Chapter 4
Atomic Structure

4.1 Defining the Atom

4.2 Structure of the Nuclear Atom

4.3 Distinguishing Among Atoms

Doctors often use X-rays to see bones and other structures that cannot be seen through your skin. Scientists use many methods to “see” inside an atom.

How did scientists determine the structures that are inside an atom?
Subatomic Particles

What are three kinds of subatomic particles?

Much of Dalton’s atomic theory is accepted today.

- One important change, however, is that atoms are now known to be divisible.
- They can be broken down into even smaller, more fundamental particles, called subatomic particles.
Three kinds of subatomic particles are electrons, protons, and neutrons.

Electrons

In 1897, the English physicist J. J. Thomson (1856–1940) discovered the electron.

- Electrons are negatively charged subatomic particles.
Electrons

Thomson performed experiments that involved passing electric current through gases at low pressure.

- He sealed the gases in glass tubes fitted at both ends with metal disks called electrodes.
- The electrodes were connected to a source of electricity.

- One electrode, the anode, became positively charged.
- The other electrode, the cathode, became negatively charged.
Electrons

The result was a glowing beam, or **cathode ray**, that traveled from the cathode to the anode.

Thomson found that a cathode ray is deflected by electrically charged metal plates.

- A positively charged plate attracts the cathode ray, while a negatively charged plate repels it.
Electrons

Thompson knew that opposite charges attract and like charges repel, so he hypothesized that a cathode ray is a stream of tiny negatively charged particles moving at high speed.

- Thompson called these particles corpuscles.
- Later they were named electrons.

Electrons

A cathode ray can also be deflected by a magnet.
Electrons

To test his hypothesis, Thompson set up an experiment to measure the ratio of an electron’s charge to its mass.

- He found this ratio to be constant.
Electrons

To test his hypothesis, Thompson set up an experiment to measure the ratio of an electron’s charge to its mass.

• He found this ratio to be constant.
• Also, the charge-to-mass ratio of electrons did not depend on the kind of gas in the cathode-ray tube or the type of metal used for the electrodes.

Thompson concluded that electrons are a component of the atoms of all elements.
Electrons
An electron has one unit of negative charge, and its mass is 1/1840 the mass of a hydrogen atom.

Protons and Neutrons
If cathode rays are electrons given off by atoms, what remains of the atoms that have lost the electrons?

• For example, after a hydrogen atom (the lightest kind of atom) loses an electron, what is left?
Protons and Neutrons

You can think through this problem using four simple ideas about matter and electric charges.

1. Atoms have no net electric charge; they are electrically neutral.

2. Electric charges are carried by particles of matter.

3. Electric charges always exist in whole-number multiples of a single basic unit; that is, there are no fractions of charges.

4. When a given number of negatively charged particles combines with an equal number of positively charged particles, an electrically neutral particle is formed.
Protons and Neutrons

It follows that a particle with one unit of positive charge should remain when a typical hydrogen atom loses an electron.

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.
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.

Protons and Neutrons

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.
The table below summarizes the properties of these subatomic particles.

<table>
<thead>
<tr>
<th>Particle</th>
<th>Symbol</th>
<th>Relative charge</th>
<th>Relative mass (mass of proton = 1)</th>
<th>Actual mass (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron</td>
<td>e⁻</td>
<td>1⁻</td>
<td>1/1840</td>
<td>9.11 × 10⁻²⁸</td>
</tr>
<tr>
<td>Proton</td>
<td>p⁺</td>
<td>1⁺</td>
<td>1</td>
<td>1.67 × 10⁻²⁴</td>
</tr>
<tr>
<td>Neutron</td>
<td>n⁰</td>
<td>0</td>
<td>1</td>
<td>1.67 × 10⁻²⁴</td>
</tr>
</tbody>
</table>

Although protons and neutrons are extremely small, theoretical physicists believe that they are composed of yet smaller subnuclear particles called *quarks*. 
What evidence did Thompson have that led him to conclude the cathode ray was a stream of tiny negatively charged particles?

The ray was attracted to a metal plate with positive electric charge, and Thompson knew that opposite charges attract and like charges repel.
The Atomic Nucleus

How can you describe the structure of the nuclear atom?

When subatomic particles were discovered, scientists wondered how the particles were put together in an atom.
When subatomic particles were discovered, scientists wondered how the particles were put together in an atom.

- Most scientists—including J. J. Thompson—thought it likely that the electrons were evenly distributed throughout an atom filled uniformly with positively charged material.

- In Thomson’s atomic model, known as the “plum-pudding model,” electrons were stuck into a lump of positive charge, similar to raisins stuck in dough.
This model of the atom turned out to be short-lived, however, due to the work of a former student of Thomson, Ernest Rutherford (1871–1937).

- Born in New Zealand, Rutherford was awarded the Nobel Prize for Chemistry in 1908. His portrait appears on the New Zealand $100 bill.

### Rutherford’s Gold-Foil Experiment

In 1911, Rutherford and his co-workers wanted to test the existing plum-pudding model of atomic structure.

- They devised the gold-foil experiment.
- Their test used alpha particles, which are helium atoms that have lost their two electrons and have a double positive charge because of the two remaining protons.
Rutherford’s Gold-Foil Experiment

In the experiment, a narrow beam of alpha particles was directed at a very thin sheet of gold.

- According to the prevailing theory, the alpha particles should have passed easily through the gold, with only a slight deflection due to the positive charge thought to be spread out in the gold atoms.
Rutherford’s Gold-Foil Experiment

Rutherford’s results were that most alpha particles went straight through, or were slightly deflected.

- What was surprising is that a small fraction of the alpha particles bounced off the gold foil at very large angles.
- Some even bounced straight back toward the source.
How did scientists “see” inside an atom to determine the structures that are inside an atom?

Scientists determined the structures inside an atom by observing how the atom interacted with particles with known properties, like negatively charged electrons or positively charged alpha particles.
The Rutherford Atomic Model

Based on his experimental results, Rutherford suggested a new theory of the atom.

- He proposed that the atom is mostly empty space.
  - Thus explaining the lack of deflection of most of the alpha particles.

- He concluded that all the positive charge and almost all of the mass are concentrated in a small region that has enough positive charge to account for the great deflection of some of the alpha particles.
The Rutherford Atomic Model

The Rutherford atomic model is known as the nuclear atom.

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

According to this model, the nucleus is tiny and densely packed compared with the atom as a whole.

- If an atom were the size of a football stadium, the nucleus would be about the size of a marble.
The Rutherford Atomic Model

Rutherford’s model turned out to be incomplete.

- The Rutherford atomic model had to be revised in order to explain the chemical properties of elements.

What evidence from Rutherford’s Gold-Foil experiment disproves J.J. Thompson’s “plum-pudding model”?
What evidence from Rutherford’s Gold-Foil experiment disproves J.J. Thompson’s “plum-pudding model”?

Rutherford observed that most of the particles passed through the foil with no deflection, and a small fraction were deflected at large angles or reflected directly back. If the plum-pudding model was true, most alpha particles would have been deflected at small angles by the evenly-spaced electrons.

Key Concepts

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

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.
• **electron**: a negatively charged subatomic particle
• **cathode ray**: a stream of electrons produced at the negative electrode (cathode) of a tube containing a gas at low pressure
• **proton**: a positively charged subatomic particle found in the nucleus of an atom
• **neutron**: a subatomic particle with no charge and a mass of 1 amu; found in the nucleus of an atom
• **nucleus**: the tiny, dense central portion of an atom, composed of protons and neutrons

**Electrons and the Structure of Atoms**
Atoms have positively-charged protons and neutral neutrons inside a nucleus, and negatively-charged electrons outside the nucleus.
END OF 4.2