Atomic Structure

Scientists once believed atoms were the smallest particles of matter. Science is continually changing as new discoveries are made, and at some point it became clear to scientists that atoms themselves are made of even tinier particles. Today we believe atoms are made of three **subatomic particles**. Subatomic particles are smaller particles that make up atoms. These include the proton, electron, and neutron. It's amazing that the incredible variety of matter around us can be built from just three subatomic particles!

Knowledge TEKS

8.5.A: Describe the structure of atoms, including the masses, electrical charges, and locations, of protons and neutrons in the nucleus and electrons in the electron cloud

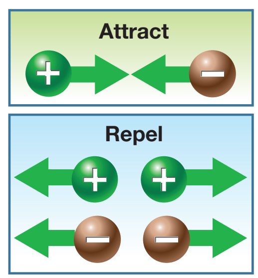
Electrical charge

Electrical charge is a property of matter

In order to understand atoms, we need to understand **electrical charge**. Electrical charge is a fundamental property of matter that can be either positive or negative. By saying that it is a fundamental property we mean that it is a basic part of all matter. One of the two forces that hold atoms together comes from electrical charge.

Positive and negative

There are two different kinds of electrical charge—positive and negative. Because there are two kinds of charge, the force between electrical charges can be either attractive or repulsive. A positive and a negative charge will attract each other. Two positive charges will repel each other. Two negative charges will also repel each other. These charges are part of the electron and proton subatomic particles.



The elementary charge

We use the lowercase letter *e* to represent the **elementary charge**. The elementary charge is the smallest unit of electrical charge that is possible in ordinary matter. At the atomic level, electrical charge always comes in whole units of +e or –e. It is only possible to have charges that are multiples of e, such as +e, +2e, –e, –2e, –3e, and so on. Scientists believe it is impossible for ordinary matter to have charges that are fractions of e. For example, a charge of +0.5e is impossible in ordinary matter. In other words, electrical charge only appears in whole units of the elementary charge (Figure 5.1).

VOCABULARY

subatomic particles – smaller particles that make up atoms

electrical charge – a fundamental property of matter that can be either positive or negative

elementary charge – the smallest unit of electrical charge that is possible in ordinary matter; represented by the lowercase letter *e*

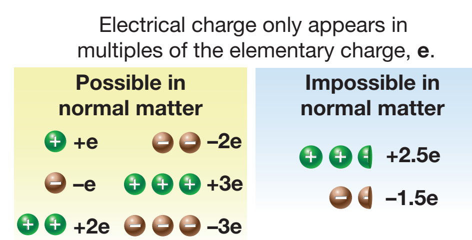


Figure 5.1: *Electrical charge appears only in whole units of the elementary charge, e.*

Inside an atom: Solving the puzzle

The electron identified

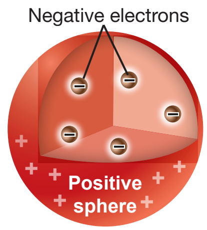
The first strong evidence that something smaller than an atom existed came in 1897. English physicist J. J. Thomson discovered that electricity passing through a gas caused the gas to give off particles that were too small to be atoms. The new particles had negative electrical charge. Atoms have zero charge. Thomson's particles are now known as **electrons**. Electrons were the first particles discovered that are smaller than atoms.

An early model of an atom

Thomson proposed that negative electrons were sprinkled around inside atoms like raisins in a loaf of raisin bread. The "bread" was positively charged and the electrons were negatively charged. This was the first real model for the inside of an atom. As it turned out, it was not the *correct* model, but it was a good place to start.

Testing the model with an experiment

In 1911, Ernest Rutherford, Hans Geiger, and Ernest Marsden did an experiment to test Thomson's model of the atom. They launched positively-charged helium ions (a charged atom is called an ion) at a very thin gold foil (Figure 5.2). They expected most of the helium ions to be deflected a little as they plowed through the gold atoms.



An unexpected result!

Instead, they found something quite unexpected. Most of the helium ions passed right through the gold foil with no deflection at all. Even more surprising, a few of the ions bounced back in the direction they came! This unexpected result prompted Rutherford to say, "It was as if you fired a five-inch [artillery] shell at a piece of tissue paper and it came back and hit you!"

The nuclear model of the atom

The best way to explain the pass-through result was if a gold atom was mostly empty space. If most of the helium ions hit nothing, they wouldn't be deflected. The best way to explain the bounce-back result was if nearly all the mass of a gold atom were concentrated in a tiny, hard core at the center and only a few of the ions hit these hard cores and bounced back. Further experiments confirmed Rutherford's idea about this hard core. We now know that every atom has a tiny **nucleus**, which contains more than 99 percent of the atom's mass.

VOCABULARY

electron – a particle with an electric charge (–e) found inside of atoms but outside the nucleus

nucleus – the tiny core at the center of an atom containing most of the atom's mass and all of its positive charge

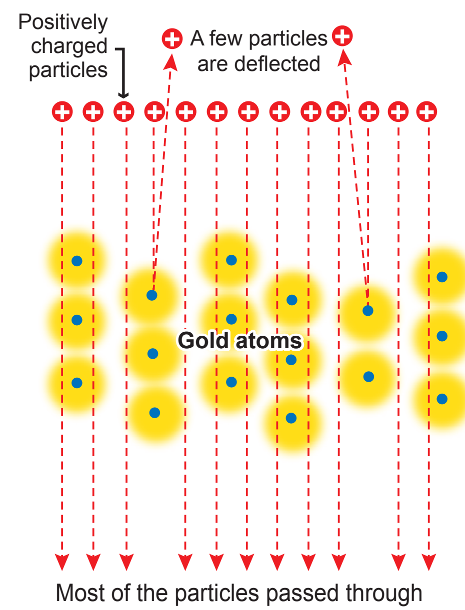


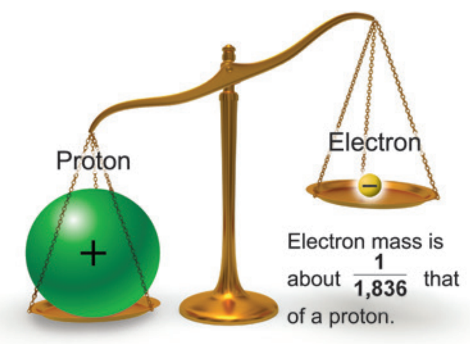
Figure 5.2: *Rutherford's famous experiment led to the discovery of the nucleus.*

Three particles make up all atoms

Protons and neutrons Today we know that the nucleus contains protons and neutrons. **Protons** have positive charge, the opposite charge of electrons. The charge on a proton (+e) and an electron (–e) are exactly equal and opposite. **Neutrons** have zero electric charge.

The nucleus contains most of the mass Protons and neutrons are *much* more massive than electrons. A proton has 1,836 times as much mass as an electron. A neutron has about the same mass as a proton. The chart below compares electrons, protons, and neutrons in terms of charge and mass. Because protons and neutrons have so much more mass, more than 99 percent of an atom's mass is in the nucleus.

The electron cloud occupies most of the volume of an atom Electrons take up the region outside the nucleus in a region called the electron cloud. The diameter of an atom is really the diameter of the electron cloud (Figure 5.3). Compared to the tiny nucleus, the electron cloud is enormous, more than 10,000 times larger than the nucleus. If an atom were the size of a football stadium, the nucleus would be the size of a pea, and the electrons would be equivalent to a small swarm of gnats buzzing around the stadium at extremely high speed. Can you imagine how much empty space there would be in the stadium? An atom is mostly empty space!



Particle	Occurence	Relative Charge	Mass (g)	Relative Mass
Electron	Found outside nucleus in electron cloud	–1	9.109×10^{-28}	1
Proton	Found in all nuclei	+1	1.673×10^{-24}	1,836
Neutron	Found in almost all nuclei (exception: most H nuclei do not have neutrons)	0	1.675×10^{-24}	1,839

VOCABULARY

proton – a particle found in the nucleus with a positive charge exactly equal and opposite to the electron

neutron – a particle found in the nucleus with mass similar to the proton but with zero electric charge

Size and Structure of the Atom

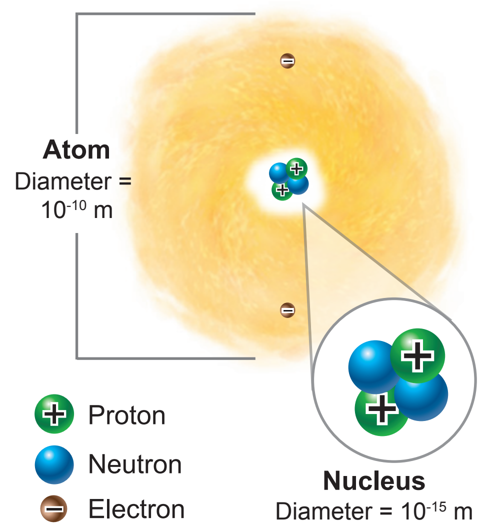


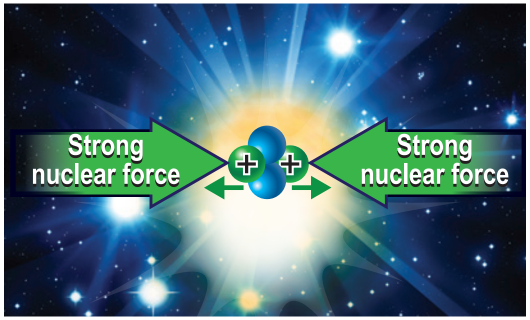
Figure 5.3: *The overall size of an atom is the size of its electron cloud. The nucleus is much, much smaller.*

Four fundamental forces of matter

Two forces, the electric force and strong nuclear force, keep the parts of atoms together. In total there are four fundamental forces in all matter: the electric force, the strong nuclear force, the weak force, and **gravity**. Although the weak force and gravity are present in atoms, in general their effects are not felt inside atoms. The electric force and strong nuclear force are the most important for understanding the ways atoms are structured.

Electric force The **electric force** is the attractive force between electrons and protons. Electrons are bound to the nucleus by the attractive force between electrons (–) and protons (+). The electrons don't fall into the nucleus because they have kinetic energy, or momentum. The energy of an electron causes it to move around the nucleus instead of falling in (Figure 5.4). This is similar to Earth orbiting the Sun. Gravity creates a force that pulls Earth toward the Sun but Earth's kinetic energy causes it to orbit the Sun rather than fall straight in.

Strong nuclear force All the positively charged protons in the nucleus repel one another due to electric force. So, what holds the nucleus together? There is another force that is even stronger than the electric force. The **strong nuclear force** is the strongest force known in science. This force attracts neutrons and protons to one another and works only at the extremely small distances inside an atom's nucleus (see image below). If there are enough neutrons, the attraction from the strong nuclear force wins out over repulsion from the electric force and the nucleus stays together. In every atom heavier than helium, there is at least one neutron for every proton in the nucleus.



VOCABULARY

gravity – the attractive force between anything that has mass

electric force – the attractive force between electrons and protons

strong nuclear force – the strongest force known to science that attracts neutrons and protons to one another

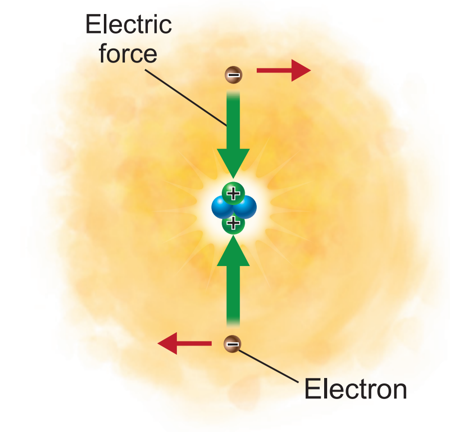
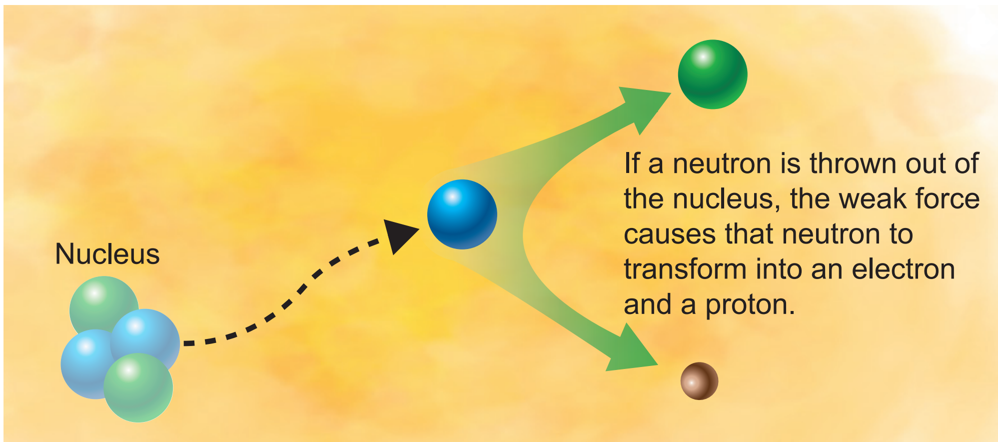


Figure 5.4: *The negative electrons are attracted to the positive protons in the nucleus, but the electrons' momentum keeps them from falling in.*

Weak force The **weak force** is the force that transforms a neutron into a proton and an electron when the neutron is outside the nucleus. While the electric force and strong nuclear force attract and repel different parts of the atom, the weak force causes a change to the neutron of an atom. This only happens in very special conditions, when the neutron is left outside the nucleus (see image below). If a single neutron is outside the nucleus, the weak force eventually causes the neutron to break down into a proton and an electron. The weak force does not play an important role in a stable atom, but comes into action in special cases when atoms break apart.



Gravity The force of gravity inside the atom is much weaker even than the weak force. It takes a relatively large mass to create enough gravity to make a significant force. We know that particles inside an atom do not have enough mass for gravity to be an important force on the scale of atoms (Figure 5.5). There are many unanswered questions about the way gravity works inside atoms. Understanding how gravity works inside atoms is an unsolved mystery in science. Perhaps this is a mystery that you will solve someday!

VOCABULARY

weak force – the force that changes a neutron to a proton and an electron when it is outside the nucleus

The Four Elementary Forces

Strong nuclear force
This force holds the nucleus of an atom together. This force is very strong but only reaches a very short distance.

Electromagnetic force
This force acts between positive and negative charges. This force holds atoms together in molecules.

Weak force
This force causes some kinds of radioactivity.

Gravity
This force causes all masses to attract one another. Your weight comes from the mass of Earth attracting the mass of your body.

Figure 5.5: *The location and strength of the four fundamental forces are described here.*

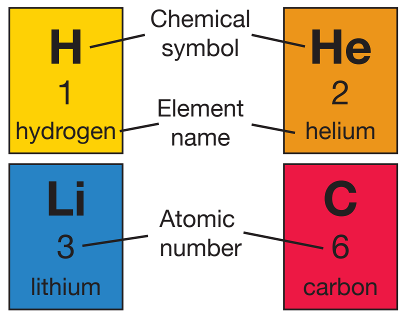
How atoms of various elements are different

The atomic number is the number of protons

How is an atom of one element different from an atom of another element? The atoms of different elements contain different numbers of protons in the nucleus. For example, all atoms of carbon have six protons in the nucleus and all atoms of hydrogen have one proton in the nucleus (Figure 5.6). Because the number of protons is so important, it is called the **atomic number**. The atomic number of an element is the number of protons in the nucleus of every atom of that element.

Elements on the periodic table

Each element has a unique atomic number. On the **periodic table of elements**, a chart that organizes the elements, the atomic number is usually written above or below the chemical symbol. In the diagram (below) you can see several examples of elements from the periodic table. An atom with only one proton in its nucleus is the element hydrogen, atomic number 1. An atom with two protons is the element helium, atomic number 2. An atom with three protons is the element lithium, atomic number 3. And an atom with six protons is the element carbon, atomic number 6.



Complete atoms are electrically neutral

The number of protons and electrons in a complete atom are always equal. For example, hydrogen has one proton in its nucleus and one electron outside the nucleus. The total electric charge of a hydrogen atom is zero because the negative charge of the electron cancels the positive charge of the proton. Each carbon atom has six electrons, one for each of carbon's six protons. Like hydrogen, a complete carbon atom is electrically neutral. If the atom was missing an electron it would have an overall positive charge. This is an important concept that we'll explore further when we talk about the ways atoms combine with one another.

VOCABULARY

atomic number – the number of protons in the nucleus of every atom of that element

periodic table of elements – a chart that organizes the elements by their chemical properties and increasing atomic numbers

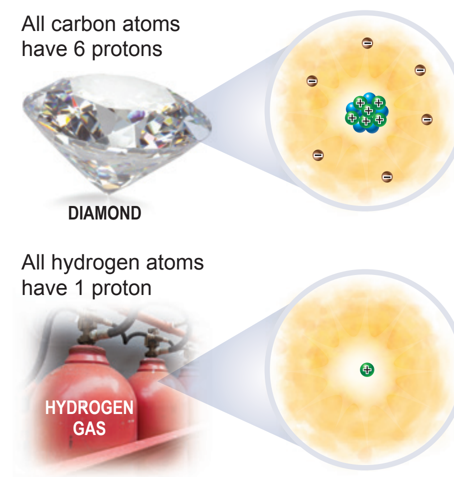


Figure 5.6: *Atoms of the same element always have the same number of protons in the nucleus.*

Isotopes

Isotopes All atoms of the same element have the same number of protons in the nucleus. However, atoms of the same element may have different numbers of neutrons in the nucleus. **Isotopes** are atoms of the *same* element that have different numbers of neutrons.

The isotopes of carbon Figure 5.7 shows three isotopes of carbon that exist in nature. Most carbon atoms have six protons and six neutrons in the nucleus. However, some carbon atoms have seven or eight neutrons. They are all carbon atoms because they all contain six protons, but they are different *isotopes* of carbon. The isotopes of carbon are called carbon-12, carbon-13, and carbon-14. The number after the name is called the mass number. The **mass number** of an isotope tells you the number of protons plus the number of neutrons.

VOCABULARY

isotopes – atoms of the same element that have different numbers of neutrons in the nucleus

mass number – the number of protons plus the number of neutrons in the nucleus

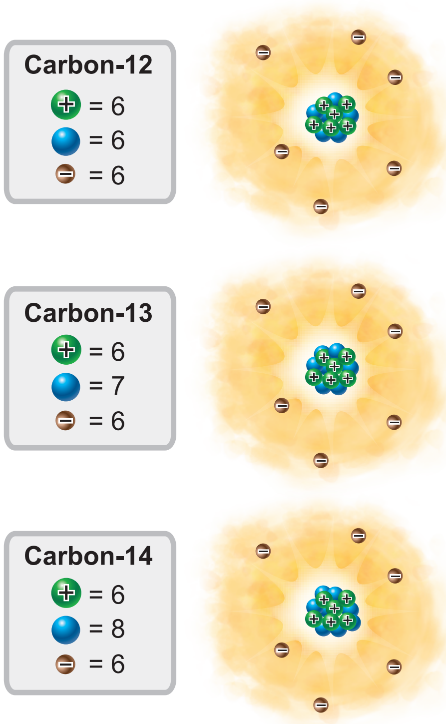


Figure 5.7: *The isotopes of carbon are shown.*

Calculating the Number of Neutrons in a Nucleus

How many neutrons are present in an aluminum atom that has an atomic number of 13 and a mass number of 27?

1.	**Looking for:**	You are asked to find the number of neutrons.
2.	**Given:**	You are given the atomic number and the mass number.
3.	**Relationships:**	Use the relationship: protons + neutrons = mass number.
4.	**Solution:**	Plug in and solve: neutrons = 27 – 13 = 14 The aluminum atom has 14 neutrons.

Your turn...

a. How many neutrons are present in a magnesium atom with a mass number of 24?

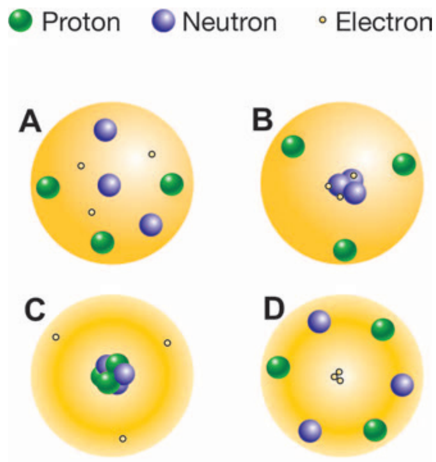
b. Find the number of neutrons in a calcium atom that has a mass number of 40.

Answers are listed at the end of the chapter.

Check Your Understanding

1. Which of the following statements regarding electric charge is true?
   - **a.** a positive charge repels a negative charge
   - **b.** a positive charge repels a neutron
   - **c.** a positive charge repels an electron
   - **d.** a positive charge repels another positive charge

2. Which of the drawings shown to the right is the most accurate model of the interior of an atom?



3. Which of the following is NOT a fundamental force of nature?
   - **a.** the weak force
   - **b.** the strong nuclear force
   - **c.** centripetal force
   - **d.** the force of gravity

4. There are three particles inside an atom. One of them has zero electric charge. Which one is it?
   - **a.** the proton
   - **b.** the neutron
   - **c.** the electron
   - **d.** the molecule

5. All atoms of the same element have ________ .
   - **a.** the same number of neutrons
   - **b.** the same number of protons
   - **c.** the same mass
   - **d.** the same temperature

6. The atomic number is ________ .
   - **a.** the number of protons in the nucleus
   - **b.** the number of neutrons in the nucleus
   - **c.** the number of neutrons plus protons
   - **d.** the number of electrons in the nucleus

Excerpt from *Texas Science, Grade 8*