Inside the Atom

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CHAPTER 1 Inside the Atom

Lesson Objectives

- Compare and contrast protons, neutrons, and electrons.
- Describe the forces that hold the particles of atoms together.
- Define atomic number and mass number.
- Describe ions and isotopes
- Identify the particles called quarks.

Vocabulary

- atomic mass unit (amu)
- atomic number
- electron
- ion
- isotope
- mass number
- neutron
- nucleus
- proton
- quark

Introduction

Atoms are the smallest particles of an element that still have the element's properties. They are the building blocks of all matter. Individual atoms are extremely small. In fact, they are so small that trillions of them would fit inside the period at the end of this sentence. Yet atoms, in turn, consist of even smaller particles.

Parts of the Atom

Figure 1.1 represents a simple model of an atom. You will learn about more complex models in later lessons, but this model is a good place to start. You can see similar, animated models of atoms at this URL: http://web.jjay.cuny.edu/~acarpi/NSC/3-atoms.htm .

The Nucleus

At the center of an atom is the **nucleus** (plural, nuclei). The nucleus contains most of the atom's mass. However, in size, it's just a tiny part of the atom. The model in **Figure** 1.1 is not to scale. If an atom were the size of a football stadium, the nucleus would be only about the size of a pea.

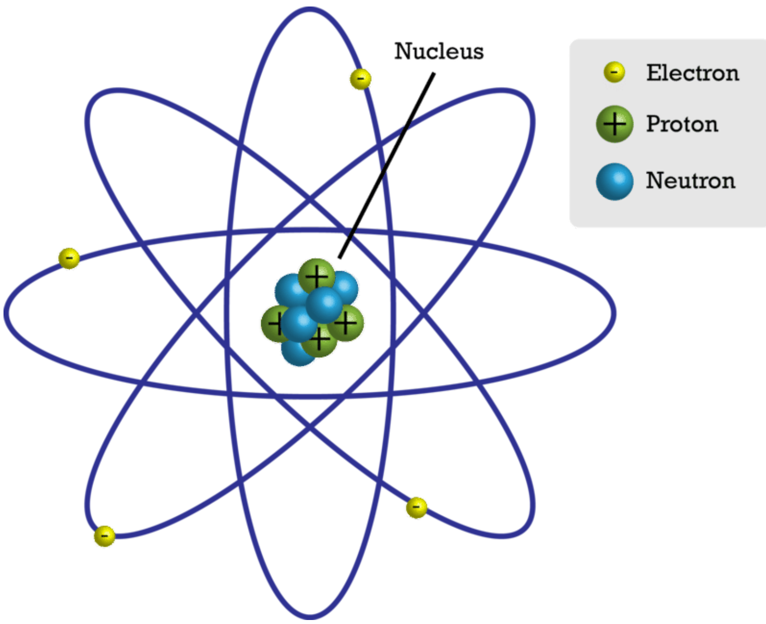


FIGURE 1.1
This simple atomic model shows the particles inside the atom.

The nucleus, in turn, consists of two types of particles, called protons and neutrons. These particles are tightly packed inside the nucleus. Constantly moving about the nucleus are other particles called electrons. You can see a video about all three types of atomic particles at this URL: http://www.youtube.com/watch?v=lP57gEWcisY (1:57).

Protons

A **proton** is a particle in the nucleus of an atom that has a positive electric charge. All protons are identical. It is the number of protons that gives atoms of different elements their unique properties. Atoms of each type of element have a characteristic number of protons. For example, each atom of carbon has six protons, as you can see in **Figure** 1.2. No two elements have atoms with the same number of protons.

Neutrons

A **neutron** is a particle in the nucleus of an atom that has no electric charge. Atoms of an element often have the same number of neutrons as protons. For example, most carbon atoms have six neutrons as well as six protons. This is also shown in **Figure** 1.2.

Electrons

An **electron** is a particle outside the nucleus of an atom that has a negative electric charge. The charge of an electron is opposite but equal to the charge of a proton. Atoms have the same number of electrons as protons. As a result, the negative and positive charges "cancel out." This makes atoms electrically neutral. For example, a carbon atom has six electrons that "cancel out" its six protons.

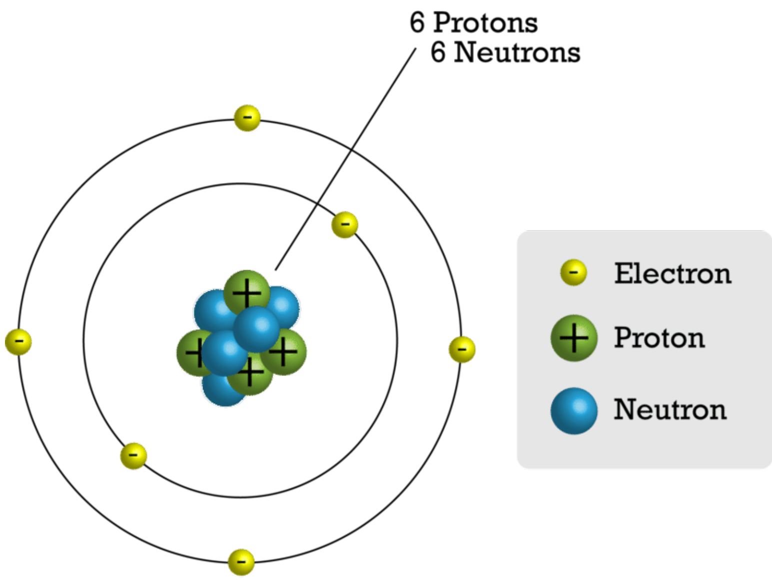


FIGURE 1.2
This model shows the particles that make up a carbon atom.

Atomic Forces

When it comes to atomic particles, opposites attract. Negative electrons are attracted to positive protons. This force of attraction keeps the electrons moving about the nucleus. An analogy is the way planets orbit the sun.

What about particles with the same charge, such as protons in the nucleus? They push apart, or repel, each other. So why doesn't the nucleus fly apart? The reason is a force of attraction between protons and neutrons called the strong force. The name of the strong force suits it. It is stronger than the electric force pushing protons apart. However, the strong force affects only nearby particles (see **Figure** 1.3). It is not effective if the nucleus gets too big. This puts an upper limit on the number of protons an atom can have and remain stable. You can learn more about atomic forces in the colorful tutorial at this URL: http://www.ric.edu/faculty/ptiskus/Atomic_Force/ .

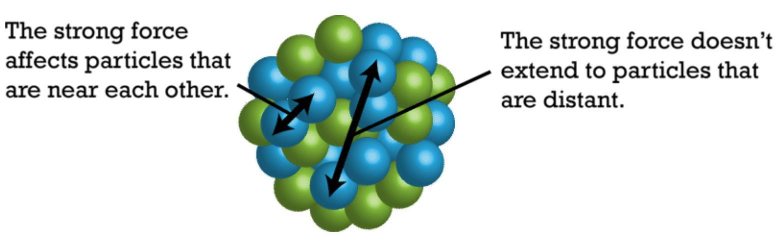


FIGURE 1.3
The strong force is effective only between particles that are very close together in the nucleus.

Atomic Number and Mass Number

Electrons have almost no mass. Instead, almost all the mass of an atom is in its protons and neutrons in the nucleus. The nucleus is very small, but it is densely packed with matter. The SI unit for the mass of an atom is the **atomic mass unit (amu)**. One atomic mass unit equals the mass of a proton, which is about 1.7×10^{-24} g. Each neutron also has a mass of 1 amu. Therefore, the sum of the protons and neutrons in an atom is about equal to the atom's total mass in atomic mass units.

Two numbers are commonly used to distinguish atoms: atomic number and mass number. **Figure** 1.4 shows how these numbers are usually written.

FIGURE 1.4
The symbol He stands for the element helium. Can you infer how many electrons a helium atom has?

- The **atomic number** is the number of protons in an atom. This number is unique for atoms of each kind of element. For example, the atomic number of all helium atoms is 2.
- The **mass number** is the number of protons plus the number of neutrons in an atom. For example, most atoms of helium have 2 neutrons, so their mass number is 2 + 2 = 4. This mass number means that an atom of helium has a mass of about 4 amu.

Problem Solving

Problem: An atom has an atomic number of 12 and a mass number of 24. How many protons and neutrons does the atom have?

Solution: The number of protons is the same as the atomic number, or 12. The number of neutrons is equal to the mass number minus the atomic number, or 24 –12 = 12.

You Try It!

Problem: An atom has an atomic number of 8 and a mass number of 16. How many neutrons does it have? What is the atom's mass in atomic mass units?

Ions and Isotopes

The number of protons per atom is always the same for a given element. However, the number of neutrons may vary, and the number of electrons can change.

Ions

Sometimes atoms lose or gain electrons. Then they become **ions**. Ions have a positive or negative charge. That's because they do not have the same number of electrons as protons. If atoms lose electrons, they become positive ions, or cations. If atoms gain electrons, they become negative ions, or anions.

Consider the example of fluorine in **Figure** 1.5. A fluorine atom has nine protons and nine electrons, so it is electrically neutral. If a fluorine atom gains an electron, it becomes a fluoride ion with a negative charge of minus one.

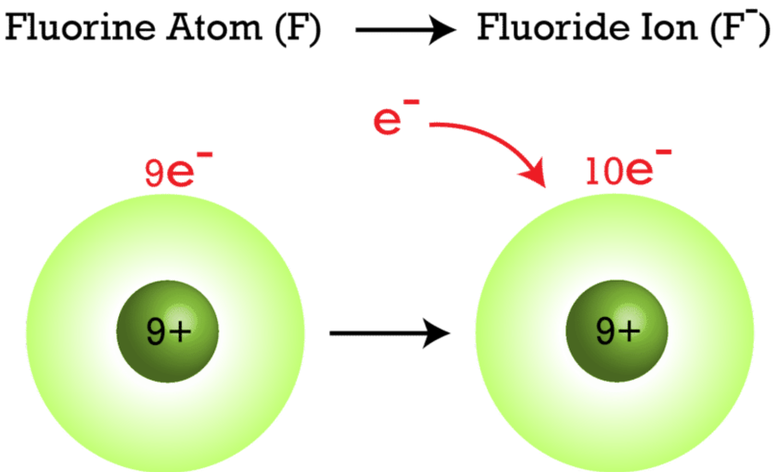
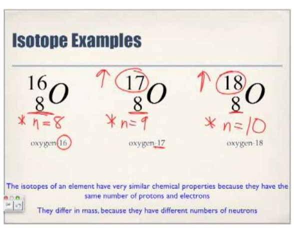


FIGURE 1.5
When a fluorine atom gains an electron, it becomes a negative fluoride ion.

Isotopes of Atoms

Some atoms of the same element may have different numbers of neutrons. For example, some carbon atoms have seven or eight neutrons instead of the usual six. Atoms of the same element that differ in number of neutrons are called **isotopes**. Many isotopes occur naturally. Usually one or two isotopes of an element are the most stable and common. Different isotopes of an element generally have the same chemical properties. That's because they have the same numbers of protons and electrons. For a video explanation of isotopes, go to this URL: http://www.youtube.com/watch?v=6w7raarHNA8 (5:23).



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An Example: Hydrogen Isotopes

Hydrogen is a good example of isotopes because it has the simplest atoms. Three isotopes of hydrogen are modeled in **Figure** 1.6. Most hydrogen atoms have just one proton and one electron and lack a neutron. They are just called hydrogen. Some hydrogen atoms have one neutron. These atoms are the isotope named deuterium. Other hydrogen atoms have two neutrons. These atoms are the isotope named tritium.

Naming Isotopes

For most other elements, isotopes are named for their mass number. For example, carbon atoms with the usual 6 neutrons have a mass number of 12 (6 protons + 6 neutrons = 12), so they are called carbon-12. Carbon atoms with 7 neutrons have an atomic mass of 13 (6 protons + 7 neutrons = 13). These atoms are the isotope called carbon-13. Some carbon atoms have 8 neutrons. What is the name of this isotope of carbon? You can learn more about this isotope at the URL below. It is used by scientists to estimate the ages of rocks and fossils.

http://www.khanacademy.org/video/carbon-14-dating-1?playlist=Chemistry

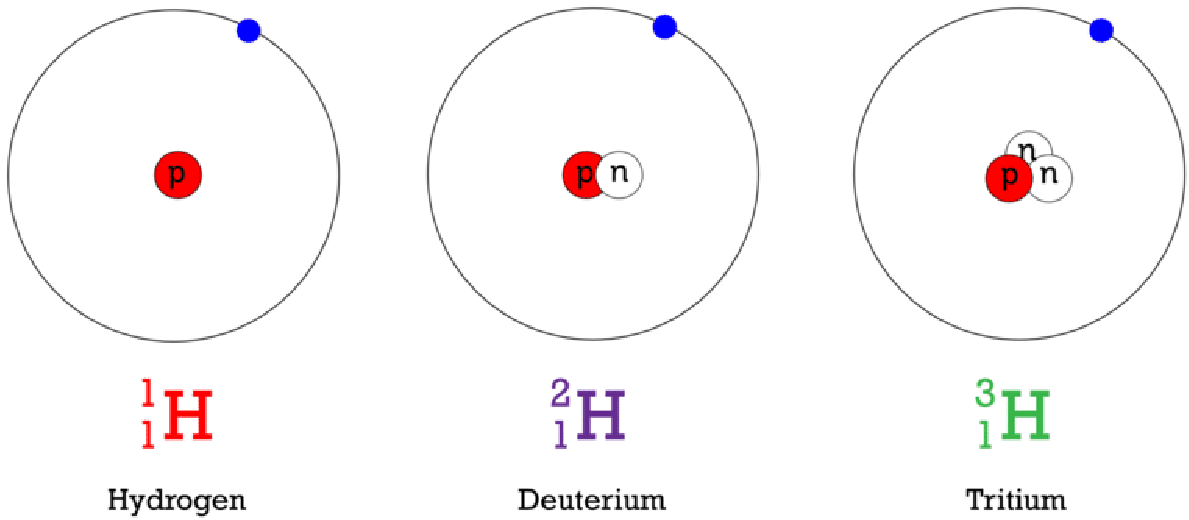

FIGURE 1.6
All isotopes of a given element have the same number of protons (P), but they differ in the number of neutrons (N). What is the mass number of each isotope shown here?

Back to Quarks

Remember the quarks from the first page of this chapter? **Quarks** are even tinier particles of matter that make up protons and neutrons. There are three quarks in each proton and three quarks in each neutron. The charges of quarks are balanced exactly right to give a positive charge to a proton and a neutral charge to a neutron. It might seem strange that quarks are never found alone but only as components of other particles. This is because the quarks are held together by very strange particles called gluons.

Gluons

Gluons make quarks attract each other more strongly the farther apart the quarks get. To understand how gluons work, imagine holding a rubber band between your fingers. If you try to move your hands apart, they will be pulled back together by the rubber band. The farther apart you move your hands, the stronger the force of the rubber band pulling your hands together. Gluons work the same way on quarks inside protons and neutrons (and other, really rare particles too).

If you were to move your hands apart with enough force, the rubber band holding them together would break. The same is true of quarks. If they are given enough energy, they pull apart with enough force to "break" the binding from the gluons. However, all the energy that is put into a particle to make this possible is then used to create a new set of quarks and gluons. And so a new proton or neutron appears.

Finding Quarks

The existence of quarks was first proposed in the 1960s. Since then, scientists have done experiments to show that quarks really do exist. In fact, they have identified six different types of quarks. However, much remains to be learned about these tiny, fundamental particles of matter. They are very difficult and expensive to study. If you want to learn more about them, including how they are studied, the URL below is a good place to start.

http://www.particleadventure.org/index.html

KQED: Homegrown Particle Accelerators

QUEST journeys back to find out how physicists on the UC Berkeley campus in the 1930s, and at the Stanford Linear Accelerator Center in the 1970s, created "atom smashers" that led to key discoveries about the tiny constituents of the atom and paved the way for the Large Hadron Collider in Switzerland. For more information on particle accelerators, see http://science.kqed.org/quest/video/homegrown-particle-accelerators/ .

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URL: https://www.ck12.org/flx/render/embeddedobject/129639

Lesson Summary

- The nucleus is at the center of the atom. It contains positive protons and neutral neutrons. Negative electrons constantly move about the nucleus.
- Atomic number is the number of protons in an atom. It is unique for the atoms of each element. Mass number is the number of protons plus neutrons in an atom. It is about equal to the mass of the atom in atomic mass units (amu).
- Negative electrons are attracted to positive protons, and this electric force keeps electrons moving about the nucleus. The force of attraction between protons and neutrons, called the strong force, holds the nucleus together.
- If atoms lose or gain electrons, they become positive or negative ions. Atoms of the same element that have different numbers of neutrons are called isotopes.
- Quarks are even tinier particles of matter that make up protons and neutrons. Scientists have identified six different types of quarks.

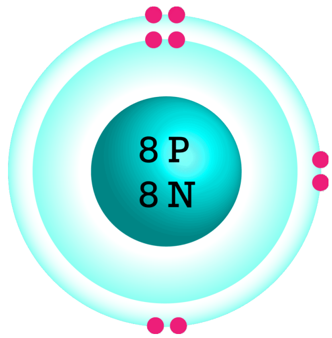
Lesson Review Questions

Recall

1. Describe the nucleus of an atom.
2. Outline the forces that hold particles together in an atom.
3. What does the atomic number of an atom represent?
4. Define isotope. Give an example.
5. What are quarks?

Apply Concepts

6. If an atom gains electrons, it becomes an ion. Is the ion positively or negatively charged? Explain your answer.
7. What is the atomic mass (in atomic mass units) of the atom represented by the model below?



Think Critically

8. Make a table comparing and contrasting protons, neutrons, and electrons. Include their location, mass, and electric charge.
9. Explain why atoms are neutral in electric charge.

Points to Consider

In this lesson, you saw several simple models of atoms. Models are useful for representing things that are very small. Scientists have used models to represent atoms for more than 200 years. In the next lesson, "History of the Atom," you'll read about some of the earlier models.

- How might scientists have modeled atoms before the particles inside atoms were discovered?
- How do you think earlier models might have differed from the models in this lesson?

References

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