3.1 Atomic Theory

Chemistry is founded on four fundamental assumptions about atoms and matter, which together make up modern **atomic theory**:

1. All matter is composed of atoms.
2. The atoms of a given element differ from the atoms of all other elements.
3. Chemical compounds consist of atoms combined in specific ratios.
4. Chemical reactions change only the way the atoms are combined in compounds; the atoms themselves are unchanged.

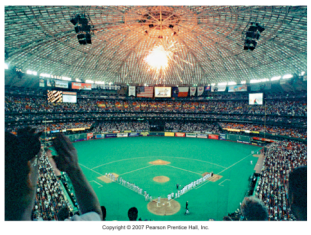
- Atoms are composed of tiny **subatomic particles** called **protons, neutrons,** and **electrons**.
- The masses of atoms and their constituent subatomic particles are very small when measured in grams. Atomic masses are expressed on a relative mass scale. One atom is assigned a mass, and all others are measured relative to it.
- The basis for the relative atomic mass scale is an atom of carbon that contains 6 protons and 6 neutrons. This carbon atom is assigned a mass of exactly 12 atomic mass units (**amu**).

- Both protons and neutrons have a mass close to one amu.
- Electrons are 1836 times lighter than protons and neutrons.
- Protons and electrons have electrical charges that are equal in magnitude but opposite in sign.

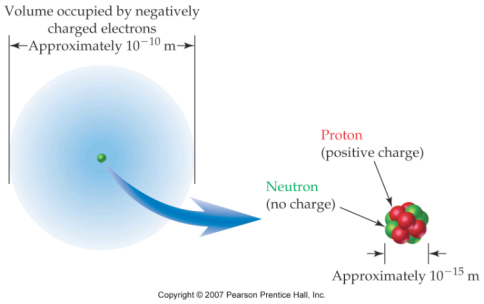
TABLE 3.1 A Comparison of Subatomic Particles

NAME	SYMBOL	MASS (GRAMS)	MASS (AMU)	CHARGE (CHARGE UNITS)
Proton	p	$1.672\,622 \times 10^{-24}$	1.007 276	+1
Neutron	n	$1.674\,927 \times 10^{-24}$	1.008 665	0
Electron	e^-	$9.109\,328 \times 10^{-28}$	$5.485\,799 \times 10^{-4}$	−1

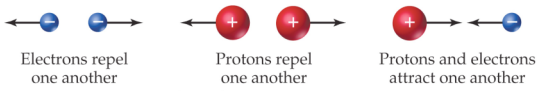
- The protons and neutrons are packed closely together in a dense core called the **nucleus**. Surrounding the nucleus, the electrons move about rapidly through a large volume of space.
- The relative size of a nucleus in an atom is the same as that of a pea in the middle of this stadium.



- Diameter of a nucleus is only about 10^{-15} m.
- Diameter of an atom is only about 10^{-10} m.



- The structure of the atom is determined by interplay of different forces.
- Opposite electrical charges attract each other, like charges repel each other.
- Protons and neutrons in the nucleus are held together by the nuclear strong force.



3.2 Element and Atomic Number

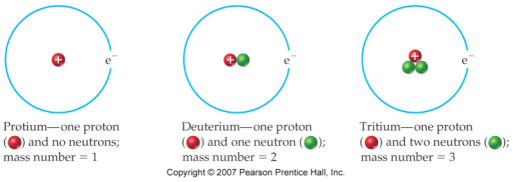
- **Atomic number (Z):** The number of protons in each atom of an element. All atoms of a particular element have the same number of protons in the nucleus.
- Atoms are neutral overall and have no net charge because the number of positively charged protons and the number of negatively charged electrons are the same in each atom.
- **Mass number (A):** The total number of protons and neutrons in an atom.

3.3 Isotopes and Atomic Weight

Isotopes: Atoms with identical atomic numbers (Z) but different mass numbers (A) are called isotopes. Protium, deuterium, and tritium are three isotopes of the element hydrogen.

- H, the most abundant hydrogen isotope, has one proton and no neutrons (Z=1, A=1)
- D, this heavy hydrogen isotope has one proton and one neutron (Z=1, A=2)
- T, this radioactive hydrogen isotope has one proton and two neutrons (Z=1, A=3).

Isotopes of Hydrogen

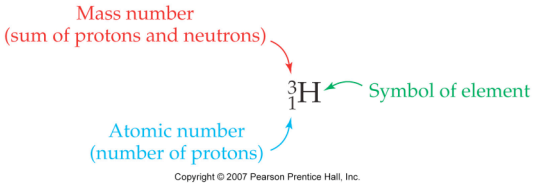


Protium—one proton (●) and no neutrons; mass number = 1

Deuterium—one proton (●) and one neutron (●); mass number = 2

Tritium—one proton (●) and two neutrons (●); mass number = 3

A specific isotope is represented by showing its mass number (A) as a superscript and its atomic number (Z) as a subscript in front of the atomic symbol. For example, the symbol for tritium is:



Atomic weight: The weighted average mass of an element's atoms in a large sample that includes all the naturally occurring isotopes of that atom.

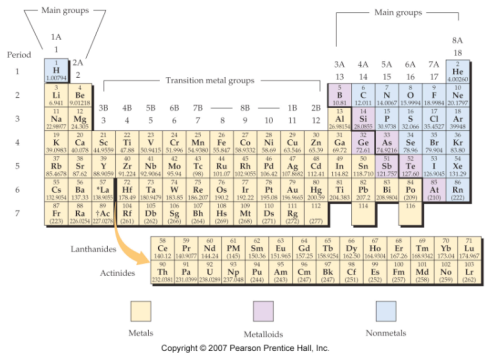
To calculate the atomic weight of an element, the individual mass and the percent abundance of each naturally occurring isotope must be known.

Atomic weight = Σ(isotope abundance)*(isotope mass)

The Greek symbol Σ indicates the summation of terms over all naturally occurring isotopes.

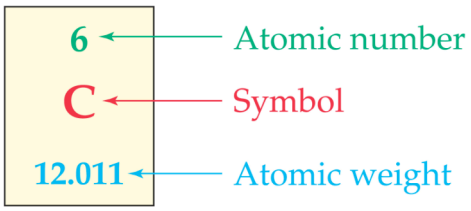
3.4 The Periodic Table

- Beginning at the upper left corner of the periodic table, elements are arranged by increasing atomic number into seven horizontal rows, called **periods**, and 18 vertical columns, called **groups**.
- The elements in a given group have similar chemical properties. Lithium, sodium, potassium, and other elements in group 1A (or 1) have similar properties. Similarly, chlorine, bromine, iodine, and other elements in group 7A (or 17) behave similarly.



The Periodic Table

The table has 114 boxes, each of which tells the symbol, atomic number, and atomic weight of an element.



All seven periods do not contain the same number of elements.

- The first period contains only 2 elements.
- The second and third periods each contain 8 elements.
- The fourth and fifth periods each contain 18 elements.
- The sixth period contains 32 elements.
- The seventh period, still incomplete, contains 27 elements.

The groups on the periodic table are divided into three main categories.

- **Main Groups:** The two groups on the far left (1-2) and the six on the far right (13-18) are the main groups.
- **Transition Metal Groups:** Elements in the groups numbered 3 through 12.
- **Inner Transition Metal Groups:** The 14 groups shown at the bottom of the table that are not numbered containing the Lanthanides and the Actinides.

3.5 Characteristics of Different Groups

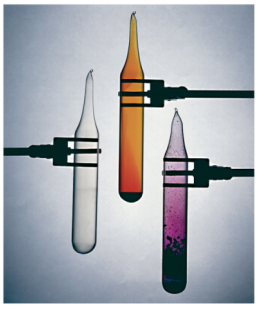
Group 1A or 1 **Alkali metals:**

- Li, Na, K, Rb, Cs, and Fr
- Shiny, soft, and low melting point metals
- All react rapidly with water to form flammable H_2 gas and alkaline or basic solutions.

- Group 2A or 2 **Alkaline earth metals:**
- Be, Mg, Ca, Sr, Ba, and Ra
- Lustrous, silvery metals
- React with O_2
- They are less reactive to water than the alkali metals.

Group 7A or 17 **Halogens:**

- F, Cl, Br, I, and At
- Colorful and corrosive nonmetals
- All are found in nature in combination with other elements, such as with sodium in sodium chloride (NaCl).



Group 8A or 18 **Noble gases:**

- He, Ne, Ar, Kr, Xe, and Rn
- Colorless gases
- Very low chemical reactivity

3. 6 Electronic Structure of Atoms

Quantum mechanical model of atomic structure:

- The electrons in an atom are grouped around the nucleus into shells, roughly like the layers in an onion.
- The farther a shell is from the nucleus, the larger it is, the more electrons it can hold, and the higher the energies of those electrons.
- The smallest shell closest to the nucleus is labeled shell 1, the next one is shell 2, and so on.

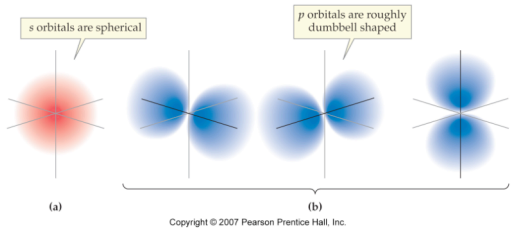
- Within the shells, electrons are further grouped into subshells of four different types, identified as *s*, *p*, *d*, and *f* in order of increasing energy.
- A shell has a number of subshells equal to its shell number.
- The first shell has only an *s* subshell; the second shell has an *s* and a *p* subshell; the third shell has an *s*, a *p*, and a *d* subshell, and so on.

Shell number:	1	2	3	4
Subshell designation:	*s*	*s* , *p*	*s* , *p* , *d*	*s* , *p* , *d* , *f*

- Within each subshell, electrons are further grouped into orbitals, regions of space within an atom where the specific electrons are more likely to be found.
- The number of orbitals within a subshell increases as the odd numbers.
- An *s* subshell has 1 orbital, a *p* has 3, a *d* has 5, and so on.

Shell number:	1	2	3	4
Subshell designation:	*s*	*s* , *p*	*s* , *p* , *d*	*s* , *p* , *d* , *f*
Number of orbitals:	1	1 , 3	1 , 3 , 5	1 , 3 , 5 , 7

Different orbitals have different shapes. Orbitals in *s* subshells are spherical (a), while orbitals in *p* subshells are roughly dumbbell shaped (b).



- Any orbital can hold a maximum of 2 electrons.
- The first shell has one 1*s* orbital and holds 2 electrons.
- The second shell can hold 8 electrons, 2 in a 2*s* orbital, and 6 in three 2*p* orbitals.
- The third shell can hold 18 electrons, 2 in a 3*s* orbital, 6 in three 3*p* orbitals, and 10 in five 3*d* orbitals, and so on.

The overall electron distribution within an atom is summarized in Table 3.2 below.

TABLE 3.2 Electron Distribution in Atoms

SHELL NUMBER:	1	2	3	4
Subshell designation:	*s*	*s* , *p*	*s* , *p* , *d*	*s* , *p* , *d* , *f*
Number of orbitals:	1	1 , 3	1 , 3 , 5	1 , 3 , 5 , 7
Number of electrons:	2	2 , 6	2 , 6 , 10	2 , 6 , 10 , 14
Total electron capacity:	2	8	18	32

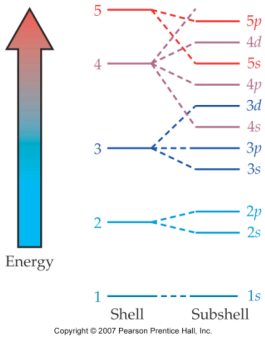
3.7 Electron Configurations

Electron Configuration: The exact arrangement of electrons in atom's shells and subshells. Rules to predict electron configuration:

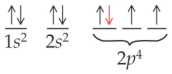
- Electrons occupy the lowest energy orbitals available first.
- Each orbital can hold only two electrons, which must be of opposite spin.
- If two or more orbitals have the same energy, each orbital gets one electron before any orbital gets two.

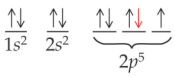
Order of orbital energy levels:

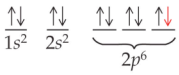
- Electrons fill orbitals from the lowest-energy orbitals upward.
- Lower numbered shells fill before higher numbered shells at first.
- Some overlap in energy levels occurs starting with shell 3 and 4.



These are the electron configurations for O - Ne

O $1s^2\ 2s^2\ 2p^4$ or  or $[He]\ 2s^2\ 2p^4$

F $1s^2\ 2s^2\ 2p^5$ or  or $[He]\ 2s^2\ 2p^5$

Ne $1s^2\ 2s^2\ 2p^6$ or 

3.8 Electron Configuration and the Periodic table

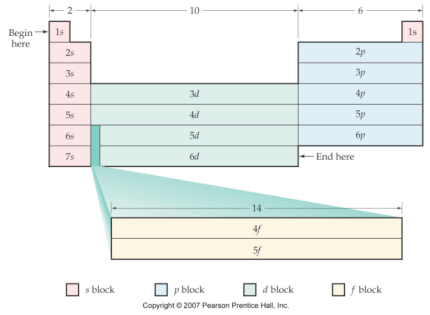
Valence shell: Outermost, highest energy shell of an atom.

Valence electrons: An electron in an outermost shell of an atom. These electrons are loosely held, they are most important in determining an element's properties.

- The periodic table can be divided into four regions or blocks, of elements according to the subshells that are last to fill, *s*, *p*, *d*, or *f*.
- Beginning at the top left corner of the periodic table, the first row contains only two elements, H and He. The 1*s* subshell is being filled here.
- The second row begins with two *s*-block elements (Li and Be) and continues with six *p*-block elements (B through Ne), so electrons fill the next available *s* orbital (2*s*) and then the first available *p* orbitals (2*p*).

- The third row is similar to the second row, so the 3*s* and 3*p* orbitals are filled next.
- The fourth row again starts with two *s*-block elements (K and Ca) but is then followed by ten *d*-block elements (Sc through Zn) and six *p*-block elements (Ga through Kr). Thus, the order of orbital filling is 4*s* followed by the first available *d* orbitals (3*d*) followed by 4*p*.
- Continuing through successive rows of the periodic table provides a visual method to recall the entire filling order.

Visual method to recall the order of orbital filling.



Chapter Summary

- An atom is the smallest unit of an element that maintains the properties of the element.
- Atoms are made up of protons, neutrons, and electrons. Protons have a positive charge, neutrons are neutral, and electrons have a negative charge.
- Protons and neutrons are present in a dense, positively charged region called the nucleus. Electrons are a relatively large distance away from the nucleus.
- The number of protons an element contains is called the atomic number (Z). The total number of protons plus neutrons in an atom is called the mass number (A).

Chapter Summary Cont.

- Atoms with identical numbers of protons and electrons but different numbers of neutrons are called isotopes.
- The atomic weight of an element is the weighted average mass of the element's naturally occurring isotopes measured in atomic mass units (amu).
- Elements are organized into the periodic table, consisting of 7 rows, or periods, and 18 columns, or groups.
- Elements in the same group have the same number of valence electrons in their outermost shell.