The Structure of the Atom

Section 4.1 Early Ideas About Matter

Objectives
- Compare and contrast the atomic models of Democritus, Aristotle, and Dalton.
- Understand how Dalton's theory explains the conservation of mass.

Review Vocabulary
- Theory: an explanation supported by many experiments; is still subject to new experimental data, can be modified, and is considered successful if it can be used to make predictions that are true.

New Vocabulary
- Dalton's atomic theory

The ancient Greeks tried to explain matter, but the scientific study of the atom began with John Dalton in the early 1800s.

Many ancient scholars believed matter was composed of such things as earth, water, air, and fire.

- Many believed matter could be endlessly divided into smaller and smaller pieces.

Democritus (460–370 B.C.) was the first person to propose the idea that matter was not infinitely divisible, but made up of individual particles called atomos.

- Aristotle (484–322 B.C.) disagreed with Democritus because he did not believe empty space could exist.
- Aristotle’s views went unchallenged for 2,000 years until science developed methods to test the validity of his ideas.

John Dalton revived the idea of the atom in the early 1800s based on numerous chemical reactions.

- Dalton’s atomic theory easily explained conservation of mass in a reaction as the result of the combination, separation, or rearrangement of atoms.
Section 4.1 Assessment

Who was the first person to propose the idea that matter was not infinitely divisible?
A. Aristotle  
B. Plato  
C. Dalton  
D. Democritus

Dalton’s theory also conveniently explained what?
A. the electron  
B. the nucleus  
C. law of conservation of mass  
D. law of Democritus

Section 4.2 Defining the Atom

Objectives
- Define atom.
- Distinguish between the subatomic particles in terms of relative charge and mass.
- Describe the structure of the atom, including the locations of the subatomic particles.

Review Vocabulary
- model: a visual, verbal, and/or mathematical explanation of data collected from many experiments

New Vocabulary
- atom  
- cathode ray  
- electron  
- nucleus  
- proton  
- neutron

An atom is made of a nucleus containing protons and neutrons; electrons move around the nucleus.

The Atom
- The smallest particle of an element that retains the properties of the element is called an atom.
- An instrument called the scanning tunneling microscope (STM) allows individual atoms to be seen.

The Electron
- When an electric charge is applied, a ray of radiation travels from the cathode to the anode, called a cathode ray.
- Cathode rays are a stream of particles carrying a negative charge.
- The particles carrying a negative charge are known as electrons.

- This figure shows a typical cathode ray tube.

The Electron (cont.)
- J.J. Thomson measured the effects of both magnetic and electric fields on the cathode ray to determine the charge-to-mass ratio of a charged particle, then compared it to known values.
- The mass of the charged particle was much less than a hydrogen atom, then the lightest known atom.
- Thomson received the Nobel Prize in 1906 for identifying the first subatomic particle—the electron.
The Electron (cont.)

- In the early 1910s, Robert Millikan used the oil-drop apparatus shown below to determine the charge of an electron.

\[
\text{Mass of an electron } = 9.1 \times 10^{-31} \text{g} = \frac{1}{1840}
\]

The Electron (cont.)

- Charges change in discrete amounts—1.602 × 10⁻¹⁹ coulombs, the charge of one electron (now equated to a single unit, 1⁻).
- With the electron’s charge and charge-to-mass ratio known, Millikan calculated the mass of a single electron.

The Nucleus (cont.)

- In 1911, Ernest Rutherford studied how positively charged alpha particles interacted with solid matter.

The Nucleus (cont.)

- Although most of the alpha particles went through the gold foil, a few of them bounced back, some at large angles.

The Nucleus (cont.)

- Rutherford refined the model to include positively charged particles in the nucleus called protons.
- James Chadwick received the Nobel Prize in 1935 for discovering the existence of neutrons, neutral particles in the nucleus which accounts for the remainder of an atom’s mass.
The Nucleus (cont.)

- The repulsive force between the positively charged nucleus and positive alpha particles caused the deflections.

- All atoms are made of three fundamental subatomic particles: the electron, the proton, and the neutron.

- Atoms are spherically shaped.
- Atoms are mostly empty space, and electrons travel around the nucleus held by an attraction to the positively charged nucleus.

- Scientists have determined that protons and neutrons are composed of subatomic particles called quarks.

- Chemical behavior can be explained by considering only an atom's electrons.

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**Section 4.2 Assessment**

Atoms are mostly ____.
A. positive  
B. negative  
C. solid spheres  
D. empty space

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**Section 4.3 How Atoms Differ**

**Objectives**
- Explain the role of atomic number in determining the identity of an atom.
- Define an isotope.
- Explain why atomic masses are not whole numbers.
- Calculate the number of electrons, protons, and neutrons in an atom given its mass number and atomic number.

**Review Vocabulary**
- periodic table: a chart that organizes all known elements into a grid of horizontal rows (periods) and vertical columns (groups or families) arranged by increasing atomic number

**New Vocabulary**
- atomic number  
- atomic mass unit (amu)  
- isotopes  
- mass number  
- atomic mass
Atomic Number

- Each element contains a unique positive charge in their nucleus.
- The number of protons in the nucleus of an atom identifies the element and is known as the element’s **atomic number**.

<table>
<thead>
<tr>
<th>Hydrogen</th>
<th>Chemical name</th>
<th>Atomic number</th>
<th>[image]</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td></td>
<td>1</td>
<td>1.008</td>
</tr>
</tbody>
</table>

- All atoms of a particular element have the same number of protons and electrons but the number of neutrons in the nucleus can differ.
- Atoms with the same number of protons but different numbers of neutrons are called **isotopes**.

Isotopes and Mass Number

- The relative abundance of each isotope is usually constant.
- Isotopes containing more neutrons have a greater mass.
- Isotopes have the same chemical behavior.
- The **mass number** is the sum of the protons and neutrons in the nucleus.

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Protons</th>
<th>Neutrons</th>
<th>Mass Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>¹⁹⁷Au</td>
<td>79</td>
<td>118</td>
<td>297</td>
</tr>
<tr>
<td>¹⁹⁸Au</td>
<td>79</td>
<td>119</td>
<td>298</td>
</tr>
<tr>
<td>¹⁹⁹Au</td>
<td>79</td>
<td>119</td>
<td>298</td>
</tr>
</tbody>
</table>

Mass of Atoms

- One **atomic mass unit** (amu) is defined as 1/12th the mass of a carbon-12 atom.
- One amu is nearly, but not exactly, equal to one proton and one neutron.

<table>
<thead>
<tr>
<th>Particle</th>
<th>Mass (amu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron</td>
<td>0.000549</td>
</tr>
<tr>
<td>Proton</td>
<td>1.007276</td>
</tr>
<tr>
<td>Neutron</td>
<td>1.008665</td>
</tr>
</tbody>
</table>

Mass of Atoms (cont.)

- The **atomic mass** of an element is the weighted average mass of the isotopes of that element.

<table>
<thead>
<tr>
<th>Calculating the Weighted Average Atomic Mass of Chlorine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atomic mass: 35.453 amu (natural abundance: 37.53%)</td>
</tr>
<tr>
<td>Atomic mass: 36.966 amu (natural abundance: 62.47%)</td>
</tr>
<tr>
<td>Atomic mass: 36.966 amu (natural abundance: 62.47%)</td>
</tr>
<tr>
<td>Weighted average atomic mass of chlorine is 35.453 amu</td>
</tr>
</tbody>
</table>

Table 4.4 Masses of Subatomic Particles

<table>
<thead>
<tr>
<th>Particle</th>
<th>Mass (amu)</th>
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<td>1.008665</td>
</tr>
</tbody>
</table>
An unknown element has 19 protons, 19 electrons, and 3 isotopes with 20, 21 and 22 neutrons. What is the element’s atomic number?

A. 38  
B. 40  
C. 19  
D. unable to determine

Elements with the same number of protons and differing numbers of neutrons are known as what?

A. isotopes  
B. radioactive  
C. abundant  
D. ions

Section 4.3 Assessment

Radioactivity can change one element into another element.  
Unstable nuclei lose energy by emitting radiation in a spontaneous process called **radioactive decay**.  
Unstable radioactive elements undergo radioactive decay thus forming stable nonradioactive elements.  
**Alpha radiation** is made up of positively charged particles called **alpha particles**.  
Each alpha particle contains two protons and two neutrons and has a 2+ charge.

Radioactive Decay (cont.)

The figure shown below is a **nuclear equation** showing the radioactive decay of radium-226 to radon-222.  

\[
_{96}^{226}\text{Ra} \rightarrow _{86}^{222}\text{Rn} + \alpha \\
\text{radium-226} \rightarrow \text{radon-222} + \text{alpha particle}
\]

The mass is conserved in nuclear equations.
Radioactive Decay (cont.)

- **Beta radiation** is radiation that has a negative charge and emits beta particles.
- Each beta particle is an electron with a 1– charge.

\[ ^{14}_6 C \rightarrow ^{14}_7 N + \beta \]

- **Carbon-14**
- **Nitrogen-14**
- **Beta particle**

Radioactive Decay (cont.)

- **Gamma rays** are high-energy radiation with no mass and are neutral.
- Gamma rays account for most of the energy lost during radioactive decay.

- Atoms that contain too many or too few neutrons are unstable and lose energy through radioactive decay to form a stable nucleus.
- Few exist in nature—most have already decayed to stable forms.

A reaction that changes one element into another is called what?
A. chemical reaction  
B. beta radiation  
C. nuclear reaction  
D. physical reaction

Why are radioactive elements rare in nature?
A. They do not occur on Earth.  
B. Most have already decayed to a stable form.  
C. They take a long time to form.  
D. They are too hard to detect.
Chapter Assessment 1
Whose work led to the modern atomic theory?
A. Dalton
B. Rutherford
C. Einstein
D. Aristotle

Chapter Assessment 2
Which particle is not found in the nucleus of an atom?
A. neutron
B. proton
C. gamma ray
D. electron

Chapter Assessment 3
Two isotopes of an unknown element have the same number of:
A. protons
B. neutrons
C. electrons
D. both A and C

Chapter Assessment 4
Lithium has an atomic mass of 6.941 and two isotopes, one with 6 neutrons and one with 7 neutrons. Which isotope is more abundant?
A. 6Li
B. 7Li
C. Both isotopes occur equally.
D. unable to determine

Chapter Assessment 5
What happens when an element emits radioactive particles?
A. It gains energy.
B. It gains neutrons.
C. It loses stability.
D. It loses energy.

Standardized Test Practice
What is the smallest particle of an element that still retains the properties of that element?
A. proton
B. atom
C. electron
D. neutron
How many neutrons, protons, and electrons does \(^{124}_{54}\text{Xe}\) have?

A. 124 neutrons, 54 protons, 54 electrons  
B. 70 neutrons, 54 protons, 54 electrons  
C. 124 neutrons, 70 protons, 54 electrons  
D. 70 neutrons, 70 protons, 54 electrons

The primary factor in determining an atom’s stability is its ratio of neutrons to ___.

A. protons  
B. electrons  
C. alpha particles  
D. isotopes

What is the densest region of an atom?

A. electron cloud  
B. nucleus  
C. isotopes  
D. atomic mass

Why are electrons attracted to the cathode in a cathode ray tube?

A. The cathode is more stable.  
B. The cathode has a positive charge.  
C. The cathode has a negative charge.  
D. The cathode has no charge.