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BEGINNING CHEMISTRY

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Chapter 1
BASIC CONCEPTS

IN THIS CHAPTER:

- ✔ *The Elements*
- ✔ *Matter and Energy*
- ✔ *Properties*
- ✔ *Classification of Matter*
- ✔ *Representation of Elements*
- ✔ *Laws, Hypotheses, and Theories*
- ✔ *Solved Problems*

The Elements

Chemistry is the study of matter and energy and the interaction between them. The **elements** are the building blocks of all types of matter in the universe. An element cannot be broken down into simpler substances by ordinary means. A few more than 100 elements and the many combinations of these elements account for all the materials of the world.

The elements occur in widely varying quantities on earth. The 10 most abundant elements make up 98 percent of the mass of the crust of the earth. Many elements occur only in traces, and a few elements are synthetic. The elements are not distributed uniformly throughout the earth. The distinct properties of the different elements cause them to be concentrated more or less, making them available as raw materials.

Matter and Energy

Chemistry is the study of matter, including its composition, its properties, its structure, the changes which it undergoes, and the laws governing those changes. **Matter** is anything that has mass and occupies space. Any material object, no matter how large or small, is composed of matter. In contrast, light, heat, and sound are forms of energy. **Energy** is the ability to produce change. Whenever a change of any kind occurs, energy is involved; and whenever any form of energy is changed to another form, it is evidence that a change of some kind is occurring or has occurred.

The concept of mass is central to the discussion of energy. The **mass** of an object depends on the quantity of matter in the object. The more mass an object has, the more it weighs, the harder it is to set in motion, and the harder it is to change the object's velocity once it is in motion.

Matter and energy are now known to be interconvertible. The quantity of energy producible from a quantity of matter, or vice versa, is given by Einstein's famous equation

$$E = mc^2$$

where E is the energy, m is the mass of the matter which is converted to energy, and c^2 is a constant—the square of the velocity of light. The constant c^2 is so large,

$$90{,}000{,}000{,}000{,}000{,}000 \text{ m}^2/\text{s}^2 \text{ or } 34{,}600{,}000{,}000 \text{ mi}^2/\text{s}^2$$

that tremendous quantities of energy are associated with conversions of minute quantities of matter to energy. The quantity of mass accounted for by the energy contained in a material object is so small that it is not measurable. Hence, the mass of an object is very nearly identical to the quantity of matter in the object. Particles of energy have very small masses despite having no matter whatsoever; that is, all the mass of a particle of light is associated with its energy.

The mass of an object is directly associated with its weight. The **weight** of a body is the pull on the body by the nearest celestial body. On earth, the weight of a body is the pull of the earth on the body, but on the moon, the weight corresponds to the pull of the moon on the body. The weight of a body is directly proportional to its mass and also depends on the distance of the body from the center of the earth or moon or whatever celestial body the object is near. In contrast, the mass of an object is independent of its position. For example, at any given location on the surface of the earth, the weight of an object is directly proportional to its mass.

You Need to Know ✓

The relationships between:
matter, mass, energy, and weight

Since the study of chemistry is concerned with the changes that matter undergoes, chemistry is also concerned with energy. Energy occurs in many forms—heat, light, sound, chemical energy, mechanical energy, electrical energy, and nuclear energy. In general, it is possible to convert each of these forms of energy to others. Except for reactions in which the quantity of matter is changed, as in nuclear reactions, the **law of conservation of energy** is obeyed. In fact, many chemical reactions are carried out for the sole purpose of producing energy in a desired form. For example, in the burning of fuels in homes, chemical energy is converted to heat; in the burning of fuels in automobiles, chemical energy is converted to mechanical energy of motion.

☆ Note!

The Law of Conservation of Energy:

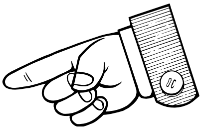
Energy can neither be created nor destroyed (in the absence of nuclear reactions).

Properties

Every substance has certain characteristics that distinguish it from other substances and that may be used to establish that two specimens of the same substance are indeed the same. Those characteristics that serve to distinguish and identify a specimen of matter are called the **properties** of the substance. The properties related to the **state** (gas, liquid, or solid) or appearance of a sample are called **physical properties**. Some commonly known physical properties are **density** (density = mass/volume), state at room temperature, color, hardness, melting point, and boiling point. The physical properties of a sample can usually be determined without changing its composition. Many physical properties can be measured and described in numerical terms, and comparison of such properties is often the best way to distinguish one substance from another.

A chemical reaction is a change in which at least one substance changes its composition and its set of properties. The characteristic ways in which a substance undergoes chemical reaction, or fails to undergo chemical reaction are called its **chemical properties**. Examples of chemical properties are flammability, rust resistance, reactivity, and biodegradability.

Classification of Matter



To study the vast variety of materials that exist in the universe, the study must be made in a systematic manner. Therefore, matter is classified according to several different schemes. Matter may be classified as organic or inorganic. It is **organic** if it is a compound of carbon and hydrogen (see Chapter 14). Otherwise, it is **inorganic**. Another such scheme uses the composition of matter as a basis for classification; other schemes are based on chemical properties of the various classes. For examples, substances may be classified as acids, bases, or salts. Each scheme is useful, allowing the study of a vast variety of materials in terms of a given class.

In the method of classification of matter based on composition, a given specimen of material is regarded as either a pure substance or a mixture. The term **pure substance** refers to a material all parts of which have the same composition and that has a definite and unique set of properties.

In contrast, a **mixture** consists of two or more substances and has a somewhat arbitrary composition. The properties of a mixture are not unique, but depend on its composition. The properties of a mixture tend to reflect the properties of the substances of which it is composed; that is, if the composition is changed a little, the properties will change a little.

There are two kinds of substances—elements and compounds. **Elements** are substances that cannot be broken down into simpler substances by ordinary chemical means. Elements cannot be made by the combination of simpler substances. There are slightly more than 100 elements, and every material object in the universe consists of one or more of these elements.

Remember

Familiar substances that are elements include carbon, aluminum, iron, copper, gold, oxygen, and hydrogen.

Compounds are substances consisting of two or more elements combined in definite proportions by mass to give a material having a definite set of properties different from that of any of its constituent elements. For example, the compound water consists of 88.8 percent oxygen and 11.2 percent hydrogen by mass. The physical and chemical properties of water are distinctly different from those of both hydrogen and oxygen. For example, water is a liquid at room temperature and pressure, while the elements of which it is composed are gases under these same conditions. Chemically, water does not burn; hydrogen may burn explosively in oxygen (or air). Any sample of pure water, regardless of its source, has the same composition and the same properties.

There are millions of known compounds, and thousands of new ones are discovered or synthesized each year. Despite such a vast number of compounds, it is possible for the chemist to know certain properties of each one, because compounds can be classified according to their composition and structure, and groups of compounds in each class have some properties in common. For example, organic compounds are generally combustible in oxygen, yielding carbon dioxide and water. So, any compound that contains carbon and hydrogen may be predicted by the chemist to be combustible in oxygen.

There are two kinds of mixtures—homogeneous mixtures and heterogeneous mixtures. **Homogeneous mixtures** are also called **solutions**, and **heterogeneous mixtures** are sometimes called simply mixtures. In heterogeneous mixtures, it is possible to see differences in the sample, merely by looking, although a microscope may be required. In contrast, homogeneous mixtures look the same throughout the sample, even under the best optical microscope.

Representation of Elements

Each element has an internationally accepted symbol to represent it. The periodic table at the back of this book includes both the names and symbols of the elements. Note that symbols for most elements are merely abbreviations of their names, consisting of either one or two letters. Three letter symbols are used for elements over number 103. The first letter of the symbol is always written as a capital letter; the second and third letters, if any, are written as lowercase letters. The symbols of a few elements do not suggest their English names, but are derived from the Latin or German names of the elements.

You Need to Memorize ✓

The names and symbols of the common elements.

A convenient way of displaying the elements is in the form of a **periodic table**, such as is shown at the end of this book. The basis for the arrangement of the elements in the periodic table will be discussed more in Chapter 2.

Laws, Hypotheses, and Theories

A statement that generalizes a quantity of experimentally observable phenomena is called a **scientific law**. For example, if a person drops a pencil, it falls downward. This result is predicted by the law of gravity. A generalization that attempts to explain why certain experimental results occur is called a **hypothesis**. When a hypothesis is accepted as true by the scientific community, it is then called a **theory**. One of the most important scientific laws is the **law of conservation of mass**: During any process (chemical reaction, physical change, or even nuclear reaction) mass is neither created nor destroyed. Because of the close approximation that the mass of an object is the quantity of matter it contains (excluding the mass corresponding to its energy), the law of conservation of mass can be approximated by the **law of conservation of matter**: During an ordinary chemical reaction, matter can be neither created nor destroyed.

You Need to Know ✓

The Law of Conservation of Mass:

During any process, mass is neither created nor destroyed.

The Law of Conservation of Matter:

During an ordinary chemical reaction, matter can neither be created nor destroyed.

Solved Problems

Solved Problem 1.1 TNT is a compound of carbon, nitrogen, hydrogen, and oxygen. Carbon occurs in two forms—graphite (the material in "lead pencils") and diamond. Oxygen and nitrogen comprise over 98 percent of the atmosphere. Hydrogen is an element that reacts explosively with oxygen. Which of the properties of the elements determines the properties of TNT?

Solution: The properties of the elements do not matter. The properties of the compound are quite independent of those of the elements. A compound has its own distinctive set of properties. TNT is most noted for its explosiveness.

Solved Problem 1.2 Name an object or instrument that changes (*a*) electrical energy to light, (*b*) motion to electrical energy, (*c*) chemical energy to heat, and (*d*) chemical energy to electrical energy.

Solution: (*a*) light bulb, (*b*) generator or alternator, (*c*) gas stove, and (*d*) battery.

Solved Problem 1.3 A teaspoon of salt is added to a cup of warm water. White crystals are seen at the bottom of the cup. Is the mixture homogeneous or heterogeneous? Then the mixture is stirred until the salt crystals disappear. Is the mixture now homogeneous or heterogeneous?

Solution: Before stirring, the mixture is heterogeneous; after stirring, the mixture is a solution.

Solved Problem 1.4 Distinguish clearly between (*a*) mass and matter and (*b*) mass and weight.

Solution: (*a*) Matter is any kind of material. The mass of an object depends mainly on the matter which it contains. It is affected only slightly by the energy in it. (*b*) Weight is the attraction of the earth on an object. It depends on the mass of the object and the distance to the center of the earth.

Solved Problem 1.5 Distinguish between a theory and a law.

Solution: A law tells what happens under a given set of circumstances, while a theory attempts to explain why that behavior occurs.

Chapter 2
ATOMS AND ATOMIC MASSES

IN THIS CHAPTER:

- ✔ *Atomic Theory*
- ✔ *Atomic Masses*
- ✔ *Atomic Structure*
- ✔ *Isotopes*
- ✔ *Periodic Table*
- ✔ *Solved Problems*

Atomic Theory

In 1804, John Dalton proposed the existence of atoms. He not only postulated that atoms exist, as had ancient Greek philosophers, but he also attributed certain properties to the atom. His postulates were as follows:

1. Elements are composed of indivisible particles, called **atoms**.
2. All atoms of a given element have the same mass, and the mass of an atom of a given element is different from the mass of an atom of any other element.
3. When elements combine to form compounds, the atoms of one element combine with those of the other element(s) to form **molecules**.
4. Atoms of two or more elements may combine in different ratios to form different compounds.

5. The most common ratio of atoms is 1:1, and where more than one compound of two or more elements exists, the most stable is the one with 1:1 ratio of atoms. (This postulate is incorrect.)

Dalton's postulates stimulated great activity among chemists, who sought to prove or disprove them. The fifth postulate was very quickly shown to be incorrect, and the first three have had to be modified in light of later knowledge. However, the first four postulates were close enough to the truth to lay the foundations for a basic understanding of mass relationships in chemical compounds and chemical reactions.

Dalton's postulates were based on three laws that had been developed shortly before he proposed his theory.

1. The **law of conservation of mass** (see Chapter 1) states that mass is neither created nor destroyed in a chemical reaction.

2. The **law of definite proportions** states that every chemical compound is made up of elements in a definite ratio by mass.

3. The **law of multiple proportions** states that when two or more different compounds are formed from the same elements, the ratio of masses of each element in the compounds for a given mass of any other element is a small whole number.

Dalton argued that these laws are entirely reasonable if the elements are composed of atoms. For example, the reason that mass is neither gained nor lost in a chemical reaction is that the atoms merely change partners with one another; they do not appear or disappear. The definite proportions of compounds stem from the fact that the compounds consist of a definite ratio of atoms, each with a definite mass. The law of multiple proportions is due to the fact that different numbers of atoms of one element can react with a given number of atoms of a second element, and since the atoms must combine in whole-number ratios, the ratio of the masses must also be in whole numbers.

You Need to Know ✓

Dalton's postulates and the laws on which those postulates are based.

Atomic Masses

Once Dalton's hypotheses had been proposed, the next logical step was to determine the relative masses of the atoms of the elements. Since there was no way at the time to determine the mass of an individual atom, the relative masses were the best information available. That is, one could tell that an atom of one element had a mass twice as great as an atom of a different element (or 15/4 as much, or 17.3 times as much, etc.). The relative masses could be determined by taking equal (large) numbers of atoms of two elements and determining the ratio of masses of these collections of atoms.

For example, a large number of carbon atoms have a total mass of 12.0 g, and an equal number of oxygen atoms have a total mass of 16.0 g. Since the number of atoms of each kind is equal, the ratio of the masses of one carbon atom to one oxygen atom is 12.0 to 16.0. One ensures equal numbers of carbon and oxygen atoms by using a compound of carbon and oxygen in which there are equal numbers of the two elements (i.e., carbon monoxide).

A great deal of difficulty was encountered at first, because Dalton's fifth postulate gave an incorrect ratio of numbers of atoms in many cases. Such a large number of incorrect results were obtained that it soon became apparent that the fifth postulate was not correct. It was not until some 50 years later that an experimental method was devised to determine the atomic ratios in compounds, at which time the scale of relative atomic masses was determined in almost the present form. These relative masses are called **atomic masses**, or sometimes **atomic weights**.

The atomic mass of the lightest element, hydrogen, was originally taken to be one **atomic mass unit** (amu). The modern values of the atomic masses are based on the most common kind of carbon atom, called "carbon-12" and written ^{12}C, as the standard. The mass of ^{12}C is measured in the modern **mass spectrometer**, and ^{12}C is defined to have an atomic mass of exactly 12 amu. On this scale, hydrogen has an atomic mass of 1.008 amu.

Remember!

Hydrogen—1.008 amu
Carbon—12 amu

Different names are used for the unit of atomic mass by different authors, and different abbreviations are used for it. The term **Dalton** is used by some, abbreviated D. Other authors use amu. The abbreviation u rather than amu is sometimes encountered.

The atomic mass of an element is the relative mass of an average atom of the element compared with ^{12}C, which has a mass of exactly 12 amu. Thus, since a sulfur atom has a mass 8/3 times that of a carbon atom, the atomic mass of sulfur is

$$12 \text{ amu} \times 8/3 = 32 \text{ amu}$$

The modern values of the atomic masses of the elements are given in the periodic table.

Atomic Structure

From 50 years to 100 years after Dalton proposed his theory, various discoveries showed that the atom is not indivisible, but is really composed of parts. Natural radioactivity and the interaction of electricity of matter are two different types of evidence for this subatomic structure. The most important subatomic particles are listed in Table 2.1, along with their most important properties. The **protons** and **neutrons** occur in a very tiny **nucleus**. The **electrons** occur outside the nucleus.

	Charge (*e*)	Mass (amu)	Location
Proton	+1	1.00728	In nucleus
Neutron	0	1.00894	In nucleus
Electron	−1	0.0005414	Outside nucleus

Table 2.1 Subatomic particles