanes belong to the alkane series. The simplest member of the alkane series is methane, CH_4. Methane consists of 1 carbon atom surrounded by 4 hydrogen atoms. Why are there 4 hydrogen atoms?

The next simplest alkane is ethane, C_2H_6. How does the formula for ethane differ from the formula for methane? After ethane, the next member of the alkane series is propane, C_3H_8. Can you begin to see a pattern to the formulas for each successive alkane? Ethane has 1 more carbon atom and 2 more hydrogen atoms than methane does. Propane has 1 more carbon atom and 2 more hydrogen atoms than ethane does. Each member of the alkane series is formed by adding 1 carbon atom and 2 hydrogen atoms to the previous compound.

The pattern that exists for the alkanes can be used to determine the formula for any member of the series. Because each alkane differs from the preceding member of the series by the group CH_2, a general formula for the alkanes can be written. That general formula is C_nH_{2n+2}. The letter n is the number of carbon atoms in the alkane.

Naming Hydrocarbons

Fig.3.10 shows the first ten members of the alkane series. Look at the names of the compounds. How is each name the same? How is each different?

Often in organic chemistry the names of the compounds in the same series will have the same ending, or suffix. Thus, the members of the alkane series all end "with the suffix *-ane*, the same ending as in the series name. The first part of each name, or the prefix, indicates the number of carbon atoms present in the compound. The prefix *meth*- indicates 1 carbon atom. The prefix *eth*-, 2 carbon atoms, and the prefix *prop*-, 3. According to *Fig.3.10*, how many carbon atoms are indicated by the prefix *pent-?* How many carbon atoms are in octane? As you study other hydrocarbon series, you will see that these prefixes are used again and again. So it will be useful for you to become familiar with the prefixes that mean 1 to 10 carbon atoms.

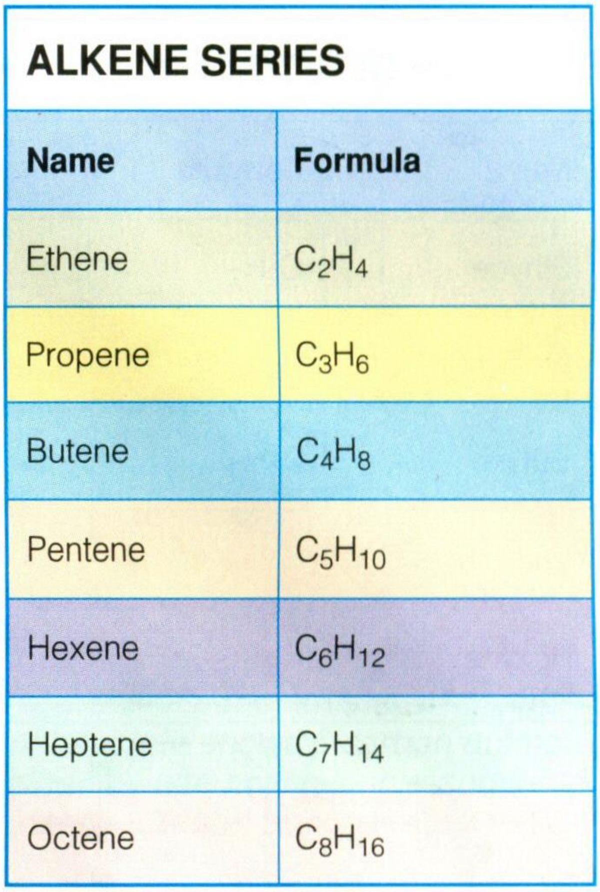
Alkenes

Hydrocarbons in which at least one pair of carbon atoms is joined by a double covalent bond are called **alkenes.** Alkenes are unsaturated hydrocarbons. The first member of the alkene series is ethene, C_2H_4. The next member of the alkene series is propene, C_3H_6. *Fig. 3.11* shows the first seven members of the alkene series.

As you look at the formulas for the alkenes, you will again see a pattern in the number of carbon and hydrogen atoms added to each successive compound. The pattern is the addition of 1 carbon atom and 2 hydrogen atoms.

The general formula for the alkenes is C_nH_{2n}. The letter n is the number of carbon atoms in the compound. What is the formula for an alkene with 12 carbons? With 20 carbons?

In general, alkenes are more reactive than alkanes because a double bond is more easily broken than a single bond. So alkenes can react chemically by adding other atoms directly to their molecules.



ALKENE SERIES

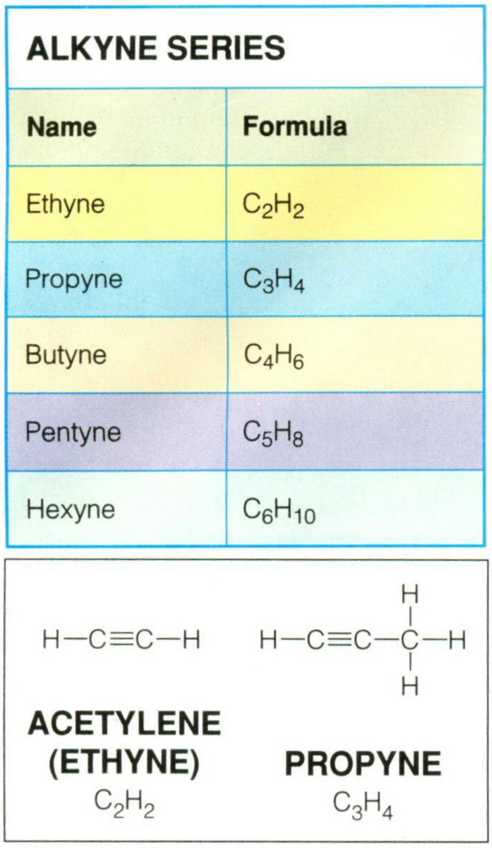
Name	Formula
Ethene	C_2H_4
Propene	C_3H_6
Butene	C_4H_8
Pentene	C_5H_{10}
Hexene	C_6H_{12}
Heptene	C_7H_{14}
Octene	C_8H_{16}

Fig.3.11 Alkene series

Alkynes

Hydrocarbons in which at least one pair of carbon atoms is joined by a triple covalent bond are called **alkynes.** Alkynes are unsaturated hydrocarbons. The simplest alkyne is ethyne, C_2H_2, which is commonly known as acetylene. Perhaps you have heard of acetylene torches, which are used in welding.

The first five members of the alkyne series are listed in *Fig.3.12*. Here again, each successive member of the alkyne series differs by the addition of 1 carbon atom and 2 hydrogen atoms. The general formula for the alkynes is C_nH_{2n-2}. The alkynes are even more reactive than the alkenes.



ALKYNE SERIES

Name	Formula
Ethyne	C_2H_2
Propyne	C_3H_4
Butyne	C_4H_6
Pentyne	C_5H_8
Hexyne	C_6H_{10}

Fig.3.12 Alkyne series.

Very little energy is needed to break a triple bond. Like the alkenes, alkynes can react chemically by adding other atoms directly to their molecules

Aromatic Hydrocarbons

All the hydrocarbons you have just learned about—the alkanes, alkenes, and alkynes—are either straight-chain or branched-chain molecules. But this is not the only structure a hydrocarbon can have. Some hydrocarbons are in the shape of rings. Probably the best-known class of hydrocarbons in the shape of rings is the aromatic hydrocarbons. The name of this class comes from the fact that aromatic hydrocarbons share a common physical property. These compounds have strong and often pleasant odors (or aromas).

The basic structure of an aromatic hydrocarbon is a ring of 6 carbon atoms joined by alternating single and double covalent bonds. This means that within the 6-carbon ring, there are 3 carbon-to-carbon double bonds. The simplest aromatic hydrocarbon is called benzene, C_6H_6. *Fig.3.13* shows the structural formula for benzene. Chemists often abbreviate this formula by drawing a hexagon with a circle in the center.

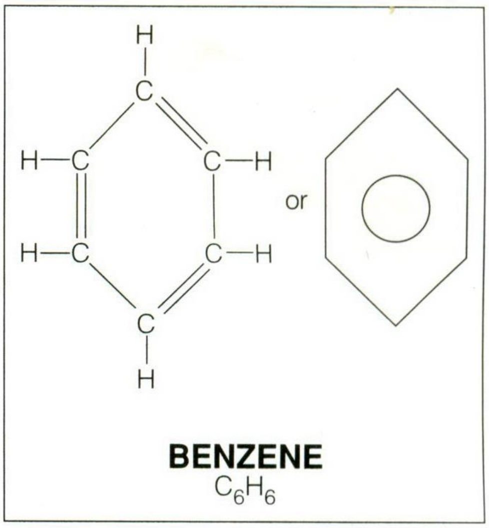


Fig.3.13 The structural formula for benzene.

Vocabulary notes:

butane lighter – бутановий ліхтар,
propane torch – пропановий факел,
high octane gasoline – висококоотановий бензин,
hydrocarbon – гідрокарбон, вуглеводень,
hydrogen – гідроген, водень,
alkanes – алкан, насичений вуглевод,
alkane series – ряд алканів,
pattern – модель,
alkene – алкен,
ethene – етилен,
propene – пропен,
alkyne – алкін,
acetylene – ацителен,
welding – зварювання,
aromatic hydrocarbon – ароматичний вуглеводень,
alternating – змінний, що чергується,
benzene – бензол,
hexagon – шестикутник.

3.6 Substituted Hydrocarbons

Hydrocarbons are but one of several groups of organic compounds. Hydrocarbons contain carbon and hydrogen atoms only. But as you have learned, carbon atoms form bonds with many other elements. So many different groups of organic compounds exist. **The important groups of organic compounds include alcohols, organic acids, esters, and halogen derivatives.** These compounds are called **substituted hydrocarbons.** A substituted hydrocarbon is formed when one or more hydrogen atoms in a hydrocarbon chain or ring is replaced by a different atom or group of atoms.

Alcohols

Alcohols are substituted hydrocarbons in which one or more hydrogen atoms have been replaced by an -OH group, or hydroxyl group. The simplest alcohol is methanol, CH_3OH. You can see from *Fig. 3.14* that methanol is formed when 1 hydrogen atom in methane is replaced by the -OH group. Methanol is used to make plastics and synthetic fibers. It is also used in automobile gas tank de-icers to prevent water that has condensed in the tank from freezing. Another important use of methanol is as a solvent. Methanol, however, is very poisonous— even when used externally.

As you can tell from the name methanol, alcohols are named by adding the suffix *-ol* to the name of the corresponding hydrocarbon. When an –OH group is substituted for 1 hydrogen atom in ethane, the resulting alcohol is ethanol, C_2H_5OH. Ethanol is produced naturally by the action of yeast or bacteria on the sugar stored in grains such as corn, wheat, and barley.

Ethanol is a good solvent for many organic compounds that do not dissolve in water. Ethanol is used in medicines.
It is also the alcohol used in alcoholic beverages. In order to make ethanol available for industrial and medicinal uses only, it must be made unfit for beverage purposes.

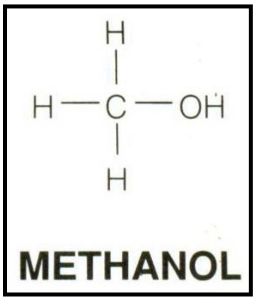


Fig 3.14 Structural formula

So poisonous compounds such as methanol are added to ethanol. The resulting mixture is called denatured alcohol.

An alcohol can be in the form of a ring as well as a chain. When 1 hydrogen atom in a benzene ring is replaced by an -OH group, the resulting alcohol is called phenol. Phenol is used in the preparation of plastics and as a disinfectant.

Organic Acids

Organic acids are substituted hydrocarbons that contain the -COOH group, or carboxyl group. *Fig. 3.15* shows the structural formula for two common organic acids. Notice that one of the carbon-oxygen bonds in the carboxyl group is a double bond.

Organic acids are named by adding the suffix *-oic* to the name of the corresponding hydrocarbon. Most organic acids, however, have common names that are used more frequently. The simplest organic acid is methanoic acid, HCOOH. Methanoic acid is commonly called formic acid. Formic acid is found in nature in the stinging nettle plant and in certain ants. Formic acid produced by an ant causes the ant bite to hurt.

The acid derived from ethane is commonly called acetic acid. Acetic acid is the acid in vinegar. Citric acid, which is found in citrus fruits, is a more complicated organic acid originally derived from the hydrocarbon propane.

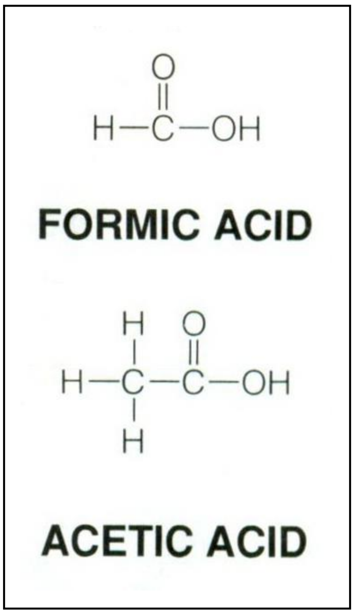


Fig.3.15 Structural formula of formic and acetic acids.

Esters

If an alcohol and an organic acid are chemically combined, the resulting compound is called an ester. Esters are noted for their pleasant aromas and flavors.

Many esters occur naturally. Fruits such as strawberries, bananas, and pineapples get their sweet smell from esters. Esters can also be produced in the laboratory. Synthetic esters are used as perfume additives and as artificial flavorings.

Halogen Derivatives

Hydrocarbons can undergo substitution reactions in which one or more hydrogen atoms are replaced by an atom or atoms of fluorine, chlorine, bromine, or iodine. The family name for these elements is halogens. So substituted hydrocarbons that contain halogens are called halogen derivatives. A variety of useful substances result from adding halogens to hydrocarbons. The compound methyl chloride, CH_3C1, is used as a refrigerant. Tetrachloroethane, $C_2H_2C1_4$, which consists of 4 chlorine atoms substituted in an ethane molecule, is used in dry cleaning.

When 2 hydrogen atoms in a methane molecule are replaced by chlorine atoms and the other 2 hydrogen atoms are replaced by fluorine atoms, a compound commonly known as Freon, CCl_2F_2, is formed. The actual name of this halogen derivative is dichlorodifluoromethane. Freon is the coolant used in many refrigerators and air conditioners.

Vocabulary notes:

alcohol – алкоголь,
organic acid – органічна кислота,
ester – ефір,
halogen derivative – похідний галогену,
substituted hydrocarbon – заміщений вуглеводень,
hydroxyl group – гідроксильна група,
methanol – метанол,
methane – метан,
plastics – пластмаса,
synthetic fibers – штучні волокна,
solvent – розчинник,
yeast – дріжджі, розчина,
bacterium (-ria) – бактерія,
barley – ячмінь,
beverage – алкогольний напій,
denatured alcohol – денатурований алкоголь,
phenol – фенол,
disinfectant – дезінфікуючий засіб,
carboxyl group – карбоксильна група,
methanoic acid – метанова кислота,
formic acid – мурашина кислота,
nettle – кропива,
ant – мурашка,
acetic acid – оцтова кислота,
citric acid – лимонна кислота,
hydrocarbon propane – вуглеводневий пропан,
perfume additives – добавки до духів,
artificial flavoring – штучний ароматизатор,
fluorine – фтор,
chlorine – хлор,
bromine – бром,
iodine – йод,
methyl chloride – метилхлорид,
tetrachloroethane – тетрахлоретан,
Freon – фреон,
dichlorodifluoromethane – дихлордифлорметан.

I. Key terms. Read, translate and memorize the following definitions:

Solution – *розчин* – mixture in which one substance is dissolved, or broken down, in another substance.

Solute – *розчинена речовина* – substance that is dissolved in a solution.

Solvent – *розчинник* – substance in a solution that does the dissolving.

Electrolyte – *електроліт* – substance whose water solution conducts electric current.

Nonelectrolyte – *неелектроліт* – substance whose water solution does not conduct electric current.

Solubility – *розчинність* – measure of how much of a solute can be dissolved in a given amount of solvent under certain conditions.

Concentration – *концентрація* – amount of a solute dissolved in a certain amount of solvent.

Concentrated solution – *концентрований розчин* – solution in which a large amount of solute is dissolved in a solvent.

Dilute solution – *розбавлений розчин* **–** solution in which there is only a little dissolved solute.

Saturated solution – *насичений розчин* – solution that contains all the solute it can hold at a given temperature.

Unsaturated solution – *ненасичений розчин* – solution that contains less solute than it can possibly hold at a given temperature.

Supersaturated solution – *перенасичений розчин* – unstable solution that holds more solute than in normal for a given temperature.

Acid – *кислота* – compound with a pH below 7 that tastes sour, turns blue litmus paper red, reacts with metals to produce hydrogen gas, and ionizes in water to produce hydrogen ions; proton donor.

Base – *основа* – compound with ph above 7 that tastes bitter, is slippery to the touch, turns red litmus paper blue, and ionizes in water to produce hydroxide ions; proton acceptor.

pH – measure of the hydronium ion concentration of a solution; measured on a scale from 0 to 14.

Salt – *сіль* – compound formed from the positive ion of a base and the negative ion of an acid.

Neutralization – *нейтралізація* – reaction in which an acid combines with a base to form a salt and water.

Organic compound – *органічна сполука* – compound that contains carbon.

Structural formula – *структурна формула* – description of a molecule that shows the kind, number and arrangement of atoms in a molecule.

Isomer – *ізомер* – one of a number of compounds that have the same molecular formula but different structures.

Hydrocarbon – *вуглеводень* – organic compound that contains only hydrogen and carbon.

Saturated hydrocarbon – *насичений вуглеводень* – hydrocarbon in which all the bonds between carbon atoms are single covalent bonds.

Unsaturated hydrocarbon – *ненасичений вуглеводень* – hydrocarbon in which one or more of the bonds between carbon atoms is a double covalent or triple covalent bond.

Alkane – *алкан* – straight-chain or branched-chain saturated hydrocarbon.

Alkene – *алкен* – unsaturated hydrocarbon in which at least one pair of carbon atoms is joined by a double covalent bond.

Alkyne – *алкін* – unsaturated hydrocarbon in which at least one pair of carbon atoms is joined by a triple covalent bond.

Substituted hydrocarbon – *заміщений вуглеводень* - hydrocarbon formed when one or more hydrogen atoms in a hydrocarbon ring or chain is replaced by a different atom or group of atoms.

II. Match the chemical terms on the left with their correct definitions on the right.

solution	measure of how much of a solute can be dissolved in a given amount of solvent under certain conditions;
solute	substance in a solution that does the dissolving;
solvent	substance that is dissolved in a solution;
solubility	mixture in which one substance is dissolved, or broken down, in another substance;
acid	one of a number of compounds that have the same molecular formula but different structures;
base	compound formed from the positive ion of a base and the negative ion of an acid;
salt	compound with ph above 7 that tastes bitter, is slippery to the touch, turns red litmus paper blue, and ionizes in water to produce hydroxide ions; proton acceptor;
isomer	compound with a pH below 7 that tastes sour, turns blue litmus paper red, reacts with metals to produce hydrogen gas, and ionizes in water to produce hydrogen ions;
alkane	unsaturated hydrocarbon in which at least one pair of carbon atoms is joined by a double covalent bond;
alkene	unsaturated hydrocarbon in which at least one pair of carbon atoms is joined by a triple covalent bond;
alkyne	straight-chain or branched-chain saturated hydrocarbone.

III. Fill in the blanks from the words below. Translate the sentences into Ukrainian:

Solution, tincture, temperature, pressure, saturated, indicators, bases, salts, hydrocarbons.

1. A mixture in which one substance is dissolved in another substance is a ….
2. When alcohol is the solvent, the solution is called a ….
3. Two main factors that affect the solubility of a solute are … and ….
4. A … … is a solution that contains all the solute it can possibly hold at a given temperature.
5. Compounds that show a definite color change when mixed with an acid or a base are ….
6. … turn litmus paper from red to blue and phenolphthalein to bright pink.
7. When acids react chemically with bases, they form a class of compounds called ….
8. Butane, propane and octane are members of a large group of organic compounds known as ….

IV. Answer the following questions:

1. Define the following terms:

a) solution;

b) solvent;

c) solute.

2. Why does a solid solute usually dissolve faster when it is in the form tiny crystals? Why do most solid solutes dissolve faster when the solute and solvent are stirred together?
3. Define the following terms:

a) saturated solution;

b) solubility;

c) supersaturated solution;

d) unsaturated solution.

4. What are electrolytes and nonelectrolytes?
5. List the common properties of water solutions of acids.
6. List the common properties of water solutions of bases.
7. What is a neutralization reaction?

8. Give a definition of pH.
9. What are organic compounds?
10. What is the difference between a molecular formula and a structural formula?
11. Describe the group of compounds known as saturated hydrocarbons or alkanes.
12. What is the distinguishing characteristic of a compound that is classed as an alkene?
13. What is an alcohol? An organic acid? An ester?

V. Make written translation into Ukrainian of the text “Acids and Bases”.

VI. Translate into English:

1. Однією з найважливіших і найбагатших **родин** хімічних речовин є **родина** кислот, основ і солей.
2. Розчин – це суміш, в якій одна речовина розчиняється в іншій.
3. Найпоширенішими розчинами є ті, в яких розчинником є рідина.
4. Усі розчини мають кілька основних властивостей.
5. Найважливішою властивістю розчину є його здатність чи нездатність проводити електричний струм.
6. Речовини, водні розчини яких проводять електричний струм, називаються електролітами.
7. На розчинність розчину впливають два основні фактори: температура і тиск.
8. Коли кислоти вступають в реакцію з основами, вони утворюють клас речовин, які називаються солями.
9. Реакція кислоти з основою утворює сіль і воду і називається реакцією нейтралізації.
10. Речовини з однаковою молекулярною формулою але різною структурою називаються ізомерами.

Petrochemical Technology

4.1 What Is Petroleum?

Have you ever seen a movie in which a group of people gathered around a well were shouting and cheering as a thick black liquid was rising up through the ground and spurting high into the air? Or have you ever read about geologists who study the composition of the Earth in an attempt to find oil? If so, you may have realized—correctly so—that crude oil is a rather valuable substance. This sought-after crude oil, one form of **petroleum,** has been called black gold because of its tremendous importance. Fuels made from petroleum provide nearly half the energy used in the world. And thousands of products—from the bathing suit you wear when swimming to the toothpaste you use when brushing your teeth—are made from this petroleum.

Petroleum is a substance believed to have been formed hundreds of millions of years ago when layers of dead plants and animals were buried beneath sediments such as mud, sand, silt, or clay at the bottom of the oceans. Over millions of years, heat and great pressure changed the plant and animal remains into petroleum. Petroleum is a non renewable resource. A nonrenewable resource is one that cannot be replaced once it is used up. There is only a certain amount of petroleum in existence. Once the existing petroleum is used up, no more will be available.

Despite the huge variety of products obtained from petroleum, few people ever see the substance itself. The liquid form that gushes from deep within the Earth is a mixture of chemicals called crude oil. Petroleum can also be found as a solid in certain rocks and sand. It has been called black gold because it is usually black or dark brown. But it can be green, red, yellow, or even colourless. Petroleum may flow as easily as water, or it may ooze slowly— like thick tar. The colour and thickness of petroleum depend on the substances that make it up.

Separating Petroleum into Parts

By itself, petroleum is almost useless. But the different parts, or **fractions,** of petroleum are among the most useful chemicals in the world. **Petroleum is separated into its useful parts by a process called fractional distillation.** The process of distillation involves heating a liquid until it vaporizes (changes into a gas) and then allowing the vapor to cool until it condenses (turns back into a liquid). The different fractions of petroleum have different boiling points. So each fraction vaporizes at a different temperature than do the others. The temperature at which a substance boils is the same as the temperature at which it condenses. So if each fraction vaporizes at a different temperature, then each fraction will condense back to a liquid at a different temperature. By removing, or drawing off, each fraction as it condenses, petroleum can easily be separated into its various parts.

Fractional distillation of petroleum is done in a fractionating tower. The process of separating petroleum into its fractions is called **refining.** Refining petroleum is done at a large plant called a refinery. At a refinery, fractionating towers may rise 30 meters or more. *Fig. 4.1* shows a fractionating tower. Petroleum is piped into the base of the fractionating tower and heated to about 385°C. At this temperature, which is higher than the boiling points of most of the fractions, the petroleum vaporizes.

When the petroleum vaporizes, the fractions rise up the tower. As they rise, they cool and condense. Some fractions condense at high temperatures. These fractions condense right away near the bottom of the tower and are drawn off into collecting vessels. Other fractions continue to rise in the tower. These fractions are drawn off at higher levels in the tower. As a result of this vaporization-condensation process, the various fractions of petroleum are separated and collected.

You will notice in *Fig. 4.1* that asphalt is collected at the bottom of the fractionating tower. Asphalt requires a temperature even higher than 385°C to vaporize. When the other fractions vaporize, asphalt is left behind as a liquid that runs out of the bottom of the tower. Which fraction in the tower condenses at the lowest temperature?

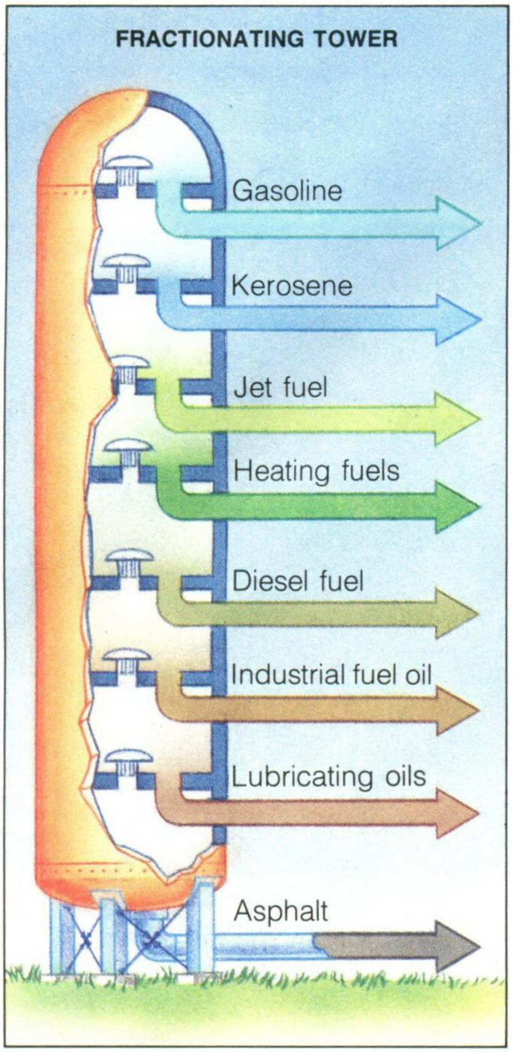


Fig. 4.1 Fractionating tower

Petroleum Products

Asphalt—the main material used for building roads—is one product that comes directly from petroleum. Wax, used in furniture polish and milk cartons, is another. Asphalt and wax fall into the category of raw materials that come from the separation of petroleum and are used in manufacturing. Many of the other raw materials in this category, however, are converted to chemicals from which a variety of products—ranging from cosmetics to fertilizers—are made.

Another group of petroleum products includes lubricants.

Lubricants are substances that reduce friction between moving parts of equipment.

The oil applied to the gears of a bicycle is an example of a lubricant. Lubricants are used in many machines— from delicate scientific equipment to the landing gear of an aircraft.

The greatest percentage of petroleum products includes fuels. Fuels made from petroleum burn easily and release a tremendous amount of energy, primarily in the form of heat. They are also easier to handle, store, and transport than are other fuels, such as coal and wood. Petroleum is the source of nearly all the fuels used for transportation and the many fuels used to produce heat and electricity.

Vocabulary notes:

to spurt – бити струменем,
geologist – геолог,
crude oil – неочищена нафта,
sought-after – бажаний,
petroleum – нафта,
sediment – осадова порода, відкладення,
silt – мул, осад,
nonrenewable – такий, що не відновлюється,
fuel – паливо, пальне,
to gush – фонтанувати,
to ooze – повільно текти,
tar – смола,
fraction – фракція,
fractional distillation – фракційна дистиляція,
to draw off – відводити,
fractionating tower – очисна вежа,
refining – очищення,
refinery – очищення,
vessel – посудина,
asphalt – асфальт,
wax – парафін, віск,
milk carton – пакет молока,
lubricant – мастило,
friction – тертя,
years – шестерня, зубчаста передача.

4.2 Petrochemical Products

Paint a picture, pour milk from a plastic container, or put on a pair of sneakers and you are using a product made from petroleum, or a **petrochemical product.**

Polymer Chemistry

The petrochemical products that are part of your life come from the chemicals produced from petroleum. Petrochemical products usually consist of molecules that take the form of long chains. Each link in the chain is a small molecular unit called a monomer. The entire molecule chain is called a **polymer.**

The types of monomers and the length and shape of the polymer chain determine the physical properties of the polymer. Manufacturers of petrochemical products join monomers together to build polymers. A general term for this process is polymer chemistry.

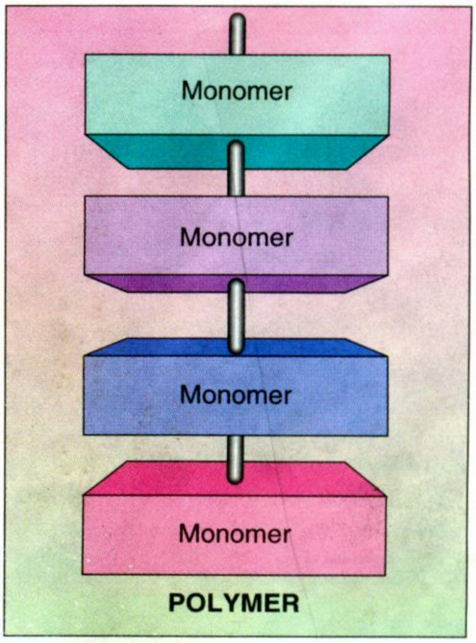


Fig. 4.2 Making up of a polymer.

Natural Polymers

Most of the polymers are made from petrochemicals. Some polymers, however, do occur in nature. Cotton, silk, wool, and natural rubber are all **natural polymers**. Cellulose and lignin, which are important parts of wood, are natural polymers. In fact, all living things contain polymers. Yes—that includes you! Protein, an essential ingredient of living matter, is a polymer. The monomers from which proteins are made are called amino acids. Combined in groups of one hundred or more units, amino-acid monomers form many of the parts of your body—from hair to heart muscle.

Synthetic Polymers

The first polymer was manufactured in 1909. Since then, polymerization has come a long way. Polymerization is the process of chemically bonding monomers to form polymers. Most early polymers consisted of fewer than two hundred monomers. Today's polymers may contain thousands of monomers. The many ways in which these monomers can be linked may be very complex. They include single chains, parallel chains, intertwining chains, spirals, loops, and loops of chains!

Polymers produced from petrochemicals are called **synthetic polymers.** Something that is synthetic does not exist naturally. Instead it is made by people. Polymer chemistry has produced synthetic materials that are strong, lightweight, heat resistant, flexible, and durable (long lasting). These properties give polymers a wide range of applications.

Although the term polymer may be new to you, you will soon discover that many polymers produced from petrochemicals are familiar to you. For example, petrochemical products such as synthetic rubber and plastic wrap are synthetic polymers. Synthetic polymers are used to make fabrics such as nylon, rayon, Orlon, and Dacron. Plastics—used in products from kitchen utensils to rocket engines—are petrochemical products made of polymers.

In medicine, polymers are used as substitutes for human tissues, such as bones and arteries. These polymers must last a lifetime and must withstand the wear and tear of constant use. Polymer adhesives, rather than thread, may be used to hold clothes togather. Polymers are replacing glass, metal, and paper as containers for food. The cup of hot chocolate you may have held today did not burn your hand because it was made of a white insulating polymer. Polymer materials are also used to make rugs, furniture, wall coverings, and curtains. Look around and see how many polymers you can spot. And remember: You have petroleum to thank for all these useful materials.

Polymer materials also can be mixed and matched to produce substances with unusual properties.

Different plastics and synthetic fibers are combined to make puncture-proof tires and bulletproof vests. Layers of polymer materials can be combined to make waterproof rain gear.

Polymer chemistry is also important in the transportation industry. Every year the number of polymer parts in cars, planes, and trains increases. A plastic car engine has been built and tested. This engine is lighter, more fuel efficient, and more durable than a metal engine. As you can see, polymers made from petroleum are extremely important today. And they will be even more important in the future.

Vocabulary notes:

sneakers – кросівки,
monomer – мономер,
polymer – полімер,
natural rubber – природний каучук,
natural polymer – природний полімер,
cellulose – целюлоза,
lignin – лігнін,
protein – протеїн,
ingredient – складова частина, компонент,
amino acids – аміно кислоти,
polymerization – полімеризація,
intertwining – переплетення,
spiral – спіраль,
loop – петля,
synthetic polymer – штучний полімер,
plastic wrap – штучна обгортка,
fabric – тканина,
nylon – нейлон,
rayon – віскоза,
Orlon – орлон,
Dacron – дакрон,
kitchen utensils – кухонне начиння,
rocket engine – ракетний двигун,
human tissue – людська тканина,
to withstand – протистояти,
adhesive – клей, клеюча речовина,
insulating – ізолюючий,
rug – килимок,
fiber – волокно,
puncture-proof tire – непробивна шина,
bullet proof vest – куленепробивний жилет.

I. Key terms. Read, translate and memorize the following definitions:

Petroleum – *нафта –* substance believed to have been formed hundreds of millions of years ago when dead plants and animals were buried beneath sediments such as mud, sand, silt, or clay at the bottom of the oceans; crude oil.

Fraction – *фракція –* petroleum part with its own boiling point.

Refining – *очищення –* process of separating petroleum into its fractions.

Petrochemical product – *нафтохімічний продукт –* product made either directly or indirectly from petroleum.

Monomer – *мономер –* smaller molecule that joins with other smaller molecule to form a chain molecule called a polymer.

Polymer – *полімер –* large molecule in the form of a chain whose links are smaller molecules called monomers.

Natural polymer – *природній полімер –* polymer molecule found in nature, for example, cotton, silk, and wool.

Polymerization – *полімеризація –* process of chemically bonding monomers to form polymers.

Synthetic polymer – *штучний полімер* – polymer that does not occur naturally; formed from petrochemicals by people.

II. Match the chemical terms on the left with their correct definitions on the right.

petroleum	large molecule in the form of a chain whose links are smaller molecules called monomers;
monomer	process of chemically bonding monomers to form polymers;
polymer	substance believed to have been formed hundreds of millions of years ago when dead plants and animals were buried beneath sediments such as mud, sand, silt, or clay at the bottom of the oceans; crude oil;
natural polymer	polymer that does not occur naturally; formed from petrochemicals by people;
synthetic polymer	smaller molecule that joins with other smaller molecule to form a chain molecule called a polymer;
polymerization	polymer compound found in nature.

III. Fill in the blanks from the words below. Translate the sentences into Ukrainian:

Petroleum, fractional distillation, fractionating tower, natural, synthetic, refining.

1. … is called black gold.
2. Petroleum is separated into its useful parts by a process called … ….
3. Fractional distillation of petroleum is done in a … ….
4. The process of separating petroleum into its fractions is called ….
5. Cotton, silk, wool and natural rubber are all … polymers.
6. Polymers produced from petrochemicals are called … polymers.

IV. Answer the following questions:

1. What is petroleum? Why is it so important?
2. Describe the process of fractional distillation.
3. Give some examples of petroleum products.
4. What is the difference between monomers and polymers?

5. Give some examples of natural polymers.
6. How are synthetic polymers used?
7. What is polymerization?

V. Make written translation into Ukrainian of the text “Petroleum Products”.

Radioactive Elements

5.1 Radioactivity

Some discoveries are made by performing experiments to find out whether hypotheses are true. Other discoveries are stumbled upon purely by accident. The majority of scientific discoveries, however, are a combination of the two—both genius and luck. One such discovery was made by the French scientist Henri Becquerel in 1896. Becquerel was experimenting with a uranium compound to determine whether it gave off X-rays. His experiments did indeed provide evidence of X-rays. But they also showed something else—something rather exciting. Quite by accident, Becquerel discovered that the uranium compound gave off other types of rays that had never before been detected. Little did Becquerel know then that these mysterious rays would open up a whole new world of modern science.

An Illuminating Discovery

At the time of Becquerel's work, scientists knew that certain substances glowed when exposed to sunlight. Such substances are said to be fluorescent. Becquerel wondered whether in addition to glowing, fluorescent substances gave off X-rays.

To test his hypothesis, Becquerel wrapped some photographic film in lightproof paper (paper that does not allow light through it). He placed a piece of fluorescent uranium salt on top of the film and the paper and set both in the sun. Becquerel reasoned that if X-rays were produced by the uranium salt when it fluoresced, the X-rays would pass through the lightproof paper and produce an image on the film. The lightproof paper would prevent light from reaching the film and creating an image, however.

When Becquerel developed the film, he was delighted to see an image. The image was evidence that fluorescent substances give off X-rays when exposed to sunlight. In order to confirm his results, he prepared another sample of uranium salt and film to repeat his experiment the following day. But much to his disappointment, the next two days were cloudy. Impatient to get on with his work, Becquerel decided to develop the film anyway. What he saw on the film amazed him. Once again there was an image of the sample, even though the uranium salt had not been made to fluoresce. In fact, the image on the film was just as strong and clear as the image that had been formed when the sample was exposed to sunlight.

Becquerel realized that an invisible "something" given off by the salt had gone through the light-proof paper and produced an image. In time, this invisible "something" was named **nuclear radiation.** Becquerel tested many more uranium compounds and concluded that the source of nuclear radiation was the element uranium. An element that gives off nuclear radiation is said to be **radioactive.**

Marie Curie, a Polish scientist working in France and a former student of Becquerel's, became interested in Becquerel's pioneering work. She and her husband, French scientist Pierre Curie, began searching for other radioactive elements. In 1898, the Curies discovered a new radioactive element in a uranium ore known as pitchblende. They named the element polonium in honor of Marie Curie's native Poland. Later that year they discovered another radioactive element. They named this element radium, which means "shining element." Both polonium and radium are more radioactive than uranium. Since the Curies' discovery of polonium and radium, many other radioactive elements have been identified and even artificially produced.

The Nature of Nuclear Radiation

Nuclear radiation cannot be seen. So radioactive elements were difficult to identify at first. But it was quickly realized that radioactive elements have certain characteristic properties. The first of these is the property observed by Becquerel. Nuclear radiation given off by radioactive elements alters photographic film. Another property of many radioactive elements is that they produce fluorescence in certain compounds. A third characteristic is that electric charge can be detected in the air surrounding radioactive elements. Finally, nuclear radiation damages cells in most organisms.

Today, scientists use the term **radioactivity** to describe the phenomenon discovered by Becquerel. **Radioactivity is the release of nuclear radiation in the form of particles and rays from a radioactive element.** The radiation given off by radioactive elements consists of three different particles or rays. The three types of radiation have been named alpha particles, beta particles, and gamma rays after the first three letters of the Greek alphabet.

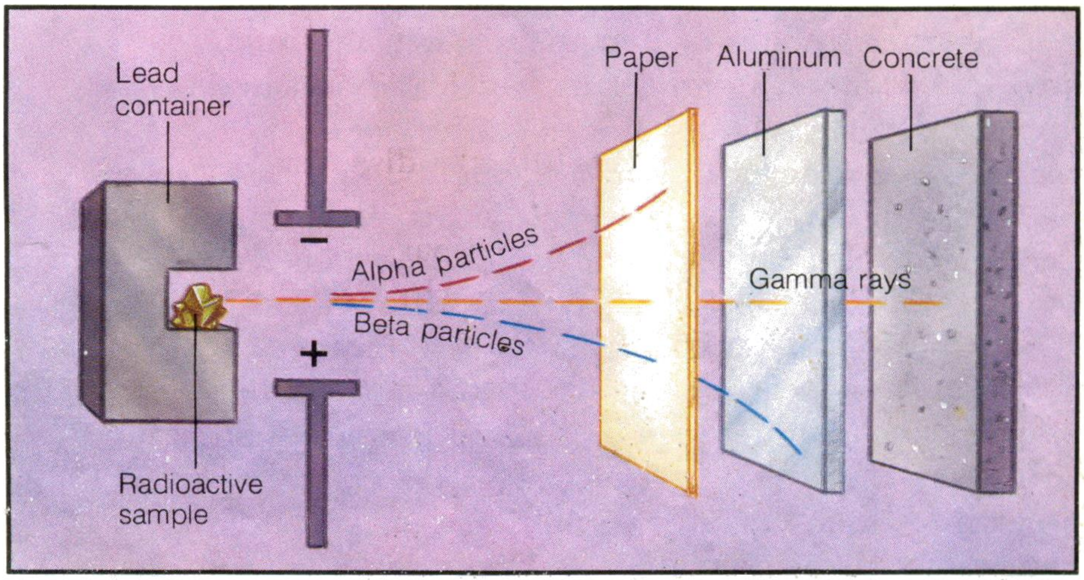


Fig.5.1 The three types of radiation.

ALPHA PARTICLES An **alpha particle** is actually the nucleus of a helium atom—2 protons and 2 neutrons. An alpha particle has a positive charge because it contains 2 positive protons and no other charges. Alpha particles are the weakest type of nuclear radiation. Although they can burn flesh, alpha particles can be stopped by a sheet of paper.

BETA PARTICLES A **beta particle** is an electron. However, a beta particle should not be confused with an electron that surrounds the nucleus of an atom. A beta particle is an electron that is formed inside the nucleus when a neutron breaks apart. Beta particles have a penetrating ability 100 times greater than alpha particles. Beta particles can pass through as much as 3 millimeters of aluminum.

GAMMA RAYS A **gamma ray** is an electromagnetic wave of extremely high frequency and short wavelength. Gamma rays are the same kind of waves as the visible light that enables you to see. That is, both are forms of electromagnetic waves. Gamma rays, however, carry a lot more energy. They are the most penetrating radiation given off by radioactive elements. Gamma rays can pass through several centimeters of lead.

Vocabulary notes:

hypothesis – гіпотеза,
to stumble upon – наткнутися на,
uranium – уран,
X-ray – рентгенівське проміння,
to glow – світитися,
fluorescent – флуоресцентний,
lightproof paper – світлонепробивний папір,
film – плівка,
sample – зразок,
nuclear radiation – ядерна реакція,
radioactive – радіоактивний,
pitchblende – ураніт,
polonium – полоній,
radium – радій,
to detect – досліджувати,
radioactivity – радіоактивність,
alpha particle – альфа часточка,
beta particle – бета часточка,
gamma ray – гама промінь,
helium atom – атом гелію,
flesh – м'ясо,
aluminum – алюміній,
electromagnetic wave – електромагнітна хвиля,
lead – свинець, олово

5.2 Nuclear Reactions

Although Becquerel and the Curies observed radioactivity, they could not explain its origin. The reason for this is understandable: The source of radioactivity is the nucleus of an atom. But Becquerel discovered radioactivity well before the nucleus was discovered. Several years after Becquerel's and the Curies' work, it was determined that radioactivity results when the nuclei of atoms of certain elements change, emitting particles and/or rays. What still remained unknown, however, was what makes a nucleus break apart and why only some elements are radioactive.

Nuclear Stability

The answers to these puzzling questions would be found in the atom—specifically, in the nucleus. The nucleus of an atom contains protons and neutrons. Protons are positively charged particles. Neutrons are neutral particles; they have no charge. It is a scientific fact that particles with the same charge (positive or negative) repel each other. Thus protons repel each other. How, then, does the nucleus hold together? A force known as the **nuclear strong force** overcomes the force of repulsion between protons and holds protons and neutrons together in the nucleus. The energy associated with the strong force is called **binding energy.**

The binding energy is essential to the stability of a nucleus. In some atoms, the binding energy is great enough to hold the nucleus together permanently. The nuclei of such atoms are said to be stable. In other atoms, the binding energy is not as great. The nuclei of these atoms are said to be unstable. An unstable nucleus will come apart. Atoms with unstable nuclei are radioactive.   .

Some elements that are not radioactive have radioactive forms, or **isotope.**

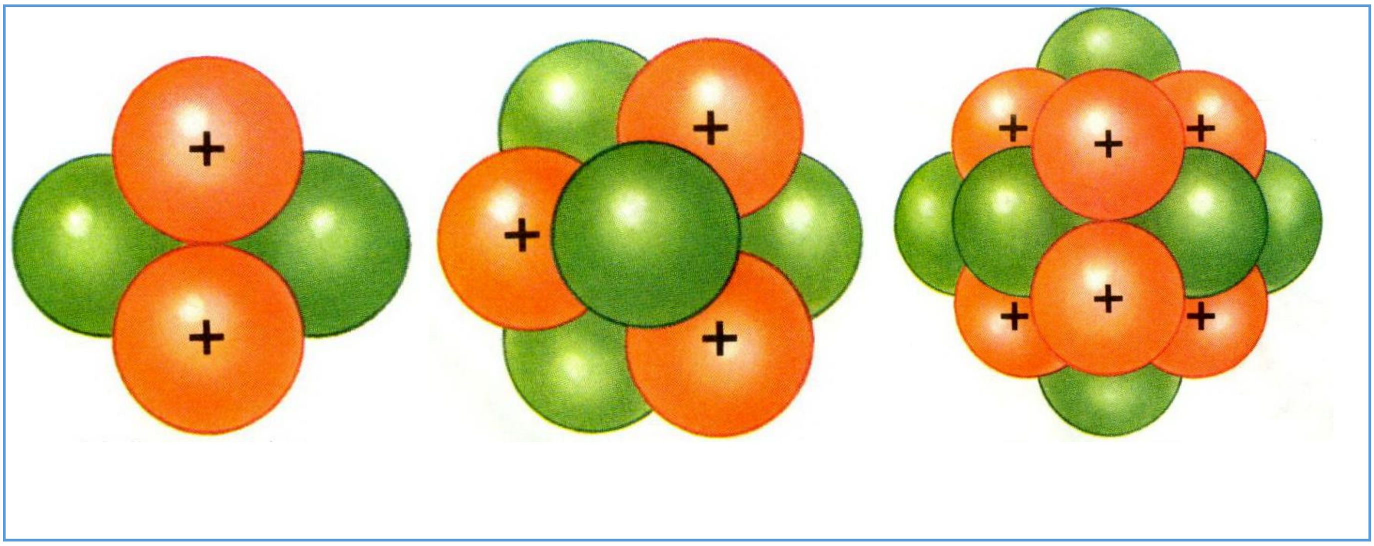


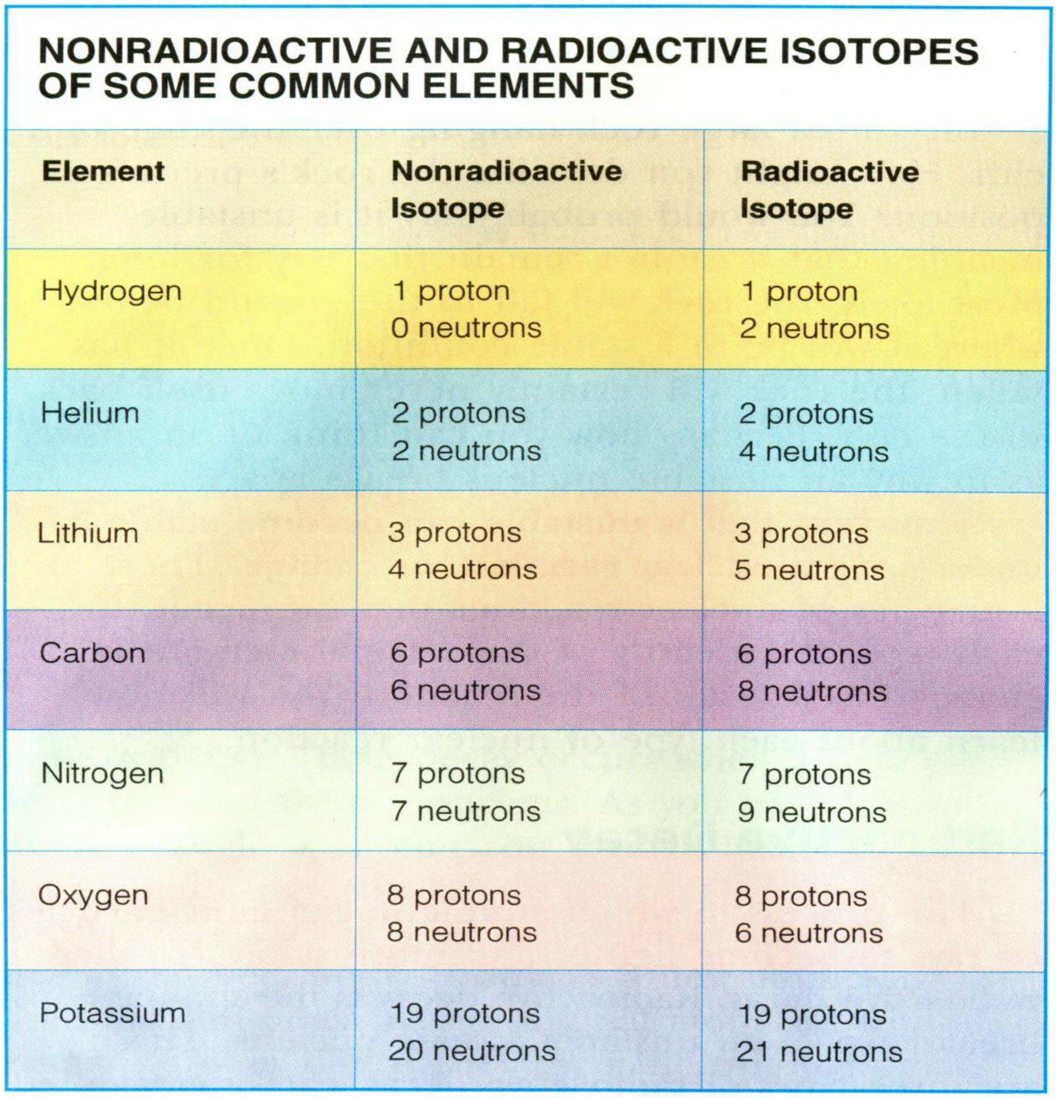
Fig.5.2 Nucleus structure of helium, lithium and carbon.

What is an isotope? The number of protons in the atoms of a particular element cannot vary. An atom is identified by the number of protons it contains. (The number of protons is called the atomic number.) Carbon atoms would not be carbon atoms if they had 5 protons or 7 protons—only 6 protons will do. Yet there are some carbon atoms that have 6 neutrons, and others that have 8 neutrons. The difference in the number of neutrons affects the characteristics of the atom but not its identity. Atoms that have the same number of protons (atomic number) but different numbers of neutrons are called isotopes.

Many elements have at least one radioactive isotope. For example, carbon has two common isotopes—carbon-12 and carbon-14. Carbon-12, which you are familiar with as coal, graphite, and diamond, is not radioactive. Carbon-14, used in dating fossils, is radioactive. *Fig. 5.3* shows the radioactive and nonradioactive isotopes of some common elements.

Becoming Stable

Imagine a large rock hanging over the edge of a cliff. How might you describe the rock's precarious position? You would probably say it is unstable, meaning that it cannot remain that way for long. Most likely, the rock will fall to the ground below, where it will be in a stable condition. Once it has fallen, the rock will certainly never move itself back to the cliff. Perhaps now you can think of an answer as to why an unstable nucleus breaks apart



NONRADIOACTIVE AND RADIOACTIVE ISOTOPES OF SOME COMMON ELEMENTS

Element	Nonradioactive Isotope	Radioactive Isotope
Hydrogen	1 proton 0 neutrons	1 proton 2 neutrons
Helium	2 protons 2 neutrons	2 protons 4 neutrons
Lithium	3 protons 4 neutrons	3 protons 5 neutrons
Carbon	6 protons 6 neutrons	6 protons 8 neutrons
Nitrogen	7 protons 7 neutrons	7 protons 9 neutrons
Oxygen	8 protons 8 neutrons	8 protons 6 neutrons
Potassium	19 protons 20 neutrons	19 protons 21 neutrons

Fig.5.3 Nonradioactive and radioactive isotopes of some common elements.

Becoming Stable

Imagine a large rock hanging over the edge of a cliff. How might you describe the rock's precarious position? You would probably say it is unstable, meaning that it cannot remain that way for long. Most likely, the rock will fall to the ground below, where it will be in a stable condition. Once it has fallen, the rock will certainly never move itself back to the cliff. Perhaps now you can think of an answer as to why an unstable nucleus breaks apart.

A nucleus that is unstable can become stable by undergoing a nuclear reaction, or change. There are four types of nuclear reactions that can occur. In each type, the identity of the original element is changed as a result of the reaction.

Radioactive Decay

The process in which atomic nuclei emit particles or rays to become lighter and more stable is called **radioactive decay**. Radioactive decay is the spontaneous breakdown of an unstable atomic nucleus. There are three types of radioactive decay, each determined by the type of radiation released from the unstable nucleus.

ALPHA DECAY Alpha decay occurs when a nucleus releases an alpha particle. The release of an alpha particle (2 protons and 2 neutrons) decreases the mass number of the nucleus by 4. The mass number is the sum of the number of protons and neutrons in the nucleus. Each proton and each neutron has a mass of 1. The release of an alpha particle decreases the number of protons, or the atomic number, by 2. Thus the original atom is no longer the same. A new atom with an atomic number that is 2 less than the original is formed.

An example of an element that undergoes alpha decay is an isotope of uranium called uranium-238. The number 238 to the right of the hyphen is the mass number for this particular nucleus. An isotope of an element is often represented by using the element's symbol, mass number, and atomic number. The mass number is written to the upper left of the symbol. At the lower left, the atomic number (or number of protons) is written. Uranium has 92 protons. So this is the way uranium-238 would be represented:

$$^{238}_{92}\mathrm{U}$$

The number of neutrons in the nucleus can be determined by subtracting the number of protons from the mass number. In this example, the number of neutrons is the mass number 238 minus the number of protons, 92, or 146 (238 - 92 = 146).

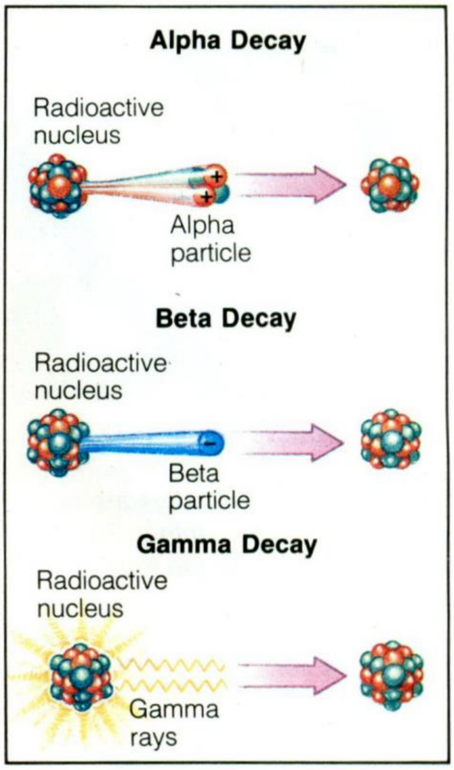


Fig.5.4 Three types of decay processes

When uranium-238 undergoes alpha decay, or loses an alpha particle, it changes into an atom of thorium (Th), which has 90 protons and 144 neutrons. What is the mass number of thorium?

BETA DECAY Beta decay occurs when a beta particle is released from a nucleus. As you have learned, a beta particle is an electron formed inside the nucleus when a neutron breaks apart. The other particle that forms when a neutron breaks apart is a proton. So beta decay produces a new atom with the same mass number as the original atom but with an atomic number one higher than the original atom. The atomic number is one higher because there is now an additional proton.

An example of an element that undergoes beta decay is carbon-14. An atom of carbon-14 has 6 protons and 8 neutrons. During beta decay it changes into an atom of nitrogen-14. An atom of nitrogen-14 has 7 protons and 7 neutrons.

When a nucleus releases either an alpha particle or a beta particle, the nucleus becomes stable. **The process in which one element is changed into another as a result of changes in the nucleus is known as transmutation.** The word **transmutation** comes from the word *mutation*, which means change, and the prefix *trans*-, which means through.

GAMMA DECAY Alpha and beta decay are almost always accompanied by gamma decay, which involves the release of a gamma ray. When a gamma ray is emitted by a nucleus, the nucleus does not change into a different nucleus. But because a gamma ray is an extremely high-energy wave, the nucleus makes a transition to a lower energy state.

Radioactive Half-Life

A sample of any radioactive element consists of a vast number of radioactive nuclei. These nuclei do not all decay at one time. Rather, they decay one by one over a period of time at a fixed rate. The fixed rate of decay of a radioactive element is called the **half-life.** The half-life is the amount of time it takes for half the atoms in a given sample of an element to decay.

The half-life of carbon-14 is 5730 years. In 5730 years, half the atoms in a given sample of carbon-14 will have decayed to another element: nitrogen-14. In yet another 5730 years, half the remaining carbon-14 will have decayed. At that time, one fourth—or one half of one half—of the original sample will be left. One fourth of the original sample will be carbon-14, and three fourths will be nitrogen-14.

Suppose you had 20 grams of pure barium-139. Its half-life is 86 minutes. So after 86 minutes, half the atoms in the sample would have decayed into another element: lanthanum-139. You would have 10 grams of barium-139 and 10 grams of lanthanum-139. After another 86 minutes, half the atoms in the 10 grams of barium-139 would have decayed into lanthanum-139. You would then have 5 grams of barium-139 and 15 grams of lanthanum-139.

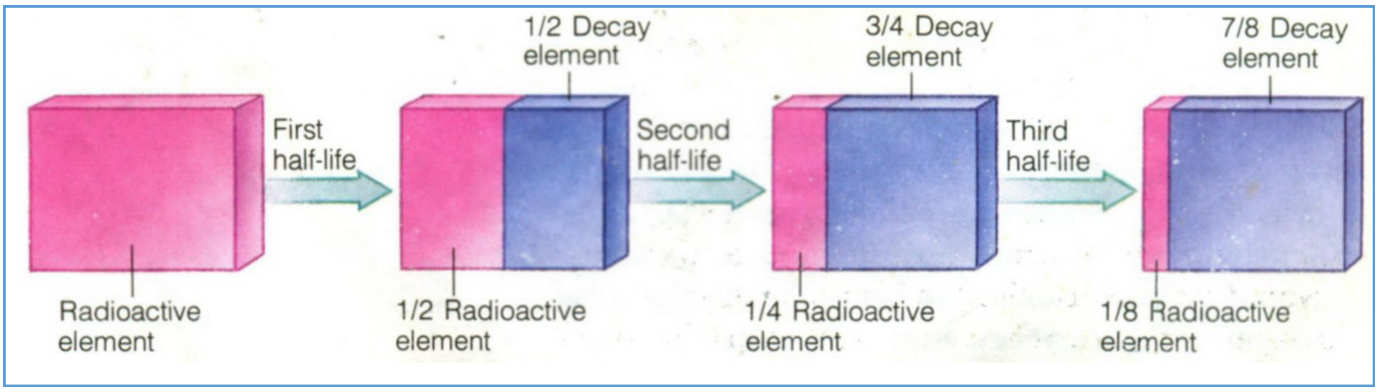
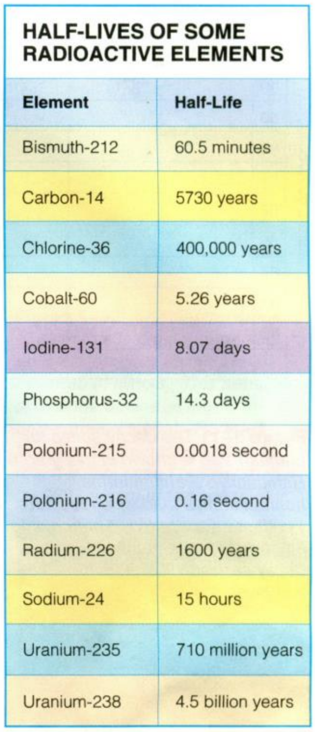


Fig.5.5 The half-life of a radioactive element.

The half-lives of certain radioactive isotopes are useful in determining the ages of rocks and fossils. Scientists can use the half-life of carbon-14 to determine the approximate age of organisms and objects less than 50,000 years old. The technique is called carbon-14 dating. Other radioactive elements, such as uranium-238, can be used to date objects many millions of years old.

Half-lives vary greatly from element to element. Some half-lives are only seconds; others are billions of years. For example, the half-life of rhodium-106 is 30 seconds. The half-life of uranium-238 is 4.5 billion years!



HALF-LIVES OF SOME RADIOACTIVE ELEMENTS

Element	Half-Life
Bismuth-212	60.5 minutes
Carbon-14	5730 years
Chlorine-36	400,000 years
Cobalt-60	5.26 years
Iodine-131	8.07 days
Phosphorus-32	14.3 days
Polonium-215	0.0018 second
Polonium-216	0.16 second
Radium-226	1600 years
Sodium-24	15 hours
Uranium-235	710 million years
Uranium-238	4.5 billion years

Fig.5.6 Half-lives of radioactive elements.

Decay Series

As radioactive elements decay, they change into other elements. These elements may in turn decay, forming still other elements. The spontaneous breakdown continues until a stable, nonradioactive nucleus is formed. The series of steps by which a radioactive nucleus decays into a nonradioactive nucleus is called a **decay**

series. *Fig. 5.7* shows the decay series for uranium. What stable nucleus results from this decay series?

Because of the occurrence of decay series, certain radioactive elements are found in nature that otherwise would not be. In the 5-billion-year history of the solar system, many isotopes with short half-lives have decayed quickly. Thus they should not exist in nature today.

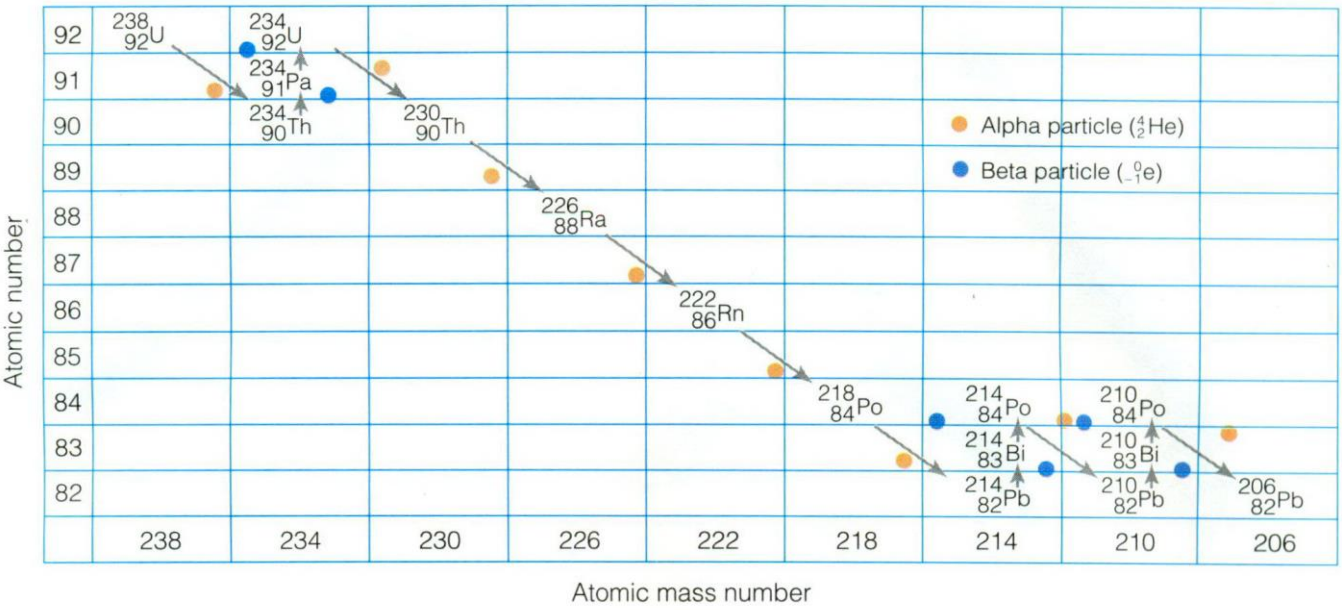


Fig.5.7 The decay series for uranium-238.

This is hardly the case, however. For example, radium, whose half-life is 1600 years, should have disappeared long ago. Yet it still exists on Earth today. This is because radium is part of the decay series for an isotope with a much longer half-life: uranium-238. Recall that uranium-238 has a half-life of 4.5 billion years.

Artificial Transmutation

Once scientists understood how natural transmutation occurred, they worked to produce **artificial transmutation.** The key was to find a way to change the number of protons in the nucleus of an atom. Ernest Rutherford, the same scientist who discovered the nucleus of the atom, produced the first artificial transmutation. By using alpha particles emitted during the radioactive decay of radium to bombard (hit forcefully) nitrogen nuclei, he produced an isotope of oxygen.

Getting the particles to hit the target nuclei with enough force to alter them is extremely difficult. In order to more effectively bombard nuclei with high-energy particles, scientists have developed devices for accelerating (speeding up) charged particles. One such device is the supercollider. Other devices are the cyclotron, synchrotron, betatron, and linear accelerator. These devices use magnets and electric fields to speed up particles and produce collisions.

Before the discovery of the neutron in 1932, mainly alpha particles and protons were used as the "bullets" to bombard nuclei. But because both these particles are positively charged, they are repelled by the positive charge of the target nucleus. A large amount of extra energy is required simply to overcome this repulsion.

Enrico Fermi, an Italian scientist, and his co-workers realized that because neutrons are neutral, they are not repelled by the nucleus. These researchers discovered that neutrons can penetrate the nucleus of an atom more easily than a charged particle can. Neutrons can go through the nucleus without changing it; they can cause the nucleus to disintegrate; or they can become trapped by the nucleus, causing it to become unstable and break apart.

After a great deal of experimentation, the elements neptunium and plutonium were created. They were the first **transuranium elements.** Transuranium elements (also known as synthetic elements) are those with more than 92 protons in their nuclei. In other words, transuranium elements have atomic numbers greater than 92. A whole series of transuranium elements have been formed by bombarding atomic nuclei with neutrons, alpha particles, or other nuclear "bullets."

Radioactive isotopes of natural elements can be made by using a similar technique. Marie Curie's daughter, Irene, and Irene's husband, Frederic Joliot, discovered that stable atoms can be made radioactive when they are bombarded with neutrons. For example, by shooting neutrons at the nucleus of an iodine atom, scientists have been able to make I-131, a radioactive isotope of iodine.

Vocabulary note:

to emit – випромінювати,
to repel – відштовхувати,
force of repulsion – сила відштовхування,
stable nuclear – стабільне ядро,
unstable nuclear – нестабільне ядро,
isotope – ізотоп,
atomic number – атомний номер,
fossil – скам'янілість, копалина, викоп,
precarious – небезпечний,
mass number – масове число,
radioactive decay – радіоактивний розпад,
spontaneous – мимовільний,
breakdown – розпад,
to decrease – зменшувати,

hyphen – дефіс,
to subtract – віднімати,
thorium – торій,
nitrogen – азот,
transmutation – перетворення,
fixed rate – фіксована швидкість,
half-life – період напіврозпаду,
barium – барій,
lanthanum – лантан,
rhodium – родій,
decay series – ряд радіоактивних перетворень,
artificial transmutation – штучне перетворення,
to bombard – бомбардувати,
to accelerate – прискорювати,
cyclotron – циклотрон,
synchrotron – синхротрон,
betatron – бетатрон,
linear accelerator – лінійний прискорювач,
to disintegrate – розпадатися,
neptunium – нептуній,
plutonium – плутоній,
transuranium element – трансурановий елемент.

5.3 Harnessing the Nucleus

Radioactive decay and the bombardment of a nucleus with particles are two ways in which energy is released from the nucleus of an atom. The amount of energy released, however, is small compared with the tremendous amount of energy known to bind the nucleus together. Long ago, scientists realized that if somehow they could release more of the energy holding the nucleus together, huge amounts of energy could be gathered from tiny amounts of mass.

Nuclear Fission

During the 1930s, several other scientists built upon the discovery of Fermi and his co-workers. In 1938, the German scientists Otto Hahn and Fritz Strassman discovered that when the nucleus of an atom of uranium-235 is struck by a neutron, two smaller nuclei of roughly equal mass were produced. Two other scientists, Lise Meitner and Otto Frisch, provided an explanation for this event: The uranium nucleus had actually split into two. What made the discovery and the explanation so startling was that until then the known nuclear reactions had involved only knocking out a tiny fragment from the nucleus—not splitting it into two!

This reaction—the first of its kind ever to be produced—is an example of **nuclear fission**. It was so named because of its resemblance to cell division, or biological fission. **Nuclear fission is the splitting of an atomic nucleus into two smaller nuclei of approximately equal mass.** Unlike radioactive decay, nuclear fission does not occur spontaneously.

In one typical fission reaction, an uranium-235 nucleus is bombarded by a neutron, or nuclear "bullet." The products of the reaction are a barium-141 nucleus and a krypton-92 nucleus. Three neutrons are also released: the original "bullet" neutron and 2 neutrons from the uranium nucleus.

The amount of energy released when a single uranium-235 nucleus splits is not very great. But the neutrons released in the first fission reaction become nuclear "bullets" that are capable of splitting otheruranium-235 nuclei.

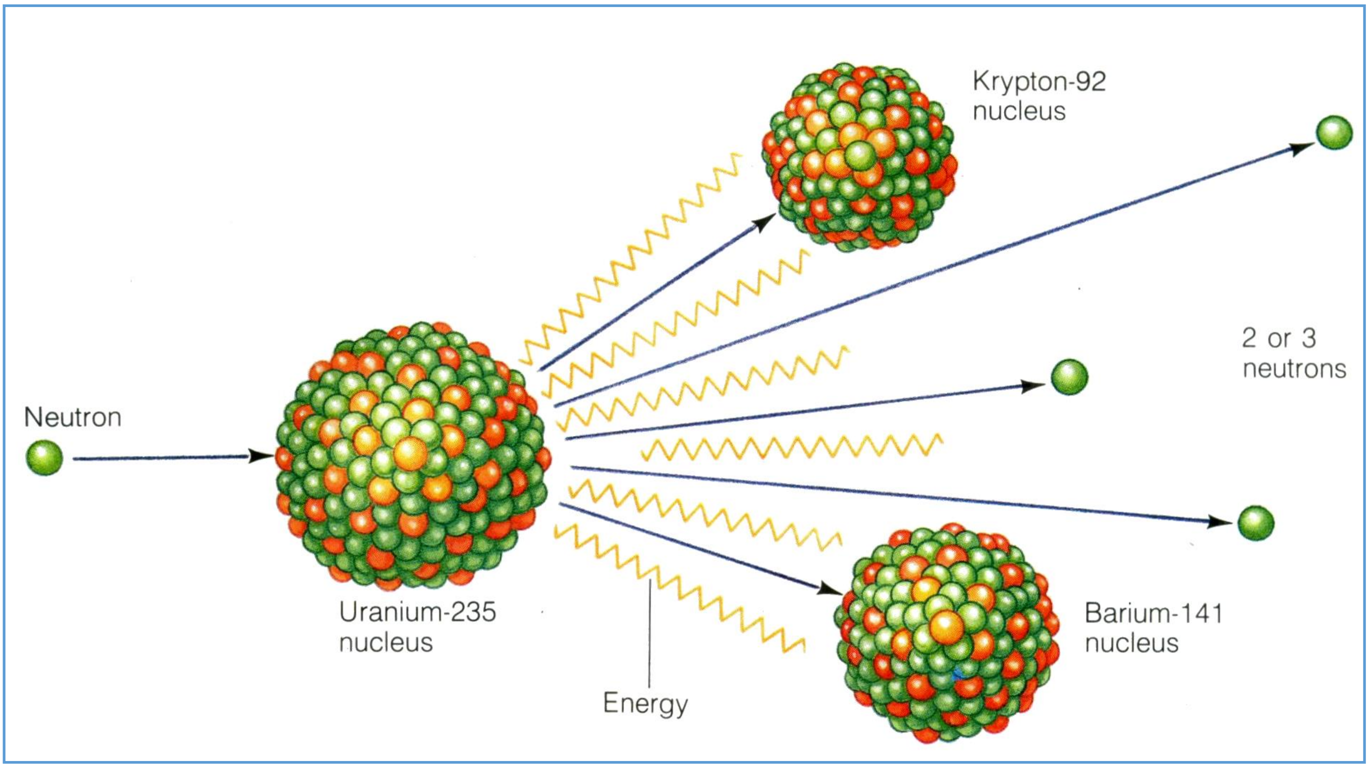


Fig. 5.8 Bombardment of a uranium-235 nucleus with a neutron.

Each uranium nucleus that is split releases 3 neutrons. These neutrons may then split even more uranium nuclei. The continuous series of fission reactions is called a **nuclear chain reaction**. Ina nuclear chain reaction, billions of fission reactions may take place each second!

When many atomic nuclei are split in a chain reaction, huge quantities of energy are released. This energy is produced as a result of the conversion of a small amount of mass into a huge amount of energy. The total mass of the barium, krypton, and 2 neutrons is slightly less than the total mass of the original uranium plus the initial neutron. The missing mass has been converted into energy. An uncontrolled chain reaction produces a nuclear explosion. The atomic bomb is an example of an uncontrolled chain reaction.

All currently operating nuclear power plants use fission reactions to produce energy. The energy is primarily in the form of heat. The heat is carried away and used to produce electricity.

Nuclear Fusion

Another type of nuclear reaction that certain radioactive elements can undergo is called **nuclear fusion**. Like fission, this kind of nuclear reaction produces a great amount of energy. But unlike fission, which involves the splitting of a high-mass nucleus, this reaction involves the joining of two low-mass nuclei. The word fusion means joining together. **Nuclear fusion is the joining of two atomic nuclei of smaller masses to form a single nucleus of larger mass.**

Nuclear fusion is a thermonuclear reaction. The prefix *thermo-* means heat. For nuclear fusion to take place, temperatures well over a million degrees Celsius must be reached. At such temperatures, the phase of matter known as plasma is formed. Plasma consists of positively charged ions, which are the nuclei of original atoms, and free electrons.

The temperature conditions required for nuclear fusion exist on the sun and on other stars. In fact, it is nuclear fusion that produces the sun's energy. In the sun's core, temperatures of about 20 million degrees Celsius keep fusion going continuously. In a series of steps, hydrogen nuclei are fused into a helium-4 nucleus. See *Fig. 5.9.*

Nuclear fusion produces a tremendous amount of energy. The energy comes from matter that is converted into energy during the reaction. In fact, the products formed by fusion have a mass that is about 1 percent less than the mass of the reactants. Although 1 percent loss of mass may seem a small amount, its conversion produces an enormous quantity of energy.

Nuclear fusion has several advantages over nuclear fission. The energy released in fusion reactions is greater for a given mass than that in fission reactions. Fusion reactions also produce less radioactive waste. And the possible fuels used for fusion reactions are more plentiful. Unfortunately, considerable difficulties exist with producing useful fusion reactions on Earth.

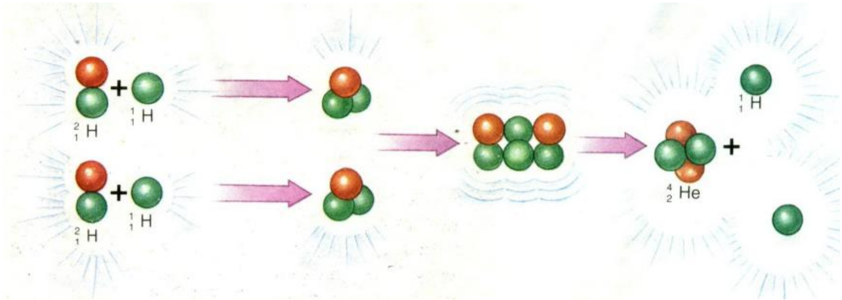


Fig.5.9 The process of nuclear fusion.

Fusion reactions are more difficult to begin, to control, and to maintain than nuclear fission reactions are. After all, no known vessel can contain reactions occurring at such tremendous temperatures. And such high temperatures are extremely difficult to achieve. In fact, a hydrogen bomb, which uses fusion, is started by an atomic bomb, which uses fission. It is the only way of achieving the necessary temperatures.

Scientists are continuing their search for ways to control this powerful reaction and to tap a tremendous energy resource. As an example, experiments using high-powered laser beams and electrons as ways of starting fusion reactions are being conducted.

Vocabulary notes:

Harnessing - використання,
startling – дивовижний,
nuclear fission – розчеплення, поділ атомного ядра,
fission reaction – реакція розчеплення,
nuclear chain reaction – ядерна ланцюгова реакція,
krypton – криптон,
nuclear explosion – ядерний вибух,
atomic bomb – атомна бомба,
nuclear fusion – злиття,
thermonuclear reaction – термоядерна реакція,
plasma – плазма,
core – ядро,
laser beam – лазерний промінь.

5.4 Detecting and Using Radioactivity

Radioactivity cannot be seen or felt. Becquerel discovered radioactivity because it left marks on photographic film. Although film is still used today to detect radioactivity, scientists have more specialized instruments for this purpose. **The instruments scientists use to detect and measure radioactivity include the electroscope, the Geiger counter, the cloud chamber, and the bubble chamber.**

Instruments for Detecting and Measuring Radioactivity

ELECTROSCOPE An **electroscope** is a simple device that consists of a metal rod with two thin metal leaves at one end. If an electroscope is given a negative charge, the metal leaves separate. In this condition, the electroscope can be used to detect radioactivity.

Radioactive substances remove electrons from molecules of air. As a result, the molecules of air become positively charged ions. When a radioactive substance is brought near a negatively charged electroscope, the air molecules that have become positively charged attract the negative charge on the leaves of the electroscope. The leaves discharge, or lose their charge, and collapse.

GEIGER COUNTER In 1928, Hans Geiger designed an instrument that detects and measures radioactivity. Named the **Geiger counter** in honor of its inventor, this instrument produces an electric current in the presence of a radioactive substance.

A Geiger counter consists of a tube filled with a gas such as argon or helium at a reduced pressure. When radiation enters the tube through a thin window at one end, it removes electrons from the atoms of the gas. The gas atoms become positively charged ions. The electrons move through the positively charged ions to a wire in the tube, setting up an electric current. The current, which is amplified and fed into a recording or counting device, produces a flashing light and a clicking sound. The number off lashes and clicks per unit time indicates the strength of the radiation. A counter attached to the wire is able to measure the amount of radioactivity by measuring the amount of current.

CLOUD CHAMBER **A cloud chamber** contains a gas cooled to a temperature below its usual condensation point (point at which it becomes a liquid). When a radioactive substance is put inside the chamber, droplets of the gas condense around the radioactive particles. The process is similar to what happens in "cloud seeding," when rain droplets condense around particles that have been injected into the clouds. The droplets formed around the particles of radiation in a cloud chamber leave a trail that shows up along the chamber lining. An alpha particle leaves a short, fat trail, whereas a beta particle's trail is long and thin.

BUBBLE CHAMBER The **bubble chamber** is similar in some ways to the cloud chamber, although its construction is more complex. A bubble chamber contains a superheated liquid. A superheated liquid is hot enough to boil—but does not. Instead, it remains in the liquid phase. The superheated liquid most often contained in a bubble chamber is hydrogen.

When radioactive particles pass through the chamber, they cause the hydrogen to boil. The boiling liquid leaves a trail of bubbles, which is used to track the radioactive particle.

Putting Radioactivity to Work

Radioactive substances have many practical uses. Dating organic objects, which you learned about earlier, is one such use. In industry, radioactive isotopes, or **radioisotopes,** have additional uses. Radioisotopes can be used to find leaks or weak spots in metal pipes, such as oil pipe lines. Radioisotopes also help study the rate of wear on surfaces that rub together. One surface is made radioactive. Then the amount of radiation on the other surface indicates the wear.

Because radioisotopes can be detected so readily, they can be used to follow an element through an organism, or through an industrial process, or through the steps of a chemical reaction. Such a radioactive element is called a **tracer,** or radiotracer. Tracers are possible because all isotopes of the same element have essentially the same chemical properties. When a small quantity of radioisotope is mixed with the naturally occurring stable isotopes of the same element, all the isotopes go through the same reactions together.

An example of a tracer is phosphorus-32. The nonradioactive element phosphorus is used in small amounts by both plants and animals. If phosphorus-32 is given to an organism, the organism will use the radioactive phosphorus just as it does the nonradioactive phosphorus. However, the path of the radioactive element can be traced. In this way, scientists can learn a great deal about how plants and animals use phosphorus.

Another area in which radioisotopes make an important contribution is in the field of medicine. The branch of medicine in which radioactivity is used is known as nuclear medicine. Tracers are extremely valuable in diagnosing diseases. For example, radioactive iodine—iodine-131—can be used to study the function of the thyroid gland, which absorbs iodine. Sodium-24 can be used to detect diseases of the circulatory system. Iron-59 can be used to study blood circulation.

Another procedure, known as radioimmunoassay, developed by Dr. Rosalyn Yalow—who won the Nobel prize for her work—involves using tracers to detect the presence of minute quantities of substances in the body. These tests can be used to detect pregnancy as well as the early signs of a disease. Another powerful research tool—nuclear magnetic resonance imaging (MRI)—has become invaluable in a variety of fields, from physics to chemistry and biochemistry. MRI involves recording changes in the energy of atomic nuclei in response to external energy changes, without altering the cells of the body in any way.

Radiation is also used to destroy unhealthy cells, such as those that cause cancer. Radiation in large doses destroys living tissues, especially cells undergoing division. Because cancer cells undergo division more frequently than normal cells do, radiation kills more cancer cells than it does normal cells. As early as 1904, physicians attempted to treat masses of unhealthy cells, known as tumors, with high-energy radiation. This treatment is called radiation therapy. Radioisotopes can also be used to kill bacteria that cause food to spoil. Radiation was used to preserve the food that the astronauts ate while on the moon and in orbit.

Dangers of Radiation

Although radioactivity has tremendous positive potential, radioactive materials must be handled with great care. Radioactive materials are extremely dangerous. Radiation can ionize—or knock electrons out of—atoms or molecules of any material it passes through. For this reason, the term ionizing radiation is sometimes used. So, oddly enough, the same radiation that is used to treat disease can also cause it.

Ionization can cause considerable damage to materials, particularly to biological tissue. When ionization is produced in cells, ions may take part in chemical reactions that would not otherwise have occurred. This may interfere with the normal operation of the cell. Damage to DNA is particularly serious. An alteration in the DNA (substance responsible for carrying traits from one generation to another) of a cell can interfere with the production of proteins and other essential cellular materials. The result may be the death of the cell. If many cells die, the organism may not be able to survive.

Large doses of radiation can cause reddening of the skin, a drop in the white blood cell count, and numerous other unpleasant symptoms, including nausea, fatigue, and loss of hair. Such effects are sometimes referred to as radiation sickness. Large doses of radiation can also be fatal. Marie Curie's death in 1934 was caused by exposure to too much radiation.

Even metals and other structural materials can be weakened by intense radiation. This is a considerable problem in nuclear-reactor power plants and for space vehicles that must pass through areas of intense cosmic radiation.

We are constantly exposed to low-level radiation from natural sources such as cosmic rays from space, radioactivity in rocks and soil, and radioactive isotopes that are present in food and in our bodies.

Today, people who work with radioactive materials take extreme precautions. They wear radiation-sensitive badges that serve as a warning of unsafe levels of radiation. Specially designed clothing is worn to block radiation. Scientists continue to search for greater understanding and control of radiation so that its benefits can be enjoyed without the threat of danger.

Vocabulary notes:

electroscope – електроскоп,
Geiger counter – лічильник Гейзера,
cloud chamber – камера Вільсона, конденсаційна камера,
bubble chamber – бульбашкова камера,
metal rod – металевий стрижень,
to collapse – стискатися,
argon – аргон,
helium – гелій,
to set up – спричиняти,
to amplify – поширюватися,
droplet – крапля,
trail – слід,
to date – датувати,
radioisotope – радіоізотоп,
leak – теча,
rate of wear – рівень зношування,
tracer – радіоактивний індикатор,
phosphorus – фосфор,
nuclear medicine – ядерна медицина,
thyroid gland – щитоподібна залоза,
circulatory system – кровоносна система,
radioimmunoassay -радіоіммуноаналіз,
nuclear magnetic resonance imaging – ядерна магнітно-резонансна томографія,
cancer – рак,
tumor – пухлина,
bacterium (pl. –ria) – бактерія,

ionizing radiation – іонізуюче випромінювання,
nausea – нудота,
fatigue – утома,
precaution – обережність,
threat of danger – загроза небезпеки.

I. Key terms. Read, translate and memorize the following definitions:

Nuclear radiation – *ядерна радіація* – particles and energy released from radioactive nucleus.

Radioactive – *радіоактивний* – description for a nucleus that gives off nuclear radiation in the form of mass and energy in order to become stable.

Radioactivity – *радіоактивність* – release of energy and matter that results from changes in the nucleus of an atom.

Alpha particle – *альфа часточка* – weakest type nuclear radiation; consists of a helium nucleus released during alpha decay.

Beta particle – *бета часточка* – electron, created in the nucleus of an atom, released during beta decay.

Gamma ray – *гама промінь* – high-frequency electro-magnetic wave released during gamma decay; strongest type of nuclear radiation.

Binding energy – *зв’язуючи енергія* **–** energy associated with the strong nuclear force that holds an atomic nucleus together; related to the stability of a nucleus.

Isotope – *ізотоп* – atom that has the same number of protons (atomic number) as another atom but a different number of neutrons.

Radioactive decay – *радіоактивний розпад* – process in which a nucleus spontaneously emits particles or rays to become lighter and more stable.

Transmutation – *перетворення* – process in which one element is changed into another as a result of changes in the nucleus.

Half-life – *період напіврозпаду* – amount of time it takes for half the atoms in a given sample of an element to decay.

Decay series – *серія розпаду* **–** sequence of steps by which a radioactive nucleus decays into a nonradioactive nucleus.

Artificial transmutation – *штучне перетворення* – changing of one element into another by unnatural means; involves bombarding a nucleus with high-energy particles to cause change.

Transuranium element – *трансурановий елемент* – element formed synthetically; has more than 92 protons in its nucleus.

Nucleus fission – *розчеплення, поділ атомного ядра* – splitting of an atomic nucleus into two smaller nuclei of approximately equal mass.

Nuclear chain reaction – *ядерна ланцюгова реакція* – series of fission reactions that occur because the products released during one fission reaction cause fission reactions in other atoms.

Nuclear fusion – *ядерний синтез* – joining of two atomic nuclei of smaller mass to form a single nucleus of larger mass.

Electroscope – *електроскоп* – device consisting of a metal rod with two thin metal leaves at one end that can be used to detect radioactivity.

Geiger counter – *лічильник Гейгера* – device that can be used to detect radioactivity because it produces an electric current in the presence of a radioactive substance.

Cloud chamber – *камера Вільсона* – device to study radioactivity, which uses a cooled gas that will condense around radioactive particles.

Bubble chamber – *бульбашкова камера* – device that uses a superheated liquid to create bubbles when radioactive particles pass through it.

Radioisotope – *радіоактивний ізотоп* – artificially produced radioactive isotope, often used in medicine or industry.

Tracer - радіоактивний індикатор - radioactive element whose pathway can be followed through the steps of a chemical reaction or industrial process.

II. Match the chemical terms on the left with their correct definitions on the right.

nuclear radiation	splitting of an atomic nucleus into two smaller nuclei of approximately equal mass;
alpha particle	electron, created in the nucleus of an atom, released during beta decay;
beta particle	weakest type of nuclear radiation; consists of a helium nucleus released during alpha decay;

gamma ray	amount of time it takes for half the atoms in a given sample of an element to decay;
isotope	amount of time it takes for half the atoms in a given sample of an element to decay;
half-life	atom that has the same number of protons (atomic number) as another atom but a different number of neutrons;
nuclear fission	particles and energy released from a radioactive nucleus.

III. Fill in the blanks from the words below. Translate the sentences into Ukrainian:
Radioactive, X-rays, polonium, alpha particles, beta particles, gamma rays, repel, transmutation, electroscope, nuclear medicine.

1. An element that gives off nuclear radiation is ….
2. H. Becquerel, a French scientist, experimented with uranium to determine whether it gave off ….
3. In 1898 Marie Curie and her husband discovered a new radioactive element in uranium ore known as ….
4. The three types of radiation are: … …, … …, … ….
5. Particles with the same charge (positive or negative) … each other.
6. The process in which one element is changed into another as a result of changes in the nucleus is known as ….
7. A simple device that consists of a metal rod with two thin metal leaves is an ….
8. The branch of medicine in which radioactivity is used is known as … ….

IV. Answer the following questions:

1. Define radioactivity.
2. The isotopes of some elements are radioactive. What does the term radioactive mean?
3. Describe an alpha particle, a beta particle, and a gamma ray. How are they alike? How are they different?

4. Define the following terms:

a) transmutation;
b) half-life;
c) decay series.

5. Describe nuclear fission and a nuclear chain reaction.
6. Describe nuclear fusion. How do fusion and fission differ?
7. What instruments do scientists use to detect and measure radioactivity?
8. What is the composition of an electroscope? How does it work?
9. Why is nuclear radiation dangerous to humans and other living organisms? Which type of radiation is most dangerous?
10. How are cancer, genetic damage, and mutation associated with nuclear radiation?

V. Make written translation into Ukrainian of the text “Nuclear Reactions”.

VI. Translate into English:

1. Ядра атомів можуть перетворюватися внаслідок саморуйнування або їхньої взаємодії з елементарними частинками.
2. Під час ядерних реакцій одні хімічні елементи перетворюються на інші.
3. Першу ядерну реакцію здійснив Резерфорд у 1919 р., штучно бомбардуючи ядра атомів нітрогену атомами гелію (α-частинками).
4. При допомозі штучних ядерних реакцій вдалося добути різновиди атомів, яких не виявлено в природі.
5. Елементи, які складаються лише з радіоактивних ізотопів, називаються радіоактивними.
6. Ядерні реакції супроводжуються радіоактивним випромінюванням, яке має велику проникну здатність, зокрема у живі системи з їхнім наступним руйнуванням.
7. Особливо негативно радіація впливає на здоров′я людей.
8. Навіть метали можуть послаблюватися сильною радіацією.

ADDITIONAL READING

Joseph Gay-Lussac was born in France in 1778. In 1795, he moved to Paris where he received an excellent education at the Ecole Polytechnique.

One day in Paris, he noticed that a young lady behind the counter of a linen drapery was reading a chemistry book. He was so intrigued that his visits to the store became more and more frequent. Eventually he proposed, and in 1808 she became his wife.

Gay-Lussac was a versatile person. In 1802, he published an excellent paper on the effect of heat on gases (Charles' Law and Gay-Lussac's Law), but gave full credit for the principles to Charles. In 1804, he made a solo balloon flight to a height of 7 km and confirmed that the earth's magnetic field persists at that height. He also showed that samples of air from this altitude have the same composition as at sea level. In 1805, he collaborated with Humboldt to show that gases combine chemically in simple whole-number ratios. He published his Law of Combining Volumes in 1808, and it has since become a fundamental proposition of chemistry.

In 1808, Gay-Lussac and Thenard devised a method for obtaining sodium and potassium in large quantity by the action of red-hot iron on their molten carbonates. They used the potassium to isolate boron from boracic acid. At the time the announcement of its isolation was made, Gay-Lussac was seriously ill because of an explosion involving potassium which nearly cost him his sight.

In 1832, he became a professor at the Jardin des Plantes. Throughout his career, his talents were devoted entirely to the cause of science. As a

Joseph Louis Gay-Lussac

(1778-1850)

lecturer, he always used clear and simple language well adapted to the subject under discussion.

The son of a Swedish school principal, Berzelius became interested in natural history and medicine at the age of 14. Two years later he began medical studies at Upsala. He actually failed the chemistry exam, but his professor gave him a passing grade on the basis of the strength of his knowledge in physics. Berzelius then studied chemistry in his free time, and learned how to blow glass and make barometers and thermometers.

In 1802 he received his degree and moved to Stockholm, where he took up hospital work and devoted his spare hours to experiments on the chemical action of voltaic cells.

By 1807, Berzelius had begun a lifelong attempt to determine with utmost accuracy the combining weights of the elements. In about a decade he prepared, purified, and analyzed at least 2000 compounds of 43 elements. He had to prepare or purify his own reagents, and the atomic weights calculated from his results were usually within about 0.3% of those determined a century later. His results also placed the Law of Multiple Proportions on a firm basis.

Jons Jakob Berzelius

(1779-1848)

John Dalton was the son of a poor English weaver. He started keeping meteorological records at the age of 11 and continued until the day before his death. He was the first person to make systematic studies of the weather. At the age of 12 he began his career, as a school teacher. He then worked at a boarding school and when he was 19 became its principal. He devoted every spare minute to intellectual pursuits.

In 1793 he became a tutor in mathematics and natural philosophy at New College, Manchester. It took so much time that he resigned six years later to support himself as a private tutor and spend his time in scientific pursuits. For financial reasons he was forced to construct his own crude instruments. Furthermore, he was a poor experimenter. Nevertheless he managed to discover several laws at the very foundations of chemistry.

By 1801 Dalton had discovered several laws involving the behaviour of gases, including his Law of Partial Pressures, all of which stemmed from his meteorological observations. His attempts to explain these led to the development of his Atomic Theory, which he published in 1808 in his book *New System of Chemical Philosophy*. He then endeavoured to determine atomic weights. This led to the discovery of the Law of Multiple Proportions. In 1826, he received a Royal Medal from the King.

Dalton's health began to fail in 1837, and in 1844 he died peacefully, having laid the basis for the development of chemistry as a science.

John Dalton

(1766-1844)

Robert Bunsen was born in Gottingen, Germany in 1811. During his childhood he was so opinionated that he drove his parents and teachers to despair. He attended university at Gottingen and obtained his doctorate in 1830.

He carried out brilliant studies on certain compounds of arsenic, and discovered an antidote against arsenic poisoning. In 1836, one of the arsenic compounds exploded in a closed glass tube. He lost the vision of one eye because of a glass splinter. This wound and the poisonous vapours almost killed him.

He became full professor at the University of Marburg in 1841. In 1852, he moved to Heidelberg University. Students and chemists came from all over the world to work with Bunsen.

In 1855, he constructed the more efficient gas burner that now bears his name. He invented the spectroscope and used it as a tool of chemical analysis. His first spectroscope consisted of a prism, a cigar box, and two ends of old telescopes. Bunsen was the first person to prepare pure compounds of potassium, sodium, lithium, barium, strontium, and calcium.

Bunsen and his colleague, Kirchoff, predicted that spectrum analysis could be used to discover new elements which would be difficult to discover by other methods. This prediction was proven correct. Rubidium and cesium, which occur in nature in minute quantities, were discovered with the aid of a spectroscope.

Bunsen retired in 1889. He showed no further interest in chemistry. However, he did continue an interest in his first love, geology, until his death in 1899.

Robert Wilhelm Bunsen

(1811-1899)

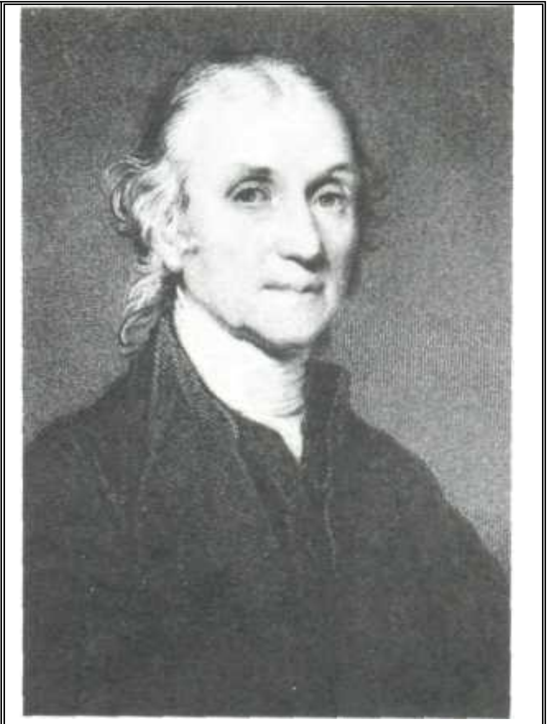
Joseph Priestley was born in Yorkshire, England, of humble parents. He was fond of books and acquired a knowledge of many languages. In 1752, he began studies for the Presbyterian ministry, but he was never a success as a cleric because of his liberal views. He turned to the study of gases, for which he was well able to use his unusual manipulative skills.

Priestley lived near a brewery, so he began his experiments on the readily available "fixed air" (CO_2). He found it dissolved in water, thereby inventing soda water, for which he received the Copley Medal from the Royal Society.

Priestley's great improvement in the manipulation of gases was that he used mercury instead of water in his pneumatic troughs. This enabled him to study gases which were soluble in water. He worked with great intensity, and in quick succession he isolated NO, N_2O, NH_3, HCI, SO_2, and SiF_4.

In 1774, Priestley was heating all the substances he could find by means of a large burning lens, in an attempt to prepare new gases and study their properties. One of the substances he heated was HgO. This led to his discovery of oxygen—an important milestone in the history of chemistry.

Priestley supported the French Revolution. He became so unpopular with his fellow citizens that they sacked his house and the chapel where he preached. His religious views, too, were still disapproved of, so in 1794 he sailed to the United States. He settled in Pennsylvania, where he died peacefully a decade later.



Joseph Priestley

(1733-1804)

Henry Cavendish was born in France of a noble English family. Educated at Cambridge University, he lived as a recluse and devoted almost all of his time to research. Although he inherited a fortune in middle life, he continued his frugal habits.

Cavendish was a magnificent experimenter, with a mathematical turn of mind. Thus, most of his researches were quantitative. He studied the various "airs" (gases), such as CO_2, H_2, and CO, that had been discovered. He was the first to study "inflammable air" (H_2). He showed that different airs had different specific gravities.

He demonstrated the composition of water by passing a spark through a mixture of "inflammable air" and "dephlogisticated air" (O_2). Although he didn't realize it, he showed that ordinary air contains not only "dephlogisticated air" and "phlogisticated air" (N_2), but also another "air" amounting to about ^ of the total. This work led Lord Rayleigh to the discovery of argon a century later. Cavendish also showed that ordinary air has a constant composition.

Cavendish was interested in many areas of physics also. He published a paper on electricity, and showed that the effects of the torpedo (a Mediterranean fish) on the human body are electrical in nature. He determined the melting point of mercury and derived an extremely accurate value for the average density of the earth.

Henry Cavendish

(1731-1812)

Svante Arrhenius was born in Wijk, Sweden, in 1859. His father was employed by the University of Upsala, and the family moved to Upsala in 1860. In 1876, Arrhenius entered the University of Upsala to study mathematics, chemistry, and physics. He was not satisified with the instruction he was receiving in physics, so he went to Stockholm to study at the Academy of Sciences.

While in Stockholm, Arrhenius tried to gain an understanding of what occurs in a solution when an electric current is passed through it. From the results of his experiments, Arrhenius decided that electrolytes become split into positive and negative ions when they dissolve in water. He recorded his theory of ionization in the doctoral thesis which he submitted to the University of Upsala. The science faculty at Upsala were not impressed with his theory, and he was just barely awarded his doctorate.

Arrhenius believed in the theory of ionization, and he eventually gained the support of Ostwald and van't Hoff, two respected scientists. The Battle of the Ions began. Ostwald led the army of lonians; his lieutenants were Arrhenius and van't Hoff. Their opponents included Lord Kelvin. The enemies of the lonians were able to postpone temporarily the appointment of Arrhenius as professor at the University of Stockholm.

The lonians were eventually victorious, and Arrhenius was appointed professor and two years later president of the University of Stockholm. In 1903, Arrhenius was awarded the Nobel Prize in Chemistry. In 1905, the King of Sweden formed the Nobel Institute for Physical Research at Stockholm, and Arrhenius was made director. The stormy period of his career had ended. He had progressed from being a scientific outcast to being a scientific

Svante August Arrhenius

(1859-1927)

oracle

Johannes van der Waals was born in Leyden, the Netherlands in 1837. After he finished his elementary education in Leyden, he became a schoolteacher. Because he had no knowledge of the classical languages, he was not allowed to take examinations in order to graduate from university. However, he continued to study physics and mathematics at Leyden University in his spare time.

Eventually, university science students were exempted from the requirement of having a classical education, and in 1873, van der Waals wrote the thesis which gained him a doctorate from Leyden University. This thesis was an outstanding piece of work, which established him at once as a first-rate physicist.

In 1877, van der Waals was made professor of physics in the University of Amsterdam. He had great influence on the development of Dutch physics. For 24 years, he was a driving force behind the Amsterdam Royal Academy of Sciences.

Van der Waals was the first person to state that molecules of the gaseous and the liquid state are identical and exert identical forces. He also realized the importance of considering molecular volumes and intermolecular forces in establishing the relationship between the pressure, volume, and temperature of gases and liquids. These intermolecular forces of attraction are now called van der Waals forces. According to van der Waals, "particles of matter must always show attraction." In 1910, van der Waals was awarded the Nobel Prize in Physics.

Johannes Diderick van der Waals
(1837-1923)

Linus Pauling was born in Portland, Oregon in 1901, the son of a druggist. He entered Oregon State College in 1917 and received his B.Sc. in chemical engineering in 1922. He was appointed a Teaching Fellow in Chemistry in the California Institute of Technology while a student there from 1922 to 1925. In 1925 he received his doctorate *(summa cum laude)* in chemistry, with minors in physics and mathematics.

Pauling's approach to research was marked by intuition and intelligent guesses. In 1922, he began the experimental determination of the structures of certain crystals and also started theoretical work on the nature of the chemical bond. He was one of the first persons to use quantum mechanics to explain the chemical bond. His work also included the areas of molecular structure determination, hydrogen bonding, metallic bonding, electronegativity, and the structure of proteins. He attempted to explain the chemical nature of sickle cell anemia and general anesthesia. Pauling is well known for his theory that large doses of Vitamin C can prevent or lessen the severity of the common cold.

He has published many books and articles. In 1931, he became the first recipient of the American Chemical Society Award in Pure Chemistry. He was awarded the 1954 Nobel Prize in Chemistry for his research into the nature of the chemical bond and the application of his bonding theory to the structural determination of complex substances. Pauling was awarded the Nobel Peace Prize in 1963 for his efforts on behalf of a nuclear test ban treaty. He became at that time only the second person to win the Nobel Prize twice. (Marie Curie was the first.) In 1981, he was still active in research.

Linus Pauling (1901)

Gilbert Lewis was born in West Newton, Massachusetts, in 1875, the son of a lawyer. He received his early education at home from his parents. He was able to read at the age of three and attended university preparatory school in Nebraska in 1889. He later went to the University of Nebraska and after two years transferred to Harvard University. In 1899, he obtained his doctorate, doing research into electrochemistry. After studying in Germany, he returned to teach at Harvard and then at the Massachusetts Institute of Technology. His early research was in the area of thermodynamics.

In 1912, Lewis became dean and chairman of the College of Chemistry at the University of California at Berkeley. There he recruited many people who would later make great contributions to chemistry and to chemical education. Lewis' work in chemical education set the standard for other chemists to follow and is one of his greatest achievements.

In 1916, he proposed a theory of chemical bonding in which electron pairs were shared between atoms. An octet of valence electrons resulted in stability for an atom.

In 1918, Lewis became a major in the Chemical Warfare Service in France. He was later decorated for his war efforts. Lewis went on to work in the areas of acid-base theory, heavy water, and photochemistry. He died in 1946 in Berkeley, California.

Gilbert Newton Lewis

(1875-1946)

Niels Bohr was born in Copenhagen, Denmark in 1885, the son of a university professor. He was the second of three children in a wealthy family. He was given much encouragement at home and grew up in a social and intellectual environment. Bohr showed his skill as an investigator while a student at the University of Copenhagen, where he won a gold medal from the Academy of Sciences for his precise measurement of the surface tension of water. He received his doctorate in 1911 for his electron theory of metals.

For a time he worked with Rutherford at Manchester. As a result of this contact with Rutherford, Bohr laid the foundations for the quantum theory of the atom in 1913 and 1914. His work on the structure of the atom won him the Nobel Prize in Physics in 1922.

Bohr visited the United States in 1939 and brought with him the news that Hahn and Strassman in Germany had been able to split the uranium atom. This prompted the Americans to increase their own research efforts in the same direction. Bohr returned to Denmark in 1940. Three years later, he was forced to leave Denmark in order to escape Nazi occupation. He fled to Sweden, then to England, and finally went to the United States. There he acted as an adviser to the physicists working on the development of the atomic bomb. However, he did not work directly on the bomb, and he was opposed to its use. After the war, he returned to Denmark. In 1950, he wrote an open letter making a plea for world peace to the United Nations. He spent most of the rest of his life working as a director of the Institute for Theoretical Physics in Denmark. He died in Copenhagen in 1962 at the age of 77.

Niels Bohr

(1885-1962)

Ernest Rutherford was born in New Zealand, the fourth in a family of twelve children.

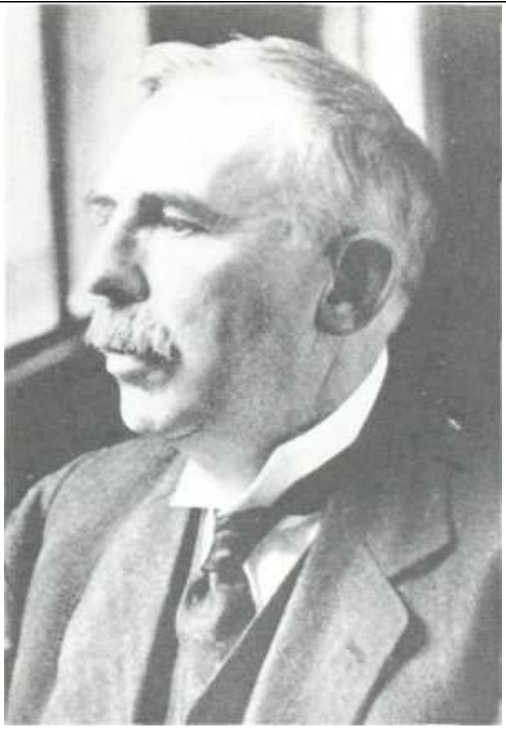
After graduating in mathematics and physics from the University of New Zealand, Rutherford was the first research student to join J.J. Thomson at Cambridge University. One of his research projects at Cambridge involved ingenious methods for measuring the velocities of ions. Rutherford once said: "Ions are jolly little beggars, you can almost see them!"

From 1898 to 1907 Rutherford was professor of physics at McGill University in Montreal, where he worked on radioactivity. In 1903, he published important results on the nature and properties of alpha particles which led him to believe that they are helium ions.

Rutherford became a professor of physics at the University of Manchester in 1907. It was there that he proved that alpha particles are helium ions. However, Rutherford's greatest contribution to atomic theory came in 1911, when he proposed the nuclear model for the atom.

Rutherford spent the years from 1919 until he died in 1937 at Cambridge University. In 1919, he became the first person to change one element into another, when he bombarded nitrogen with alpha particles to produce oxygen atoms. Changing elements into other elements was the crowning achievement of his life's work and held for Rutherford a deep fascination.

Rutherford was awarded the Nobel Prize in Chemistry in 1908, and he was knighted in 1914. In 1931, he was made Baron Rutherford of Nelson and took his seat in the House of Lords. Sir James Jeans said, "Rutherford was ever the happy warrior—happy in his work, happy in its outcome,



Ernest Rutherford

(1871-1937)

and happy in its human contacts." Rutherford had great energy, intense enthusiasm, and an immense capacity for work. A writer once said to him, "You are a lucky man, Rutherford, always on the crest of the wave." Rutherford laughingly replied, "Well! I made the wave, didn't I?"	
Antoine Lavoisier was born in Paris, where he studied mathematics and the physical sciences. He was so productive that at the age of 23 he received a gold medal from the Academy of Sciences for his work on the problems of lighting a large town. Two years later he was admitted to the Academy. Lavoisier became a member of the Ferme Generate, a hated financial company which was allowed to collect taxes on the condition that it pay an annual fee to the state. Lavoisier received a large income which enabled him to equip his lab fully. Lavoisier was always interested in some great or far-reaching principle, not in isolated facts. Furthermore, his experiments were usually quantitative— he preferred to weigh and measure. By careful measurements of the masses involved during the reactions of metals and nonmetals with air, he concluded that combustion involves the combination of a substance with oxygen. Lavoisier was a pioneer in the analysis of organic compounds—he burned the compounds and determined the masses of their products to calculate their percentage composition. He also wrote the first modern textbook on chemistry. In 1793, the French revolution was sweeping the country. All members of the Ferme Generate were arrested and tried. Lavoisier was denounced by a chemist named Fourcroy as a counterrevolutionary, sentenced to death, and	 Antoine Laurent Lavoisier (1743-1794)

executed by guillotine in 1794.

Humphrey Davy was born in Cornwall, England, the eldest of eight children. He did badly at school, mainly because of his love of sport. At age 16 he started assisting a local physician with the preparation of remedies, but his taste for startling experiments and explosions quickly got him fired.

At 19, he began his study of chemistry, using materials and apparatus at hand. He made such progress that he was placed in charge of patients at the Pneumatic institution, which had been established to study the medical effects of the gases discovered in the previous twenty years. He inhaled many gases such as N_2O, CH_4, CO_2, N_2, H_2, and NO. Somehow, he managed to survive.

He prepared N_2O in large quantities by heating NH_4NO_3. Sniffing N_2O became a fad, and Davy's resulting popularity led to his appointment at the age of 22 as an assistant lecturer at the Royal Philosophical Institution of London. Here he prepared a treatise on agricultural science which was the authority for the next 50 years.

He began studies on electrolysis, and quickly isolated for the first time the elements K, Na, Ba, Sr, Ca, and Mg. He discovered H_2Te and PH,,and proved that Ci_2 and l_2 were elements. He invented the safety lamp for miners. He also discovered that he could protect the copper sheathing of naval vessels from corrosion by attaching to it a more reactive metal. At the age of 34 he was knighted and six years later he was made a baronet. At age 42 he became President of the Royal Society.

His health began to decline in 1826, and in 1829 at the age of 51 he died, one of the most

Humphrey Davy

(1778-1829)

remarkable men of his time.

Dmitri Mendeleev was the fourteenth and youngest child of a Siberian teacher. He studied at a teacher's training college in St. Petersburg and at the University of St. Petersburg. After he obtained his doctorate in chemistry, he became Professor of General Chemistry in the University of St. Petersburg in 1866.

Mendeleev is best known for his work on the periodic law. He treated the periodic law not only as a system for classifying the elements according to their properties, but as a "law of nature" which could be used to predict new facts. He presented his periodic law in 1869, and two years later gaps in his tables led him to predict the existence of three new elements. He called them eka-boron, eka-aluminum, and eka-silicon, and he predicted their properties. Within 15 years he was proven correct by the discovery of gallium in 1871, scandium in 1879, and germanium in 1886.

Mendeleev was one of the greatest teachers of his day. His lecture room was always crowded with students. His students thought of him as a comrade, and on more than one occasion he supported students in their disputes with the university administration.

Mendeleev had strong views about the Russian education system. He believed that education should not be based on a study of the classics. He wrote, "We could live at the present day without a Plato, but a double number of Newtons is required to discover the secrets of nature, and to bring life into harmony with the laws of nature."

Dmitri Mendeleev
(1834-1907)

In 1890, because of a dispute with the university administration, Mendeleev resigned his professorship at St. Petersburg. A probable cause of this resignation was his outspoken criticism of the classical system of education which irritated officials in the Ministry of Education. However, in 1893 he was appointed Director of the Bureau of Weights and Measures, and he retained this position until his death in 1907.

Marie Sklodowska was born in Poland. She dreamed of a career in science, and at the age of 24 she moved to Paris to study and teach. After graduating from the Sorbonne, she met Pierre Curie in the Municipal School of Physics and Chemistry and worked beside him in the laboratory. They were married in 1895.

In 1896 Becquerel found that pitchblende, a uranium ore, darkened a photographic plate more than could be accounted for by the amount of uranium present. He asked Madame Curie, a trained and gifted experimenter, to undertake the search for the element responsible.

The Curies boiled and cooked a ton of the ore, filtered and separated impurity after impurity. When the poison fumes threatened to stifle them under the leaky roof of their improvised lab, Mme. Curie herself moved large vats of liquid to the adjoining yard. For hours at a time she stood beside the boiling pots stirring the thick liquids with a great iron rod. That bitter winter of 1896 Mme. Curie caught pneumonia. It was three months before she could return to work. Later, she became pregnant, but even then she continued working. During the later stages of their work,

Marie Sklodowska Curie

(1867-1934)

both the Curies were continually ill. Finally, after two years, they had a small quantity of material about 300 times as potent as uranium. From this, Mme. Curie isolated a new element which she named polonium in honour of her native land, Poland.

Mme. Curie kept working with the residues, which seemed to be even more radioactive than polonium. After a long series of fractional crystallizations, she isolated a very small amount of a radium salt.

Mme. Curie studied every property of this strange new element. After five more years of research, she presented her thesis in 1902. Her examining committee unanimously agreed that it was the greatest single contribution of any doctors thesis in the history of science. The Curies became world-famous and, along with Becquerel, were awarded the Nobel prize.

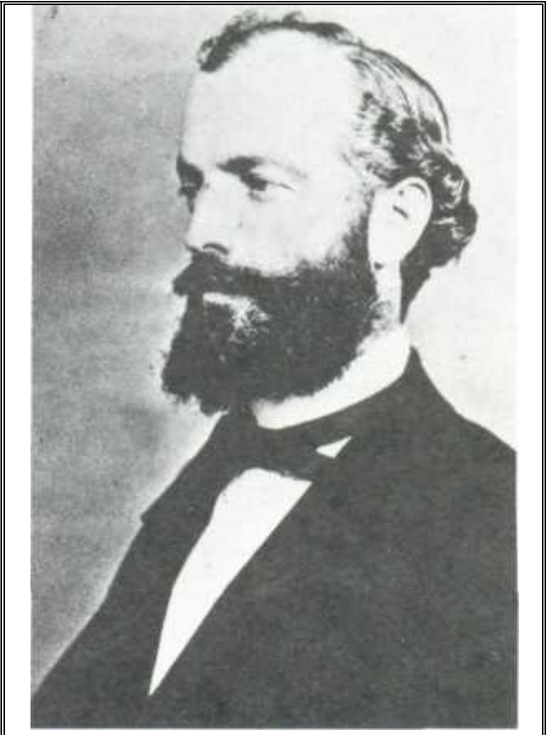
In 1906, Pierre Curie was killed in a traffic accident. Marie Curie was asked to accept the chair in physics he had held at the Sorbonne, where no woman had ever held a professorship. She also retained the professorship at the normal school in Sevres which she had held since 1900. Mme. Curie continued to work with radium. Finally, in 1910, she isolated pure radium by electrolysis of radium chloride. For this she was awarded a second Nobel prize in 1911. She was the first person to win the Nobel Prize twice.

Kekule was born in 1829 at Darmstadt, Germany. He studied architecture at the University of Giessen. However, the lectures of Justus von Liebig won him over to chemistry. He obtained his doctorate in 1852. Following study in Paris and London, Kekule returned to Germany in 1856 and became a lecturer at the University of Heidelberg. In 1858, he became a full professor of pure chemistry at the Belgian State University of Ghent. In 1867, he became a professor of chemistry at Bonn. He held that post until his death in 1896.

Kekule made important contributions to chemical theory, especially with regard to the structures of carbon compounds. He published a famous paper in which he stated that carbon is tetravalent. In another paper, he explained the large number of carbon compounds in terms of the ease with which carbon atoms bond to one another to form chains.

In 1865, as the result of a dream concerning benzene, Kekule made "the most brilliant prediction to be found in the whole of organic chemistry." He had dozed off while writing his textbook. In his strange dream, chains of carbon atoms appeared as snakes. "And look, what was that? One snake grabbed its own tail, and mockingly the shape whirled before my eyes." He had hit upon the idea of assuming that the six carbon atoms of benzene were arranged in a ring. In this way, he opened up the field of aromatic chemistry.

Kekule was a great promoter of chemistry. He was a good lecturer, combining the abilities of a great researcher with those of an impressive speaker. In order to help his students understand his theories of chains and rings of carbon atoms, Kekule invented atomic models. These consisted of



August Kekule

(1829-1896)

coloured wooden spheres which could be attached to one another. Similar models are still used in classrooms today.

Alfred Nobel was born in Stockholm, Sweden, in 1833. His father was a builder, industrialist, and inventor. Nobel attended school in Stockholm from 1841 to 1842. When his family moved to St. Petersburg in Russia, he was given private instruction by Russian and Swedish tutors from 1843 to 1850. He then made a two year trip to study chemistry in Italy, France, Germany, and North America. Nobel became interested in the explosive nitroglycerine, and in 1863 he made his first important invention, a detonator for nitroglycerine. In 1865, he set up the world's first nitroglycerine factory. Because of the large number of accidents involving the explosive he experimented with ways of reducing the danger of handling it. He found that it could be adsorbed on (mixed with) a powder called kieselguhr, which is made up of the remains of marine organisms called diatoms. Mixing nitroglycerine with kieselguhr made the explosive harder to detonate and enabled it to be transported much more safely. This mixture is called dynamite. Nobel went on to invent other types of explosives. He also did work in the areas of optics, electrochemistry, biology, and physiology. He held over 350 patents throughout the world. As a result of his many inventions and factories, he became quite wealthy. Nobel died in 1896 in Italy, leaving his whole fortune of millions of dollars to be used to establish the Nobel Prizes in literature, science, and international understanding.

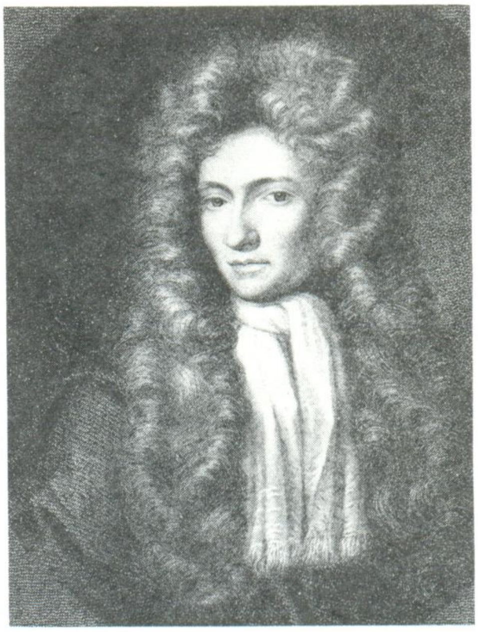
Alfred Nobel
(1833-1896)

Robert Boyle was the seventh son and fourteenth child of fifteen born to the Earl of Cork. He was sent to Eton at age 8 and to Geneva three years later for completion of his studies. He returned to England in 1644 to reside in Dorset. Here he was admitted to the *invisible college,* the forerunner of the Royal Institution. In the same year he moved to Oxford, where young Robert Hooke assisted him in his investigation of "The Spring of the Air."

By 1659 he had constructed a new and superior air pump, which he used to prove that air pressure supports the column of a mercury barometer and to demonstrate the connection between pressure and the boiling point of water. Criticism led him to conduct further experiments, which resulted in the publication of his famous law two years later.

In addition to the formulation of his Law, Boyle taught the value of experimentation. In his book *The Sceptical Chymist*, he examined the pretensions of the chemists of his time and exposed the mixture of error and imposture in most of their writings. He was the first to use the term "chemical analysis" in its modern sense. He showed that not only fire is to be used in the analysis of compounds, but other substances may also be necessary. He laid the foundations of modern analytical chemistry.

In 1669, Boyle moved to London and lived as an invalid, the victim of a lifelong kidney disorder which led to his death in 1691.



Robert Boyle
(1627-1691)

ПЕРІОДИЧНА СИСТЕМА ХІМІЧНИХ ЕЛЕМЕНТІВ Д.І. МЕНДЕЛЄЄВА

Період	Ряд	Група									
		A I B	A II B	A III B	A IV B	A V B	A VI B	A VII B	A	VIII	B
1	1	H 1 Гідроген χ = 2,20 Ar = 1,0079						(H)	He 2 Гелій χ = 4,5 Ar = 4,0026	Символ елемента Порядковий номер Назва елемента Електронегативність елемента за Полінгом Відносна атомна маса елемента	Ca 20 Кальцій χ = 1,00 Ar = 40,078
2	2	Li 3 Літій χ = 0,98 Ar = 6,941	Be 4 Берилій χ = 1,57 Ar = 9,012	B 5 Бор χ = 2,04 Ar = 10,811	C 6 Карбон χ = 2,55 Ar = 12,011	N 7 Нітроген χ = 3,04 Ar = 14,007	O 8 Оксиген χ = 3,44 Ar = 15,999	F 9 Флуор χ = 3,98 Ar = 18,998	Ne 10 Неон χ = 4,4 Ar = 20,18		
3	3	Na 11 Натрій χ = 0,93 Ar = 22,99	Mg 12 Магній χ = 1,31 Ar = 24,305	Al 13 Алюміній χ = 1,61 Ar = 26,982	Si 14 Силіцій χ = 1,90 Ar = 28,086	P 15 Фосфор χ = 2,19 Ar = 30,974	S 16 Сульфур χ = 2,58 Ar = 32,065	Cl 17 Хлор χ = 3,16 Ar = 35,453	Ar 18 Аргон χ = 4,3 Ar = 39,948		
4	4	K 19 Калій χ = 0,82 Ar = 39,098	Ca 20 Кальцій χ = 1,00 Ar = 40,078	21 Sc Скандій χ = 1,36 Ar = 44,956	22 Ti Титан χ = 1,54 Ar = 47,867	23 V Ванадій χ = 1,63 Ar = 50,942	24 Cr Хром χ = 1,66 Ar = 51,996	25 Mn Манган χ = 1,55 Ar = 54,938	26 Fe Ферум χ = 1,83 Ar = 55,845	27 Co Кобальт χ = 1,88 Ar = 58,933	28 Ni Нікель χ = 1,91 Ar = 58,693
	5	29 Cu Купрум χ = 1,90 Ar = 63,546	30 Zn Цинк χ = 1,65 Ar = 65,409	Ga 31 Галій χ = 1,81 Ar = 69,723	Ge 32 Германій χ = 2,01 Ar = 72,64	As 33 Арсен χ = 2,18 Ar = 74,922	Se 34 Селен χ = 2,55 Ar = 78,96	Br 35 Бром χ = 2,96 Ar = 79,904	Kr 36 Криптон χ = 3,00 Ar = 83,798	🟪 — *s - елементи* 🟨 — *p - елементи*	
5	6	Rb 37 Рубідій χ = 0,82 Ar = 85,468	Sr 38 Стронцій χ = 0,95 Ar = 87,62	39 Y Ітрій χ = 1,22 Ar = 88,906	40 Zr Цирконій χ = 1,33 Ar = 91,224	41 Nb Ніобій χ = 1,6 Ar = 92,906	42 Mo Молібден χ = 2,16 Ar = 95,94	43 Tc Технецій χ = 1,9 Ar = [98,906]	44 Ru Рутеній χ = 2,2 Ar = 101,07	45 Rh Родій χ = 2,28 Ar = 102,906	46 Pd Паладій χ = 2,20 Ar = 106,42
	7	47 Ag Аргентум χ = 1,93 Ar = 107,868	48 Cd Кадмій χ = 1,69 Ar = 112,411	In 49 Індій χ = 1,78 Ar = 114,818	Sn 50 Станум χ = 1,96 Ar = 118,71	Sb 51 Стибій χ = 2,05 Ar = 121,76	Te 52 Телур χ = 2,1 Ar = 127,60	I 53 Йод χ = 2,66 Ar = 126,904	Xe 54 Ксенон χ = 2,60 Ar = 131,293	🟦 — *d - елементи* 🟩 — *f - елементи*	
6	8	Cs 55 Цезій χ = 0,79 Ar = 132,905	Ba 56 Барій χ = 0,89 Ar = 137,327	57 La* Лантан χ = 1,1 Ar = 138,905	72 Hf Гафній χ = 1,3 Ar = 178,49	73 Ta Тантал χ = 1,5 Ar = 180,948	74 W Вольфрам χ = 2,36 Ar = 183,84	75 Re Реній χ = 1,9 Ar = 186,207	76 Os Осмій χ = 2,2 Ar = 190,23	77 Ir Іридій χ = 2,20 Ar = 192,217	78 Pt Платина χ = 2,28 Ar = 195,084
	9	79 Au Аурум χ = 2,54 Ar = 196,967	80 Hg Меркурій χ = 2,00 Ar = 200,59	Tl 81 Талій χ = 1,62 Ar = 204,383	Pb 82 Плюмбум χ = 2,33 Ar = 207,2	Bi 83 Бісмут χ = 2,02 Ar = 208,98	Po 84 Полоній χ = 2,0 Ar = [208,98]	At 85 Астат χ = 2,2 Ar = [209,98]	Rn 86 Радон χ = 2,2 Ar = [222,02]		
7	10	Fr 87 Францій χ = 0,7 Ar = [223,02]	Ra 88 Радій χ = 0,9 Ar = [226,03]	89 Ac** Актиній χ = 1,1 Ar = [227,03]	104 Rf Резерфордій Ar = [261,1087]	105 Db Дубній Ar = [262,1138]	106 Sg Сиборгій Ar = [263,1182]	107 Bh Борій Ar = [262,1229]	108 Hs Гасій Ar = [265]	109 Mt Майтнерій Ar = [266]	110 Ds Дармштадтій Ar = [269]
	11	111 Rg Рентгеній Ar = [272]	112 Cn Коперницій Ar = [285]	Uut 113 Унунтрій Ar = [284]	Uuq 114 Унунквадій Ar = [289]	Uup 115 Унунпентій Ar = [288]	Uuh 116 Унунгексій Ar = [292]	Uus 117 Унунсептій Ar = [295]	Uuo 118 Унуноктій Ar = [294]		
Вищі оксиди		R_2O	RO	R_2O_3	RO_2	R_2O_5	RO_3	R_2O_7	RO_4		
Леткі сполуки з гідрогеном					RH_4	RH_3	H_2R	HR			

*Лантаноїди

58 Ce Церій χ = 1,12 Ar = 140,12	59 Pr Празеодим χ = 1,3 Ar = 140,91	60 Nd Неодим χ = 1,14 Ar = 144,24	61 Pm Прометій χ = 1,13 Ar = [146,9]	62 Sm Самарій χ = 1.17 Ar = 150,36	63 Eu Європій χ = 1,2 Ar = 151,96	64 Gd Гадоліній χ = 1,2 Ar = 157,25	65 Tb Тербій χ = 1,1 Ar = 158,93	66 Dy Диспрозій χ = 1,22 Ar = 162,50	67 Ho Гольмій χ = 1,23 Ar = 164,93	68 Er Ербій χ = 1,24 Ar = 167,26	69 Tm Тулій χ = 1,25 Ar = 168,93	70 Yb Ітербій χ = 1,1 Ar = 173,04	71 Lu Лютецій χ = 1,27 Ar = 174,97

**Актиноїди

90 Th Торій χ = 1,3 Ar = 232,04	91 Pa Протактиній χ = 1,5 Ar = 231,04	92 U Уран χ = 1,38 Ar = 238,03	93 Np Нептуній χ = 1,36 Ar = [237,05]	94 Pu Плутоній χ = 1,28 Ar = [244,06]	95 Am Америцій χ = 1,13 Ar = [243,06]	96 Cm Кюрій χ = 1,28 Ar = [247,07]	97 Bk Берклій χ = 1,3 Ar = [247,07]	98 Cf Каліфорній χ = 1,3 Ar = [251,08]	99 Es Ейнштейній χ = 1,3 Ar = [252,08]	100 Fm Фермій χ = 1,3 Ar = [257,1]	101 Md Менделєвій χ = 1,3 Ar = [258,1]	102 No Нобелій χ = 1,3 Ar = [259,1]	103 Lr Лоуренсій χ = 1,3 Ar = [260,11]

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