

2.9: Summary of Atomic Theory and the Construction of Atoms

Learning Objectives

- State the modern atomic theory.
- Describe the locations, charges, and masses of the three main subatomic particles.
- Determine the number of protons and electrons in an atom.
- Define atomic number and mass number.
- Determine the number of protons, neutrons, and electrons in an atom.
- Explain how elements are organized into the periodic table.
- Explain what isotopes are and how an isotope affects an element's atomic mass.
- Determine the number of protons, electrons, and neutrons of an element with a given mass number.
- Define the two types of ions.

The smallest piece of an element that maintains the identity of that element is called an atom. Individual atoms are extremely small. It would take about fifty million atoms in a row to make a line that is 1 cm long. The period at the end of a printed sentence has several million atoms in it. Atoms are so small that it is difficult to believe that all matter is made from atoms—but it is.

The concept that atoms play a fundamental role in chemistry is formalized by the modern atomic theory, first stated by John Dalton, an English scientist, in 1808. It consists of three parts:

1. All matter is composed of atoms.
2. Atoms of the same element are the same; atoms of different elements are different.
3. Atoms combine in whole-number ratios to form compounds.

These concepts form the basis of chemistry. Although the word *atom* comes from a Greek word that means "indivisible," we understand now that atoms themselves are composed of smaller parts called *subatomic particles*. The first part to be discovered was the electron, a tiny subatomic particle with a negative charge. It is often represented as e^- , with the right superscript showing the negative charge. Later, two larger particles were discovered. The proton is a more massive (but still tiny) subatomic particle with a positive charge, represented as p^+ . The neutron is a subatomic particle with about the same mass as a proton, but no charge. It is represented as either n or n^0 . We now know that all atoms of all elements are composed of electrons, protons, and (with one exception) neutrons. Table 2.9.1 summarizes the properties of these three subatomic particles.

Table 2.9.1: Properties of the Three Subatomic Particles

Name	Symbol	Mass (approx.; kg)	Charge
Proton	p^+	1.6×10^{-27}	1+
Neutron	n, n^0	1.6×10^{-27}	none
Electron	e^-	9.1×10^{-31}	1-

How are these particles arranged in atoms? They are not arranged at random. Experiments by Ernest Rutherford in England in the 1910s pointed to a nuclear model with atoms that has the protons and neutrons in a central nucleus with the electrons in orbit about the nucleus. The relatively massive protons and neutrons are collected in the center of an atom, in a region called the nucleus of the atom (plural *nuclei*). The electrons are outside the nucleus and spend their time orbiting in space about the nucleus. (Figure 2.9.1).

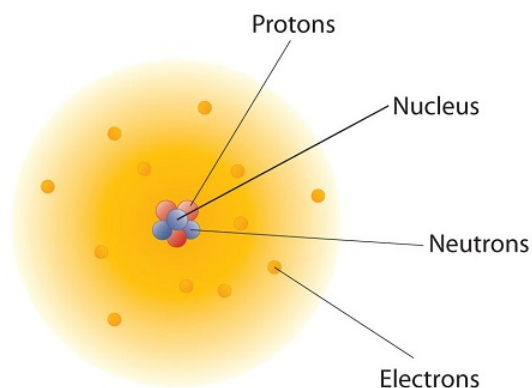


Figure 2.9.1: The Structure of the Atom. Atoms have protons and neutrons in the center, making the nucleus, while the electrons orbit the nucleus.

The modern atomic theory states that atoms of one element are the same, while atoms of different elements are different. What makes atoms of different elements different? The fundamental characteristic that all atoms of the same element share is the *number of protons*. All atoms of hydrogen have one and only one proton in the nucleus; all atoms of iron have 26 protons in the nucleus. This number of protons is so important to the identity of an atom that it is called the atomic number. The number of protons in an atom is the atomic number of the element. Thus, hydrogen has an atomic number of 1, while iron has an atomic number of 26. Each element has its own characteristic atomic number.

Atoms of the same element can have different numbers of neutrons, however. Atoms of the same element (i.e., atoms with the same number of protons) with different numbers of neutrons are called isotopes. Most naturally occurring elements exist as isotopes. For example, most hydrogen atoms have a single proton in their nucleus. However, a small number (about one in a million) of hydrogen atoms have a proton and a neutron in their nuclei. This particular isotope of hydrogen is called deuterium. A very rare form of hydrogen has one proton and two neutrons in the nucleus; this isotope of hydrogen is called tritium. The sum of the number of protons and neutrons in the nucleus is called the mass number of the isotope.

Neutral atoms have the same number of electrons as they have protons, so their overall charge is zero. However, as we shall see later, this will not always be the case.

✓ Example 2.9.1:

- The most common carbon atoms have six protons and six neutrons in their nuclei. What are the atomic number and the mass number of these carbon atoms?
- An isotope of uranium has an atomic number of 92 and a mass number of 235. What are the number of protons and neutrons in the nucleus of this atom?

Solution

- If a carbon atom has six protons in its nucleus, its atomic number is 6. If it also has six neutrons in the nucleus, then the mass number is $6 + 6$, or 12.
- If the atomic number of uranium is 92, then that is the number of protons in the nucleus. Because the mass number is 235, then the number of neutrons in the nucleus is $235 - 92$, or 143.

? Exercise 2.9.1

The number of protons in the nucleus of a tin atom is 50, while the number of neutrons in the nucleus is 68. What are the atomic number and the mass number of this isotope?

Answer

Atomic number = 50, mass number = 118

When referring to an atom, we simply use the element's name: the term *sodium* refers to the element as well as an atom of sodium. But it can be unwieldy to use the name of elements all the time. Instead, chemistry defines a symbol for each element. The atomic

symbol is a one- or two-letter representation of the name of an element. By convention, the first letter of an element's symbol is always capitalized, while the second letter (if present) is lowercase. Thus, the symbol for hydrogen is H, the symbol for sodium is Na, and the symbol for nickel is Ni. Most symbols come from the English name of the element, although some symbols come from an element's Latin name. (The symbol for sodium, Na, comes from its Latin name, *natium*.)

The elements are grouped together in a special chart called the periodic table of all the elements. A simple periodic table is shown in Figure 2.9.2, while one may view a more extensive periodic table from another source. The elements on the periodic table are listed in order of ascending atomic number. The periodic table has a special shape that will become important to us when we consider the organization of electrons in atoms (Chapter 8). One immediate use of the periodic table helps us identify metals and nonmetals. Nonmetals are in the upper right-hand corner of the periodic table, on one side of the heavy line splitting the right-side part of the chart. All other elements are metals.

<div><div><div><div><div>1</div><div>H</div><div>1.00794</div></div></div><div><div><div>3</div><div>Li</div><div>6.941</div></div><div><div>4</div><div>Be</div><div>9.012182</div></div></div><div><div><div>11</div><div>Na</div><div>22.989770</div></div><div><div>12</div><div>Mg</div><div>24.3050</div></div></div></div></div> <div><div><div>1</div><div>H</div><div>1.00794</div></div><div><div>2</div><div>He</div><div>4.002602</div></div></div>																				<div><div><div><div><div>5</div><div>B</div><div>10.811</div></div></div><div><div><div>6</div><div>C</div><div>12.0107</div></div><div><div>7</div><div>N</div><div>14.00674</div></div><div><div>8</div><div>O</div><div>15.9994</div></div></div><div><div><div>9</div><div>F</div><div>18.9984032</div></div><div><div>10</div><div>Ne</div><div>20.1797</div></div></div></div><div><div><div>13</div><div>Al</div><div>26.981538</div></div><div><div>14</div><div>Si</div><div>28.0855</div></div><div><div>15</div><div>P</div><div>30.973761</div></div><div><div>16</div><div>S</div><div>32.066</div></div></div><div><div><div>17</div><div>Cl</div><div>35.4527</div></div><div><div>18</div><div>Ar</div><div>39.948</div></div></div></div>									
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58 Ce 140.116	59 Pr 140.90765	60 Nd 144.24	61 Pm (145)	62 Sm 150.36	63 Eu 151.964	64 Gd 157.25	65 Tb 158.92534	66 Dy 162.50	67 Ho 164.93032	68 Er 167.26	69 Tm 168.93421	70 Yb 173.04	71 Lu 174.967
90 Th 232.0381	91 Pa 231.035888	92 U 238.0289	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (262)

Figure 2.9.1: A Simple Periodic Table

There is an easy way to represent isotopes using the atomic symbols. We use the construction:

A_ZX

where X is the symbol of the element, A is the mass number, and Z is the atomic number. Thus, for the isotope of carbon that has 6 protons and 6 neutrons, the symbol is:



where C is the symbol for the element, 6 represents the atomic number, and 12 represents the mass number.

✓ Example 2.9.2:

- What is the symbol for an isotope of uranium that has an atomic number of 92 and a mass number of 235?
- How many protons and neutrons are in ${}^{56}_{26}\text{Fe}$?

Solution

- The symbol for this isotope is ${}^{235}_{92}\text{U}$
- This iron atom has 26 protons and $56 - 26 = 30$ neutrons.

? Exercise 2.9.2

How many protons are in ${}_{11}^{23}\text{Na}$

Answer

11 protons

It is also common to state the mass number after the name of an element to indicate a particular isotope. Atoms of the same element that differ in their numbers of neutrons are called **isotopes**. Different isotopes of an element generally have the same physical and chemical properties because they have the same numbers of protons and electrons. *Carbon-12* represents an isotope of carbon with 6 protons and 6 neutrons, while *uranium-238* is an isotope of uranium that has 146 neutrons.

So far, we have discussed elements and compounds that are electrically neutral. They have the same number of electrons as protons, so the negative charges of the electrons are balanced by the positive charges of the protons. However, this is not always the case. Electrons can move from one atom to another; when they do, species with overall electric charges are formed. Such species are called ions. Species with overall positive charges are termed **cations**, while species with overall negative charges are called **anions**. Remember that ions are formed only when *electrons* move from one atom to another; a proton never moves from one atom to another.

Key Takeaways

- Chemistry is based on the modern atomic theory, which states that all matter is composed of atoms.
- Atoms themselves are composed of protons, neutrons, and electrons.
- Each element has its own atomic number, which is equal to the number of protons in its nucleus.
- Isotopes of an element contain different numbers of neutrons.
- Elements are represented by an atomic symbol.
- The periodic table is a chart that organizes all the elements.
- Ions form when atoms lose or gain electrons.

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