Chapter 4: Atomic Structure

4.1 Defining the Atom

Early Models of the Atom

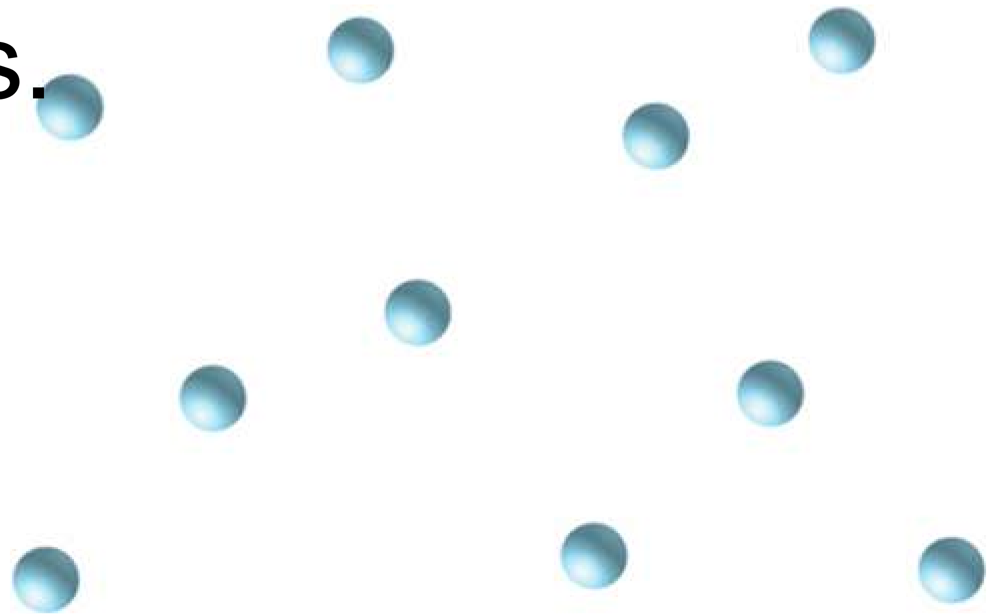
- An **atom** is the smallest particle of an element that retains its identity in a chemical reaction.
  - Philosophers and scientists have proposed many ideas on the structure of atoms.

Early Models of the Atom

- Democritus believed that atoms were indivisible and indestructible.
- **Democritus's ideas were limited because they didn't explain chemical behavior and they lacked experimental support.**

Dalton’s Atomic Theory

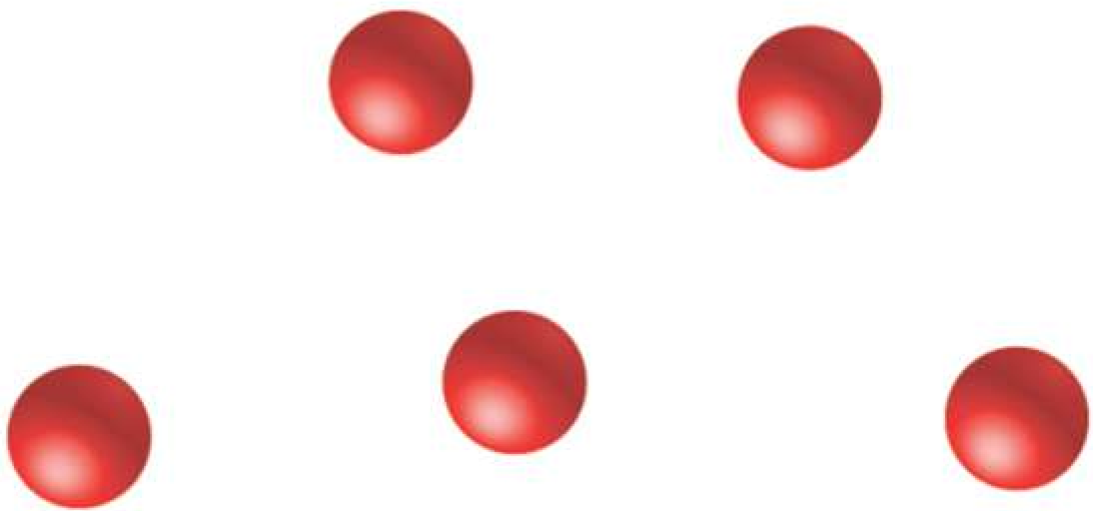
- All elements are composed of tiny indivisible particles called atoms.



Atoms of element A

Dalton's Atomic Theory

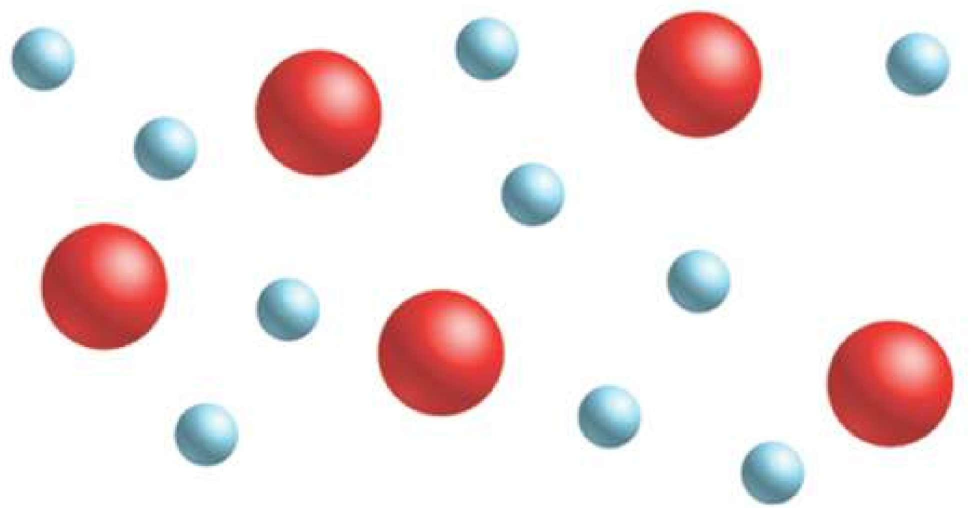
- Atoms of the same element are identical. The atoms of any one element are different from those of any other element.



Atoms of element B

Dalton's Atomic Theory

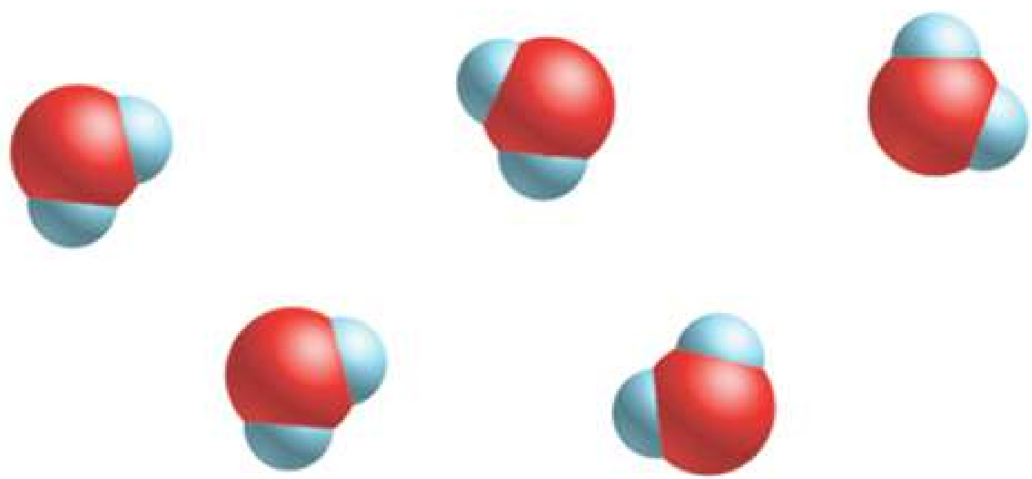
- Atoms of different elements can physically mix together or can chemically combine in simple whole-number ratios to form compounds.



Mixture of atoms
of elements A and B

Dalton's Atomic Theory

- Chemical reactions occur when atoms are separated, joined, or rearranged.



Compound made by chemically combining atoms of elements A and B

Sizing up the Atom

- Despite their small size, individual atoms are observable with instruments such as scanning tunneling microscopes.

4.1 Section Quiz

- 1. The ancient Greek philosopher credited with suggesting all matter is made of indivisible atoms is

  a) Plato.

  b) Aristotle.

  c) Democritus.

  d) Socrates.

4.1 Section Quiz

- 2. Dalton's atomic theory improved earlier atomic theory by

  a) teaching that all matter is composed of tiny particles called atoms.

  b) theorizing that all atoms of the same element are identical.

  c) using experimental methods to establish a scientific theory.

  d) not relating atoms to chemical change.

4.1 Section Quiz

- 3. Individual atoms are observable with

  a) the naked eye.

  b) a magnifying glass.

  c) a light microscope.

  d) a scanning tunneling microscope.

4.2 Structure of the Nuclear Atom

Subatomic Particles

- Three kinds of subatomic particles are electrons, protons, and neutrons.

Subatomic Particles

- Electrons
  - In 1897, the English physicist J. J. Thomson (1856–1940) discovered the electron. **Electrons** are negatively charged subatomic particles.

Subatomic Particles

- Thomson performed experiments that involved passing electric current through gases at low pressure.
  The result was a glowing beam, or **cathode ray**, that traveled from the cathode to the anode.

Subatomic Particles

- Thomson concluded that a cathode ray is a stream of electrons. Electrons are parts of the atoms of all elements.

Subatomic Particles

- Protons and Neutrons
  - In 1886, Eugen Goldstein (1850–1930) observed a cathode-ray tube and found rays traveling in the direction opposite to that of the cathode rays. He concluded that they were composed of positive particles.
  - Such positively charged subatomic particles are called **protons**.

Subatomic Particles

- In 1932, the English physicist James Chadwick (1891–1974) confirmed the existence of yet another subatomic particle: the neutron.
- **Neutrons** are subatomic particles with no charge but with a mass nearly equal to that of a proton.

Subatomic Particles

Table 4.1

Properties of Subatomic Particles				
Particle	**Symbol**	**Relative charge**	**Relative mass (mass of proton = 1)**	**Actual mass (g)**
Electron	e^-	1−	1/1840	9.11×10^{-28}
Proton	p^+	1+	1	1.67×10^{-24}
Neutron	n^0	0	1	1.67×10^{-24}

The Atomic Nucleus

- J.J. Thompson and others supposed the atom was filled with positively charged material and the electrons were evenly distributed throughout – **plum pudding model**
- This model of the atom turned out to be short-lived, however, due to the work of Ernest Rutherford (1871–1937).

The Atomic Nucleus

- Rutherford's Gold-Foil Experiment
  - In 1911, Rutherford and his coworkers at the University of Manchester, England, directed a narrow beam of alpha particles at a very thin sheet of gold foil.

- The Rutherford Atomic Model
  - Rutherford concluded that the atom is mostly empty space. All the positive charge and almost all of the mass are concentrated in a small region called the nucleus.
  - The **nucleus** is the tiny central core of an atom and is composed of protons and neutrons.

The Atomic Nucleus

- In the nuclear atom, the protons and neutrons are located in the nucleus. The electrons are distributed around the nucleus and occupy almost all the volume of the atom.

4.2 Section Quiz

- 1. Which of the following is NOT an example of a subatomic particle?
  - a) proton
  - b) molecule
  - c) electron
  - d) neutron

4.2 Section Quiz

- 2. The nucleus of an atom consists of

  a) electrons only.

  b) protons only.

  c) protons and neutrons.

  d) electrons and neutrons.

4.2 Section Quiz

- 3. Most of the volume of the atom is occupied by the

  a) electrons.

  b) neutrons.

  c) protons and neutrons.

  d) protons.

4.3 Distinguishing Among Atoms

Atomic Number

- Elements are different because they contain different numbers of protons.
- **The** atomic number **of an element is the number of protons in the nucleus of an atom of that element.**

CONCEPTUAL PROBLEM 4.1

Understanding Atomic Number

The element nitrogen (N), shown here in liquid form, has an atomic number of 7. How many protons and electrons are in a neutral nitrogen atom?

for Conceptual Problem 4.1

15. Complete the table.

Element	Atomic number	Protons	Electrons
K	19	(a)	19
(b)	(c)	(d)	5
S	16	(e)	(f)
V	(g)	23	(h)

Mass Number

- The total number of protons and neutrons in an atom is called the **mass number.**
  - The number of neutrons in an atom is the difference between the mass number and atomic number.

Number of neutrons = mass number − atomic number

Sample Problem 4.1

Determining the Composition of an Atom

How many protons, electrons, and neutrons are in each atom?

	Atomic number	Mass number
a. Beryllium (Be)	4	9
b. Neon (Ne)	10	20
c. Sodium (Na)	11	23

for Sample Problem 4.1

17. How many neutrons are in each atom?

a. $^{16}_{8}O$ **b.** $^{32}_{16}S$ **c.** $^{108}_{47}Ag$

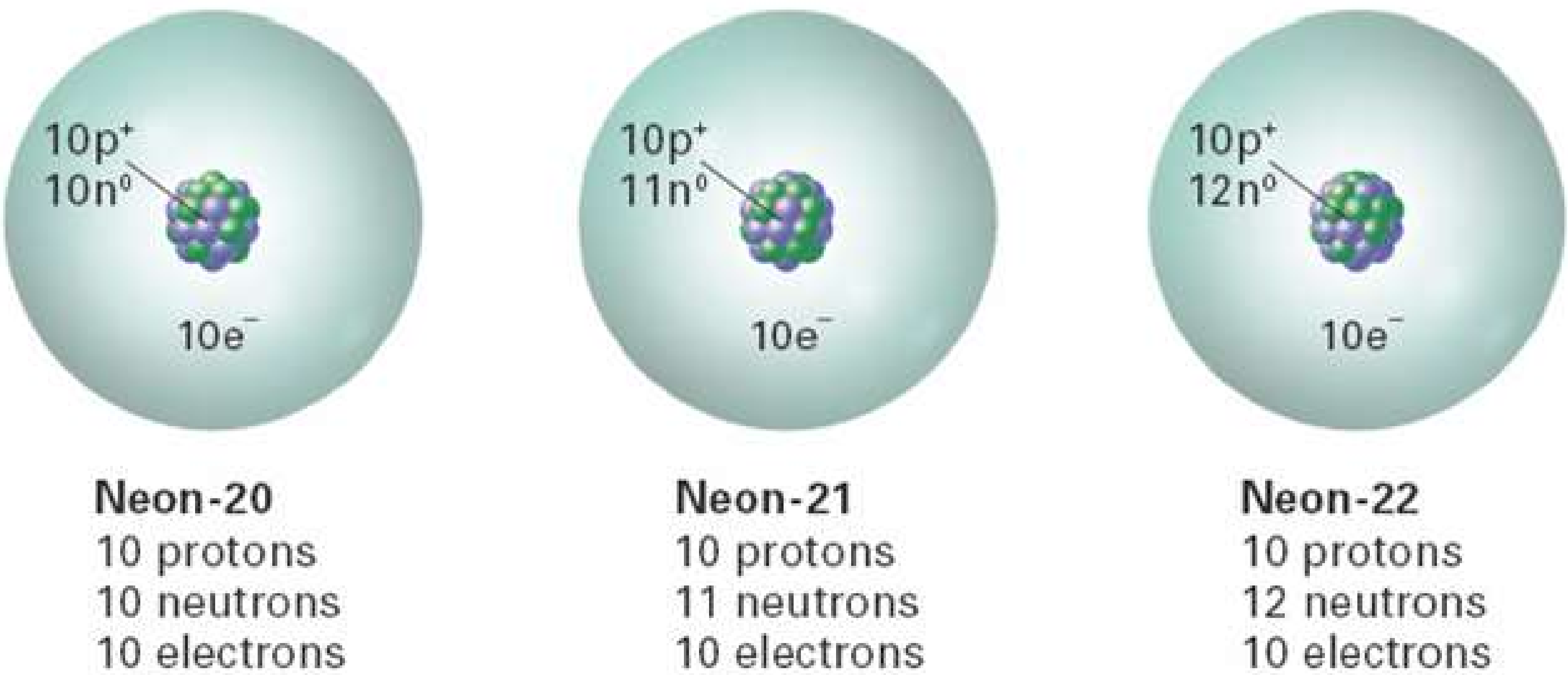
d. $^{80}_{35}Br$ **e.** $^{207}_{82}Pb$

Isotopes

- **Isotopes** are atoms that have the same number of protons but different numbers of neutrons.
  - Because isotopes of an element have different numbers of neutrons, they also have different mass numbers.

Isotopes

- Despite these differences, isotopes are chemically alike because they have identical numbers of protons and electrons.



CONCEPTUAL PROBLEM 4.2

Writing Chemical Symbols of Isotopes

Diamonds are a naturally occurring form of elemental carbon. Two stable isotopes of carbon are carbon-12 and carbon-13. Write the symbol for each isotope using superscripts and subscripts to represent the mass number and the atomic number.

for Conceptual Problem 4.2

20. Three isotopes of chromium are chromium-50, chromium-52, and chromium-53. How many neutrons are in each isotope, given that chromium has an atomic number of 24?

Tell protons, neutrons and electrons for:

1) $^{60}_{27}Co$
2) $^{37}_{17}Cl$
3) $^{238}_{92}U$

- 4) Carbon-12
- 5) Carbon -14
- 6) Strontium-90
- 7) Mercury-201

Examples

	#p	#n	#e	Z	A
Carbon- 13					
Xenon-131					
Sodium-24					
Oxygen- 15					

Isotopes

- An atom has a mass number of 55. Its number of neutrons is the sum of its atomic number and five. How many protons, neutrons, and electrons does it have? What is the identity of this atom?

Atomic Mass

- It is useful to to compare the relative masses of atoms to a standard reference isotope. Carbon-12 is the standard reference isotope. Cabon-12 has a mass of exactly 12 atomic mass units.
- An **atomic mass unit (amu)** is defined as one twelfth of the mass of a carbon-12 atom.

Atomic Mass

- The **atomic mass** of an element is a weighted average mass of the atoms in a naturally occurring sample of the element.
  - A weighted average mass reflects both the mass and the relative abundance of the isotopes as they occur in nature.

CONCEPTUAL PROBLEM 4.3

Using Atomic Mass to Determine the Relative Abundance of Isotopes

The atomic mass of copper is 63.546 amu. Which of copper's two isotopes is more abundant: copper-63 or copper-65?

21. Boron has two isotopes: boron-10 and boron-11. Which is more abundant, given that the atomic mass of boron is 10.81?

Atomic Mass

- To calculate the atomic mass of an element, multiply the mass of each isotope by its natural abundance, expressed as a decimal, and then add the products.

Atomic Mass

- For example, carbon has two stable isotopes:
  - Carbon-12, which has a natural abundance of 98.89%, and
  - Carbon-13, which has a natural abundance of 1.11%.

Sample Problem 4.2

Calculating Atomic Mass

Element X has two natural isotopes. The isotope with a mass of 10.012 amu (^{10}X) has a relative abundance of 19.91%. The isotope with a mass of 11.009 amu (^{11}X) has a relative abundance of 80.09%. Calculate the atomic mass of this element.

Practice Problem 23

- The element copper has naturally occurring isotopes with mass numbers of 63 and 65. The relative abundance and atomic masses are 69.2% for mass = 62.93 amu, and 30.8% for mass = 64.93 amu. Calculate the average atomic mass for copper.

for Sample Problem 4.2

24. Calculate the atomic mass of bromine. The two isotopes of bromine have atomic masses and relative abundance of 78.92 amu (50.69%) and 80.92 amu (49.31%).

Average atomic mass

- Indium has two naturally occurring isotopes and an atomic mass of 114.818 amu. In-113 has a mass of 112.904 amu and an abundance of 4.3%. What is the identity and percent abundance of indium's other isotope?

The Periodic Table—A Preview

- A **periodic table** is an arrangement of elements in which the elements are separated into groups based on a set of repeating properties.
  - A periodic table allows you to easily compare the properties of one element (or a group of elements) to another element (or group of elements).

The Periodic Table—A Preview

- Each horizontal row of the periodic table is called a **period**.
- Within a given period, the properties of the elements vary as you move across it from element to element.

The Periodic Table—A Preview

- Each vertical column of the periodic table is called a **group**, or family.
- Elements within a group have similar chemical and physical properties.

4.3 Section Quiz

- 1. Isotopes of an element have

  a) the same mass number.

  b) different atomic numbers.

  c) the same number of protons but different numbers of neutrons.

  d) the same number of protons but different numbers of electrons.

4.3 Section Quiz

- 2. How many neutrons are in sulfur-33?
  - a) 16 neutrons
  - b) 33 neutrons
  - c) 17 neutrons
  - d) 32.06 neutrons

4.3 Section Quiz

- 3. If sulfur contained 90.0% sulfur-32 and 10.0% sulfur-34, its atomic mass would be
  - a) 32.2 amu.
  - b) 32.4 amu.
  - c) 33.0 amu.
  - d) 35.4 amu.