Pearson

1.8: Subatomic Particles: Protons, Neutrons, and Electrons

Key Concept Video **Subatomic Particles and Isotope Symbols**

All atoms are composed of the same subatomic particles: protons, neutrons, and electrons. Protons and neutrons, as we saw in Section 1.7, have nearly identical masses. In SI units, the mass of the proton is 1.67262×10^{-27} kg, and the mass of the neutron is 1.67493×10^{-27} kg. A more common unit to express these masses is the **atomic mass unit (amu)**, defined as 1/12 the mass of a carbon atom containing six protons and six neutrons. The mass of a proton or neutron is approximately 1 amu. Electrons, by contrast, have an almost negligible mass of 0.00091×10^{-27} kg or 0.00055 amu.

Recall that the proton and the electron both have electrical *charge*. We know from Millikan's oil drop experiment that the electron has a charge of -1.60×10^{-19} C. In atomic (or relative) units, the electron is assigned a charge of 1– and the proton is assigned a charge of 1+. *The charges of the proton and the electron are equal in magnitude but opposite in sign*, so that when the two particles are paired, the charges sum to zero. The neutron has no charge.

Most matter is charge-neutral (it has no overall charge) because protons and electrons are present in equal numbers. When matter does acquire charge imbalances, these imbalances usually equalize quickly, often in dramatic ways. For example, the shock you receive when touching a doorknob during dry weather is the equalization of a charge imbalance that develops as you walk across the carpet. Lightning is an equalization of charge imbalances that develop during electrical storms.

A sample of matter—even a tiny sample, such as a grain of sand—composed of only protons or only electrons, would have extraordinary repulsive forces inherent within it and would be unstable. Luckily, matter is not that way. Table 1.1 summarizes the properties of protons, neutrons, and electrons.

Table 1.1 **Subatomic Particles**

	Mass (kg)	Mass (amu)	Charge (relative)	Charge (C)
Proton	1.67262×10^{-27}	1.00727	1+	$+1.60218 \times 10^{-19}$
Neutron	1.67493×10^{-27}	1.00866	0	0
Electron	0.00091×10^{-27}	0.00055	1–	-1.60218×10^{-19}

Elements: Defined by Their Numbers of Protons

If all atoms are composed of the same subatomic particles, what makes the atoms of one element different from those of another? The answer is the *number* of these particles. The most important number to the *identity* of an atom is the number of protons in its nucleus. *The number of protons defines the element*. For example, an atom with 2 protons in its nucleus is a helium atom; an atom with 6 protons in its nucleus is a carbon atom (Figure 1.9); and an atom with 92 protons in its nucleus is a uranium atom. The number of protons in an atom's nucleus is its **atomic number** and is given the symbol Z. The atomic numbers of known elements range from 1 to 116 (although additional elements may still be discovered), as shown in the **periodic table** of the elements (Figure 1.10). In the periodic table, which we will describe in more detail in Chapter 3, the elements are arranged so that those with similar properties are in the same column.

The number of protons in the nucleus of an atom determines the charge of the nucleus. For example, carbon has 6 protons and therefore a nuclear charge of 6+.

Figure 1.9 How Elements Differ

Each element is defined by a unique atomic number (Z), the number of protons in the nucleus of every atom of that element. The number of protons determines the charge of the nucleus.

The Number of Protons Defines the Element

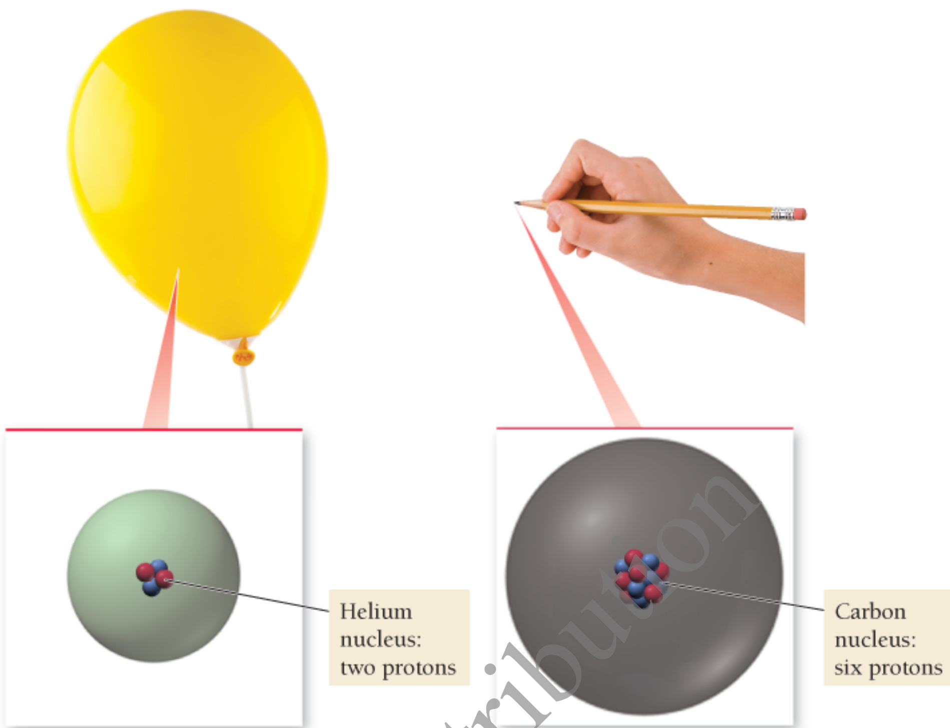
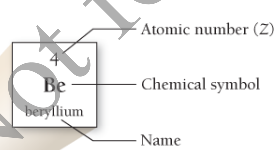


Figure 1.10 The Periodic Table

Each element is represented by its symbol and atomic number. Elements in the same column have similar properties.

The Periodic Table



1 H hydrogen																	2 He helium
3 Li lithium	4 Be beryllium											5 B boron	6 C carbon	7 N nitrogen	8 O oxygen	9 F fluorine	10 Ne neon
11 Na sodium	12 Mg magnesium											13 Al aluminum	14 Si silicon	15 P phosphorus	16 S sulfur	17 Cl chlorine	18 Ar argon
19 K potassium	20 Ca calcium	21 Sc scandium	22 Ti titanium	23 V vanadium	24 Cr chromium	25 Mn manganese	26 Fe iron	27 Co cobalt	28 Ni nickel	29 Cu copper	30 Zn zinc	31 Ga gallium	32 Ge germanium	33 As arsenic	34 Se selenium	35 Br bromine	36 Kr krypton
37 Rb rubidium	38 Sr strontium	39 Y yttrium	40 Zr zirconium	41 Nb niobium	42 Mo molybdenum	43 Tc technetium	44 Ru ruthenium	45 Rh rhodium	46 Pd palladium	47 Ag silver	48 Cd cadmium	49 In indium	50 Sn tin	51 Sb antimony	52 Te tellurium	53 I iodine	54 Xe xenon
55 Cs cesium	56 Ba barium	57 La lanthanum	72 Hf hafnium	73 Ta tantalum	74 W tungsten	75 Re rhenium	76 Os osmium	77 Ir iridium	78 Pt platinum	79 Au gold	80 Hg mercury	81 Tl thallium	82 Pb lead	83 Bi bismuth	84 Po polonium	85 At astatine	86 Rn radon
87 Fr francium	88 Ra radium	89 Ac actinium	104 Rf rutherfordium	105 Db dubnium	106 Sg seaborgium	107 Bh bohrium	108 Hs hassium	109 Mt meitnerium	110 Ds darmstadtium	111 Rg roentgenium	112 Cn copernicium	113 Nh nihonium	114 Fl flerovium	115 Mc moscovium	116 Lv livermorium	117 Ts tennessine	118 Og oganesson

58 Ce cerium	59 Pr praseodymium	60 Nd neodymium	61 Pm promethium	62 Sm samarium	63 Eu europium	64 Gd gadolinium	65 Tb terbium	66 Dy dysprosium	67 Ho holmium	68 Er erbium	69 Tm thulium	70 Yb ytterbium	71 Lu lutetium
90 Th thorium	91 Pa protactinium	92 U uranium	93 Np neptunium	94 Pu plutonium	95 Am americium	96 Cm curium	97 Bk berkelium	98 Cf californium	99 Es einsteinium	100 Fm fermium	101 Md mendelevium	102 No nobelium	103 Lr lawrencium

Each element, identified by its unique atomic number, is represented with a unique **chemical symbol**, a one- or two-letter abbreviation listed directly below its atomic number on the periodic table. The chemical symbol for helium is He; for carbon, it is C; and for uranium, it is U. The chemical symbol and the atomic number always go together. If the atomic number is 2, the chemical symbol *must be* He. If the atomic number is 6, the chemical symbol *must be* C. This is another way of saying that the number of protons defines the element.

Most chemical symbols are based on the English name of the element. For example, the symbol for sulfur is S; for oxygen, O; and for chlorine, Cl. Several of the oldest known elements, however, have symbols based on their Latin names. For example, the symbol for sodium is Na from the Latin *natrium*, and the symbol for tin is Sn from the Latin *stannum*. Early scientists often gave newly discovered elements names that reflect their properties. For example, argon originates from the Greek word *argos* meaning inactive, referring to argon's chemical inertness (it does not react with other elements). Chlorine originates from the Greek word *chloros* meaning pale green, referring to chlorine's pale green color. Other elements, including helium, selenium, and mercury, are named after figures from Greek or Roman mythology or astronomical bodies. Still others (such as europium, polonium, and berkelium) are named for the places where they were discovered or where their discoverers were born. More recently, elements have been named after scientists—for example, curium for Marie Curie, einsteinium for Albert Einstein, and rutherfordium for Ernest Rutherford.

Element 96 is named curium, after Marie Curie, co-discoverer of radioactivity.

Isotopes: When the Number of Neutrons Varies

All atoms of a given element have the same number of protons; however, they do not necessarily have the same number of neutrons. Since neutrons have nearly the same mass as protons (1 amu), this means that—contrary to what John Dalton originally proposed in his atomic theory—all atoms of a given element *do not* have the same mass. For example, all neon atoms contain 10 protons, but they may contain 10, 11, or 12 neutrons. All three types of neon atoms exist, and each has a slightly different mass. Atoms with the same number of protons but different numbers of neutrons are called **isotopes**. Some elements, such as beryllium (Be) and aluminum (Al), have only one naturally occurring isotope, while other elements, such as neon (Ne) and chlorine (Cl), have two or more.

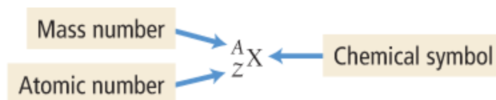
The relative amount of each different isotope in a naturally occurring sample of a given element is roughly constant. For example, in any natural sample of neon atoms, 90.48% of them are the isotope with 10 neutrons, 0.27% are the isotope with 11 neutrons, and 9.25% are the isotope with 12 neutrons. These percentages are called the **natural abundance** of the isotopes. Each element has its own characteristic natural abundance of isotopes. However, advances in mass spectrometry have allowed accurate measurements that reveal small but significant variations in the natural abundance of isotopes for many elements.

The sum of the number of neutrons and protons in an atom is its **mass number** and is represented by the symbol A:

$$A = \text{number of protons (p)} + \text{number of neutrons (n)}$$

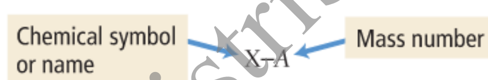
For neon, with 10 protons, the mass numbers of the three different naturally occurring isotopes are 20, 21, and 22, corresponding to 10, 11, and 12 neutrons, respectively.

We symbolize isotopes using this notation:



where X is the chemical symbol, A is the mass number, and Z is the atomic number. Therefore, the symbols for the neon isotopes are $^{20}_{10}\text{Ne}\,^{21}_{10}\text{Ne}\,^{22}_{10}\text{Ne}$. Notice that the chemical symbol, Ne, and the atomic number, 10, are redundant: If the atomic number is 10, the symbol must be Ne. The mass numbers, however, are different for the different isotopes, reflecting the different number of neutrons in each one.

A second common notation for isotopes is the chemical symbol (or chemical name) followed by a dash and the mass number of the isotope.



In this notation, the neon isotopes are:

Ne-20	Ne-21	Ne-22
neon-20	neon-21	neon-22

We can summarize what we have discussed about the neon isotopes in a table:

Symbol	Number of Protons	Number of Neutrons	A (Mass Number)	Natural Abundance (%)
Ne-20 or $^{20}_{10}\text{Ne}$	10	10	20	90.48
Ne-21 or $^{21}_{10}\text{Ne}$	10	11	21	0.27
Ne-22 or $^{22}_{10}\text{Ne}$	10	12	22	9.25

Notice that all isotopes of a given element have the same number of protons (otherwise they would be different elements). Notice also that the mass number is the *sum* of the number of protons and the number of neutrons. The number of neutrons in an isotope is therefore the difference between the mass number and the atomic number (A–Z). The different isotopes of an element generally exhibit the same chemical behavior—the three isotopes of neon, for example, all exhibit chemical inertness.

Example 1.3 Atomic Numbers, Mass Numbers, and Isotope Symbols

a. What are the atomic number (Z), mass number (A), and symbol of the chlorine isotope with 18 neutrons?

b. How many protons, electrons, and neutrons are present in an atom of ${}^{52}_{24}\mathrm{Cr}$?

SOLUTION

(a) Look up the atomic number (Z) for chlorine on the periodic table. The atomic number specifies the number of protons.

The mass number (A) for an isotope is the sum of the number of protons and the number of neutrons.

The symbol for an isotope is its two-letter abbreviation with the atomic number (Z) in the lower left corner and the mass number (A) in the upper left corner.

$Z = 17$, so chlorine has 17 protons.

$$\begin{aligned} A &= \text{number of protons} + \text{number of neutrons} \\ &= 17 + 18 = 35 \end{aligned}$$

${}^{35}_{17}\mathrm{Cl}$

(b) For any isotope (in this case ${}^{52}_{24}\mathrm{Cr}$), the number of protons is indicated by the atomic number located at the lower left. Since this is a neutral atom, the number of electrons equals the number of protons.

The number of neutrons is equal to the mass number (upper left) minus the atomic number (lower left).

Number of protons = Z = 24

Number of electrons = 24 (neutral atom)

Number of neutrons = 52 − 24 = 28

FOR PRACTICE 1.3

a. What are the atomic number, mass number, and symbol for the carbon isotope with 7 neutrons?

b. How many protons and neutrons are present in an atom of ${}^{39}_{19}\mathrm{K}$?

Interactive Worked Example 1.3 **Atomic Numbers, Mass Numbers, and Isotope Symbols**

Conceptual Connection 1.6 **Isotopes**

Ions: Losing and Gaining Electrons

Interactive

The number of electrons in a neutral atom is equal to the charge of its nucleus, which is determined by the number of protons in its nucleus (designated by its atomic number Z). During chemical changes, however, atoms can lose or gain electrons and become charged particles called **ions**. For example, neutral lithium (Li) atoms contain 3 protons and 3 electrons; however, in many chemical reactions lithium atoms lose one electron (e^-) to form Li^+ ions.

$$\mathrm{Li} \rightarrow \mathrm{Li}^+ + 1\ \mathrm{e}^-$$

The charge of an ion is indicated in the upper right corner of the chemical symbol. Since the Li^+ *ion* contains 3 protons and only 2 electrons, its charge is 1+ (ion charges are written as the magnitude first followed by the sign of the charge; for a charge of 1+, the 1 is usually dropped and the charge is written as simply +).

Ions can also be negatively charged. For example, neutral fluorine (F) atoms contain 9 protons and 9 electrons; however, in many chemical reactions fluorine atoms gain one electron to form F^- ions.

$$F + 1\,e^- \rightarrow F^-$$

The F^- *ion* contains 9 protons and 10 electrons, resulting in a charge of 1– (written simply –). For many elements, such as lithium and fluorine, the ion is much more common than the neutral atom. Lithium and fluorine occur in nature mostly as ions.

Positively charged ions, such as Li^+, are **cations** and negatively charged ions, such as F^-, are **anions**. Ions behave quite differently than the atoms from which they are formed (because the structure of particles—including their charge—determines the properties of the matter they compose). Neutral sodium atoms, for example, are extremely unstable, reacting violently with most things they contact. Sodium cations (Na^+), by contrast, are relatively inert—we eat them all the time in sodium chloride (table salt). In ordinary matter, cations and anions always occur together so that matter is charge-neutral overall.

Conceptual Connection 1.7 **The Nuclear Atom, Isotopes, and Ions**

Interactive