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Chapter 5

ATOMS AND MOLECULES

As mentioned earlier, Greek philosophy produced two theories on the nature of matter: a theory of fundamental *elements*, and a theory of indivisible *atoms*. Both concepts were eventually incorporated in the scientific theory of matter that evolved during the 1700s and 1800s.

In the Middle Ages, alchemists engaged in occult practices, whose main goals were to transform base metals such as lead and copper into gold and silver, and to discover an elixir of perpetual youth.

Modern chemistry gradually evolved from medieval alchemy and early medicine into a quantitative science. Among its early accomplishments was the distinction between "chemical compounds" and "elements". Most forms of matter are compounds, or mixtures of compounds. In order to find the elements that form a compound, the compound is chemically broken down into its components; these components, in turn, are broken down into their components, and so on, until no further breakdown is possible. The substances that cannot be broken down further are, by definition, "elements".

By this process, in the 19th century, it was established that such substances as hydrogen, oxygen, copper, lead, silver and gold are elements. The present count of chemical elements is somewhat over 100, a relatively small number compared to the very large number of compounds observed in nature.

Dalton's Atomic Theory

On the basis of extensive experimental data, the British chemist and physicist John Dalton (1766-1844) formulated a "*law of definite proportions*". It states that, for any chemical compound, the weights of its ingredients are always in fixed proportions. For instance, when a sample of water is broken down and its two constituents, hydrogen and oxygen, are weighed, their ratio is invariably 2 to 16, in round numbers, regardless of the size of the sample. For carbon monoxide, the ratio of carbon to oxygen is 12 to 16.

To account for this, Dalton proposed an atomic theory of matter, which was published in 1808. He speculated that a sample of any element cannot be subdivided indefinitely into ever smaller pieces, but consists of some very large number of identical indivisible atoms. Atoms of different elements have different weights. Thus, there are as many kinds of atoms as there are elements. The most basic unit of any compound of two or more elements is called a "molecule", in which two or more atoms are bonded together. In a chemical reaction, the atoms remain unchanged but become bonded in different combinations.

If a sample of a compound consists of a very large number of identical molecules, and, within each molecule, the atoms of the elements involved are in some fixed ratio by weight (say, 1 to 8), the same ratio must apply to the sample as a whole, which is what the law of definite proportions states.

Atomic Weights

Eventually, it was determined how many atoms of what elements make up the molecules of the compounds they form. Dalton's law could be used then to determine the *relative* atomic weights of the various elements.

The table below lists a few familiar elements and their *relative* atomic weights, in round numbers. Hydrogen is the lightest of all atoms, followed by helium, which is about 4 times heavier. Note the substantial difference in atomic weights between hydrogen and uranium.

Hydrogen	1
Helium	4
Oxygen	16
Aluminum	27
Iron	56
Silver	108
Gold	197
Uranium	238

The Periodic Table

In 1869, the Russian chemist Dmitry Mendeleyev proposed his "periodic law", whereby the chemical elements show a periodic recurrence of certain physical properties, when they are arranged in the order of increasing atomic weights.

Mendeleyev introduced the first "periodic table", in which the 63 elements then known were arranged in rows and columns, with gaps here and there. An abbreviated version of the current periodic table appears in Table I, which shows the names of most elements and, in some cases, their standard symbols. The current periodic table accounts without gaps for all the elements presently known, including 12 that have been synthetically prepared. The known elements are identified by a sequential number ranging from 1 to 106. (The significance of this number will be explained later.)

Table I
PERIODIC TABLE OF ELEMENTS

1 H hydro-gen								2 He heli-um
3 Li lithium	4 Be berylli um		5 B boron	6 C car-bon	7 N nitro-gen	8 O oxygen	9 F fluo-rine	10 Ne neon
11 Na sodium	12 Mg magn esium		13 Al alumin um	14 Si sili-con	15 P phos-phorus	16 S sul-phur	17 Cl chlo-rine	18 Ar argon
19 K potas-sium	20 Ca calciu m	a	31 Ga galliu m	32 Ge germa nium	33 As arse-nic	34 Se sele-nium	35 Br bro-mine	36 Kr kryp-ton
37 Rb rubi-dium	38 Sr stronti um	b	49 In indi-um	50 Sn tin	51 Sb anti-mony	52 Te tellu-rium	53 I io dine	54 Xe xenon
55 Cs cesium	56 Ba bari-um	c	81 Tl thal-lium	82 Pb lead	83 Bi bis-muth	84 Po polo-nium	85 At asta-tine	86 Rn radon
87 Fr franci-um	88 Ra radi-um	d	113	114	115	116	117	118

a	10 elements (#21 to #30), including chromium (#24), manganese (#25), iron (#26), cobalt (#27), nickel (#28), copper (#29) and zinc (#30)
b	10 elements (#39 to #48), including silver (#47)
c	24 elements (#57 to #80), including platinum (#78), gold (#79), and mercury (#80)
d	18 elements (#89 to #106), including uranium (#92) and plutonium (#94)

The periodic table is an intriguing blueprint of matter. It has 7 rows containing a variable number of elements (2, 8, 8, 18, 18, 32 and 20, for a total of 106). Elements that appear in the same column all display similar properties. For instance, the 6 elements in the last column on the right, helium (#2) to radon (#86), called the "rare gases", are all odorless, tasteless, colorless, nonflammable gases with very limited, if any, tendency to combine with other elements. The periodic recurrence of physical properties of elements remained unexplained until the late 1920's.

Hydrogen, the first element in the periodic table, is by far the most abundant in the universe. By mass, it accounts for about 75% of the visible matter in the universe. Helium, the second element, accounts for about 23%; all the remaining elements together account for a mere 2%.