2.3: The Atomic Theory

The development of the atomic theory owes much to the work of two men: Antoine Lavoisier, who did not himself think of matter in terms of atoms but whose work laid organization groundwork for thinking about elements, and John Dalton, to whom the atomic theory is attributed. Much of Lavoisier’s work as a chemist was devoted to the study of combustion. He became convinced that when a substance is burned in air, it combines with some component of the air. Eventually he realized that this component was the *dephlogisticated air* which had been discovered by Joseph Priestly (1733 to 1804) a few years earlier. Lavoisier renamed this substance *oxygen*. In an important series of experiments he showed that when mercury is heated in oxygen at a moderate temperature, a red substance, *calx of mercury*, is obtained. (A *calx* is the ash left when a substance burns in air.) At a higher temperature this calx decomposes into mercury and oxygen. Lavoisier’s careful experiments also revealed that the combined masses of mercury and oxygen were exactly equal to the mass of calx of mercury. That is, there was no change in mass upon formation or decomposition of the calx. Lavoisier hypothesized that this should be true of all chemical changes, and further experiments showed that he was right. This principle is now called the *law of conservation of mass*.

As Lavoisier continued his experiments with oxygen, he noticed something else. Although oxygen combined with many other substances, it never behaved as though it were itself a combination of other substances. Lavoisier was able to decompose the red calx into mercury and oxygen, but he could find no way to break down oxygen into two or more new substances. Because of this he suggested that oxygen must be an **element**—an ultimately simple substance which could not be decomposed by chemical changes.

> Lavoisier did not originate the idea that certain substances (elements) were fundamental and all others could be derived from them. This had first been proposed in Greece during the fifth century B.C. by Empedocles, who speculated that all matter consisted of combinations of earth, air, fire, and water. These ideas were further developed and taught by Aristotle and remained influential for 2000 years.

Lavoisier did produce the first table of the elements which contained a large number of substances that modern chemists would agree should be classifies as elements. He published it with the knowledge that further research might succeed decomposing some of the substances listed, thus showing them not to be elements. One of his objectives was to prod his contemporaries into just that kind of research. Sure enough the “earth substances” listed at the bottom were eventually shown to be combinations of certain metals with oxygen. It is also interesting to note that not even Lavoisier could entirely escape from Aristotle’s influence. The second element in his list is Aristotle’s “fire,” which Lavoisier called “caloric,” and which we now call “heat.” Both heat and light, the first two items in the table, are now regarded as forms of energy rather than of matter.

Although his table of elements was incomplete, and even incorrect in some instances, Lavoisier’s work represented a major step forward. By classifying certain substances as elements, he stimulated much additional chemical research and brought order and structure to the subject where none had existed before. His contemporaries accepted his ideas very readily, and he became known as the father of chemistry.

John Dalton (1766 to 1844) was a generation younger than Lavoisier and different from him in almost every respect. Dalton came from a working class family and only attended elementary school. Apart from this, he was entirely self-taught. Even after he became famous, he never aspired beyond a modest bachelor’s existence in which he supported himself by teaching mathematics to private pupils. Dalton made many contributions to science, and he seems not to have realized that his atomic theory was the most important of them. In his “New System of Chemical Philosophy” published in 1808, only the last seven pages out of a total of 168 are devoted to it!

The postulates of the atomic theory are given below. The first is no advance on the ancient Greek philosopher Democritus who had theorized almost 2000 years earlier that matter consists of very small particles.

The Postulates of Dalton's Atomic Theory

1. All matter is composed of a very large number of very small particles called atoms.
2. For a given element, all atoms are identical in all respects. In particular all atoms of the same element have the same constant mass, while atoms of different elements have different masses.
3. The atoms are the units of chemical changes. Chemical reactions involve the combination, separation, or rearrangement of atoms, but atoms are neither created, destroyed, divided into parts, or converted into atoms of any other kind.
4. Atoms combine to form molecules in fixed ratios of small whole numbers.

The second postulate, however, shows the mark of an original genius; here Dalton links the idea of *atom* to the idea of *element*. Lavoisier's criterion for an element had been essentially a macroscopic, experimental one. If a substance could not be decomposed chemically, then it was probably an element. By contrast, Dalton defines an element in theoretical, sub-microscopic terms. *An element is an element because all its atoms are the same*. Different elements have different atoms. There are just as many different kinds of elements as there are different kinds of atoms.

Now look back a moment to the physical states of mercury, where sub-microscopic pictures of solid, liquid, and gaseous mercury were given. Applying Dalton's second postulate to this figure, you can immediately conclude that mercury is an element, because only one kind of atom appears. Although mercury atoms are drawn as spheres in the figure, it would be more common today to represent them using chemical symbols. The chemical symbol for an element (or an atom of that element) is a one- or two-letter abbreviation of its name. Usually, but not always, the first two letters are used. To complicate matters further, chemical symbols are sometimes derived from a language other than English. For example the symbol for Hg for mercury comes from the first and seventh letters of the element's Latin name, *hydrargyrum*.

Table 2.3.1: Names, Chemical Symbols, and Atomic Weights of the Element

Name	Symbol	Atomic Number	Atomic Weight	Name	Symbol	Atomic Number	Atomic Weight
Actinium[2]	Ac	89	(227)	Molybdenum	Mo	42	95.96(2)
Aluminum	Al	13	26.981 5386(8)	Neodymium	Nd	60	144.242(3)
Americium[2]	Am	95	(243)	Neon	Ne	10	20.1797(6)
Antimony	Sb	51	121.760(1)	Neptunium[2]	Np	93	(237)
Argon	Ar	18	39.948(1)	Nickel	Ni	28	58.6934(4)
Arsenic	As	33	74.92160(2)	Niobium	Nb	41	92.90638(2)
Astatine[2]	At	85	(210)	Nitrogen	N	7	14.0067(2)
Barium	Ba	56	137.327(7)	Nobelium[2]	No	102	(259)
Berkelium[2]	Bk	97	(247)	Osmium	Os	76	190.23(3)
Beryllium	Be	4	9.012182(3)	Oxygen	O	8	15.9994(3)
Bismuth	Bi	83	208.98040(1)	Palladium	Pd	46	106.42(1)
Bohrium[2]	Bh	107	(272)	Phosphorus	P	15	30.973762(2)
Boron	B	5	10.811(7)	Platinum	Pt	78	195.084(9)
Bromine	Br	35	79.904(1)	Plutonium[2]	Pu	94	(244)
Cadmium	Cd	48	112.411(8)	Polonium[2]	Po	84	(209)
Calcium	Ca	20	40.078(4)	Potassium	K	19	39.0983(1)
Californium[2]	Cf	98	(251)	Praseodymium	Pr	59	140.90765(2)
Carbon	C	6	12.0107(8)	Promethium[2]	Pm	61	(145)
Cerium	Ce	58	140.116(1)	Protactinium[2]	Pa	91	231.03588(2)
Cesium	Cs	55	132.9054519(2)	Radium[2]	Ra	88	(226)
Chlorine	Cl	17	35.453(2)	Radon[2]	Rn	86	(222)
Chromium	Cr	24	51.9961(6)	Rhenium	Re	75	186.207(1)

Name	Symbol	Atomic Number	Atomic Weight	Name	Symbol	Atomic Number	Atomic Weight
Cobalt	Co	27	58.933195(5)	Rhodium	Rh	45	102.90550(2)
Copper	Cu	29	63.546(3)	Roentgenium[2]	Rg	111	(280)
Curium[2]	Cm	96	(247)	Rubidium	Rb	37	85.4678(3)
Darmstadtium[2]	Ds	110	(281)	Ruthenium	Ru	44	101.07(2)
Dubnium[2]	Db	105	(268)	Rutherfordium[2]	Rf	104	(267)
Dysprosium	Dy	66	162.500(1)	Samarium	Sm	62	150.36(2)
Einsteinium[2]	Es	99	(252)	Scandium	Sc	21	44.955912(6)
Erbium	Er	68	167.259(3)	Seaborgium[2]	Sg	106	(271)
Europium	Eu	63	151.964(1)	Selenium	Se	34	78.96(3)
Fermium[2]	Fm	100	(257)	Silicon	Si	14	28.0855(3)
Fluorine	F	9	18.9984032(5)	Silver	Ag	47	107.8682(2)
Francium[2]	Fr	87	(223)	Sodium	Na	11	22.98976928(2)
Gadolinium	Gd	64	157.25(3)	Strontium	Sr	38	87.62(1)
Gallium	Ga	31	69.723(1)	Sulfur	S	16	32.065(5)
Germanium	Ge	32	72.64(1)	Tantalum	Ta	73	180.94788(2)
Gold	Au	79	196.966569(4)	Technetium[2]	Tc	43	(98)
Hafnium	Hf	72	178.49(2)	Tellurium	Te	52	127.60(3)
Hassium[2]	Hs	108	(277)	Terbium	Tb	65	158.92535(2)
Helium	He	2	4.002602(2)	Thallium	Tl	81	204.3833(2)
Holmium	Ho	67	164.93032(2)	Thorium[2]	Th	90	232.03806(2)
Hydrogen	H	1	1.00794(7)	Thulium	Tm	69	168.93421(2)
Indium	In	49	114.818(3)	Tin	Sn	50	118.710(7)
Iodine	I	53	126.90447(3)	Titanium	Ti	22	47.867(1)
Iridium	Ir	49	192.217(3)	Tungsten	W	74	183.84(1)
Iron	Fe	26	55.845(2)	Uranium[2]	U	92	238.02891(3)
Krypton	Kr	36	83.798(2)	Vanadium	V	23	50.9415(1)
Lanthanum	La	57	138.90547(7)	Xenon	Xe	54	131.293(6)
Lawrencium[2]	Lr	103	(262)	Ytterbium	Yb	70	173.054(5)
Lead	Pb	82	207.2(1)	Yttrium	Y	39	88.90585(2)
Lithium	Li	3	[6.941(2)][1]	Zinc	Zn	30	65.38(2)
Lutetium	Lu	71	174.9668(1)	Zirconium	Zr	40	91.224(2)
Magnesium	Mg	12	24.3050(6)	-[2,3,4]		112	(285)

Name	Symbol	Atomic Number	Atomic Weight	Name	Symbol	Atomic Number	Atomic Weight
Manganese	Mn	25	54.938045(5)	-[2,3]		113	(284)
Meitnerium[2]	Mt	109	(276)	-[2,3]		114	(287)
Mendelevium[2]	Md	101	(258)	-[2,3]		115	(288)
Mercury	Hg	80	200.59(2)	-[2,3]		116	(293)
				-[2,3]		118	(294)

The chemical symbols for all the currently known elements are listed above in the table, which also includes atomic weights. These symbols are the basic vocabulary of chemistry because the atoms they represent make up all matter. You will see symbols for the more important elements over and over again, and the sooner you know what element they stand for, the easier it will be for you to learn chemistry. These more important element have been indicated in the above table by colored shading around their names.

Dalton's fourth postulate states that atoms may combine to form molecules. An example of this is provided by bromine, the only element other than mercury which is a liquid at ordinary room temperature (20°C). Macroscopically, bromine consists of dark-colored crystals below –7.2°C and a reddish brown gas above 58.8°C. The liquid is dark red-brown and has a pungent odor similar to the chlorine used in swimming pools. It can cause severe burns on human skin and should not be handled without the protection of rubber gloves.

Three states of Matter

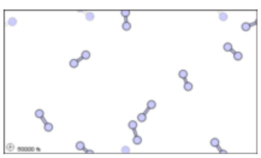
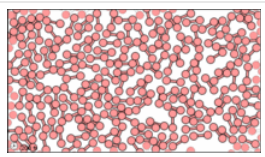
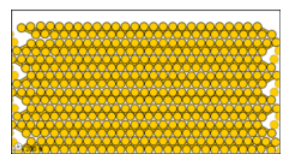
	 Many diatomic spheres are closely packed with gaps between clusters of spheres. The diatomic spheres are moving around and crashing onto one another.	
(a) in the gaseous state	*(b) as a liquid*	*(c) in solid form*

Figure $2.3.1$: Sub-microscopic view of the diatomic molecules of the element bromine (a) in the gaseous state (above 58°C); (b) in liquid form (between -7.2 and 58.8°C); and (c) in solid form (below -7.2°C).

The sub-microscopic view of bromine in the following figure is in agreement with its designation as an element—only one kind of atom is present. Except at very high temperatures, though, bromine atoms always double up. Whether in solid, liquid, or gas, they go around in pairs. Such a tightly held combination of two or more atoms is called a **molecule**.

Figure 2.3.1: Macroscopic view of the diatomic molecules of the element bromine (top) in the gaseous state (above 58°C); (middle) and in liquid form (between -7.2 and 58.8°C); (bottom) bromine atoms are present in the solid compound Silver Bromide (AgBr).

A plastic spoon holds few chunks of brownish yellow solids. This spoon rests beside a cylindrical glassware also containing the chunks of solid. Glassware is labeled A g B r.

The composition of a molecule is indicated by a **chemical formula**. A subscript to the right of the symbol for each element tells how many atoms of that element are in the molecule. For example, the atomic weights table gives the chemical *symbol* Br for bromine, but each molecule contains two bromine atoms, and so the chemical *formula* is Br_2. According to Dalton's fourth postulate, atoms combine in the ratio of small whole numbers, and so the subscripts in a formula should be small whole numbers.
