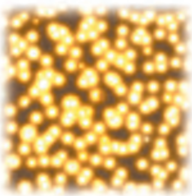
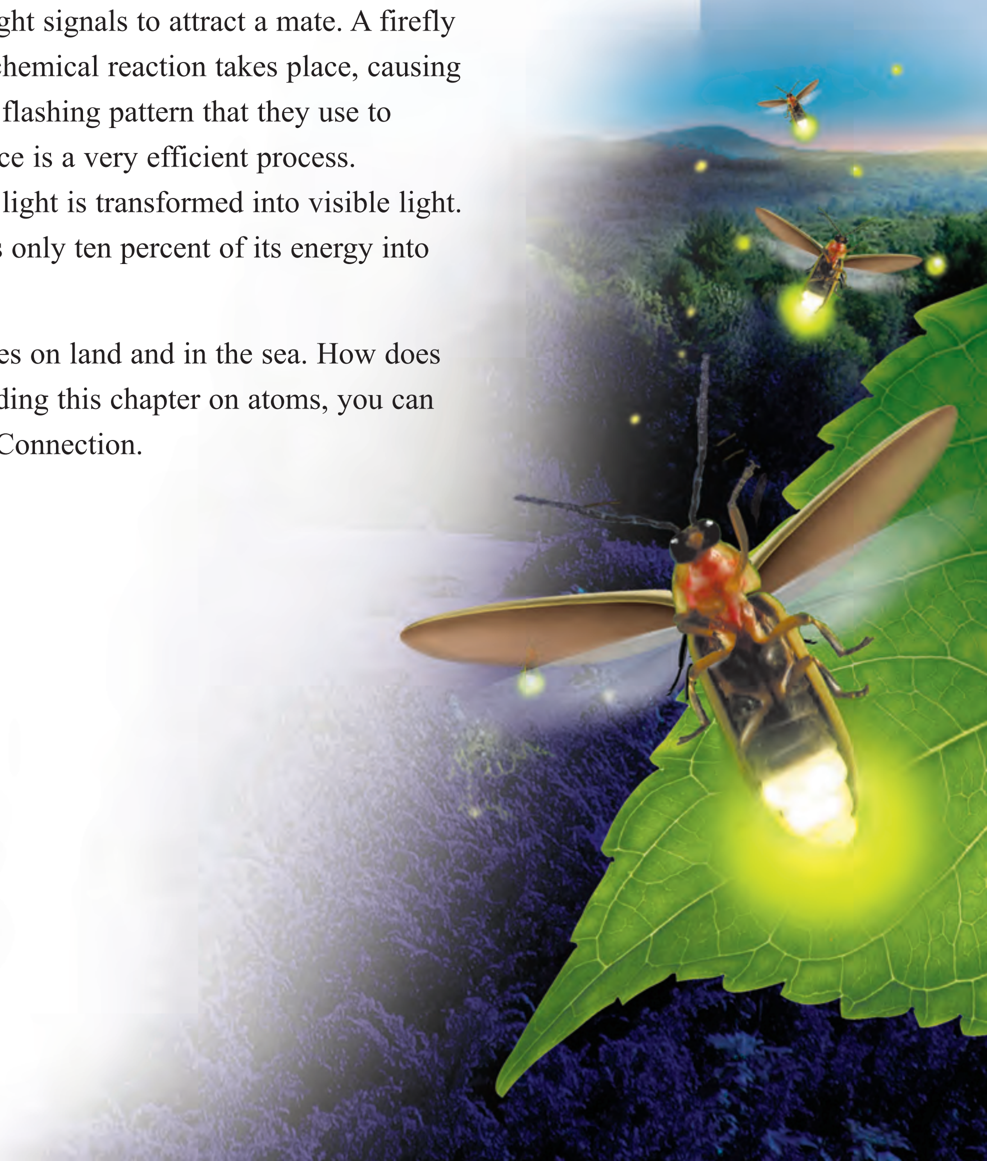
Chapter 14

Atoms



Have you ever seen fireflies on a warm summer night? These amazing creatures use a process called bioluminescence (bio means "living" and luminesce means "to glow") to create light signals to attract a mate. A firefly has special light-emitting organs in its abdomen where a chemical reaction takes place, causing the emission of light. Each species of firefly has a unique flashing pattern that they use to locate other members of the same species. Bioluminescence is a very efficient process. About 90 percent of the energy used by a firefly to create light is transformed into visible light. Contrast that with an incandescent light bulb that converts only ten percent of its energy into visible light.

There are many other examples of bioluminescent creatures on land and in the sea. How does bioluminescence work? It has to do with atoms! After reading this chapter on atoms, you can read about how living things produce light in the chapter Connection.



Key Questions:

- ✔ *What is the structure of an atom?*
- ✔ *What holds an atom together?*
- ✔ *What does light have to do with atoms?*

14.1 The Structure of the Atom

Scientists once believed atoms were the smallest particles of matter. With the advancement of technology, it became clear that atoms themselves are made of simpler particles. Today, we believe atoms are made of three basic particles: the proton, electron, and neutron. It's amazing that the incredible variety of matter around us can all be built from just three subatomic particles!

Electric charge

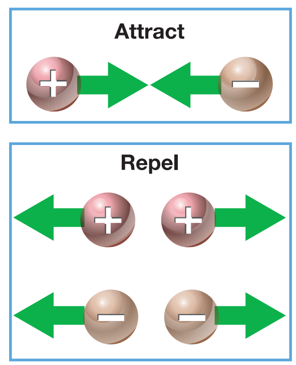
Electric charge is a property of matter

In order to understand atoms, we need to understand the idea of *electric charge*. **Electric charge** is a fundamental property of matter that can be either positive or negative. One of the two forces that hold atoms together comes from electric charge.

Positive and negative

There are two different kinds of electric charge—*positive* and *negative*. Because there are two kinds of charge, the force between electric 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.



The elementary charge

Scientists use the letter *e* to represent the **elementary charge**. At the size of atoms, electric charge always comes in units of +*e* or –*e*. It is *only* possible to have charges that are multiples of *e*, such as +e, +2*e*, –*e*, –2*e*, –3*e*, and so on. Scientists believe it is *impossible* for ordinary matter to have charges that are fractions of *e*. For example, a charge of +0.5*e* is impossible in ordinary matter. Electric charge only appears in whole units of the elementary charge (Figure 14.1).

VOCABULARY

electric charge - a fundamental property of matter that can be either positive or negative.

elementary charge - the smallest unit of electric charge that is possible in ordinary matter; represented by the lowercase letter *e*.

Electric charge only appears in multiples of the elementary charge, *e*.

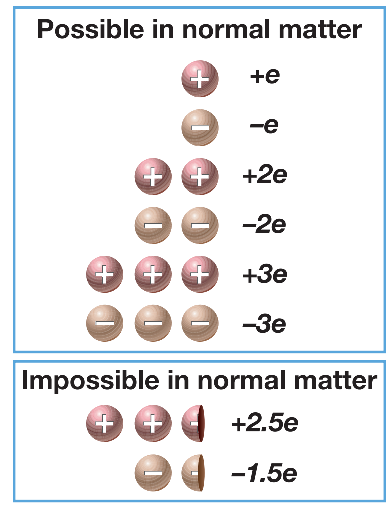


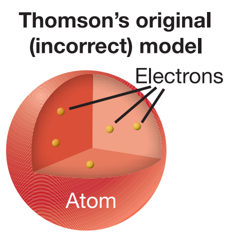
Figure 14.1: *Just as normal matter is divided into atoms, electric charge appears only in whole units of the elementary charge,* e.

Inside an atom: Solving the puzzle

The electron identified

The first strong evidence that something smaller than an atom existed was found 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 electric 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 soon turned out, it was not the *right* 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 an *ion*) at a very thin gold foil (Figure 14.2). They expected most of the helium ions to be deflected a little as they plowed through the gold atoms.

An unexpected result!

They found something quite unexpected. Most of the helium ions passed right through the foil with no deflection at all. Even more surprising—a few bounced back in the direction they came! This unexpected result prompted Rutherford to remark, "It was as if you fired a fifteen-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, dense core at the center. Further experiments confirmed Rutherford's idea about this dense 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.

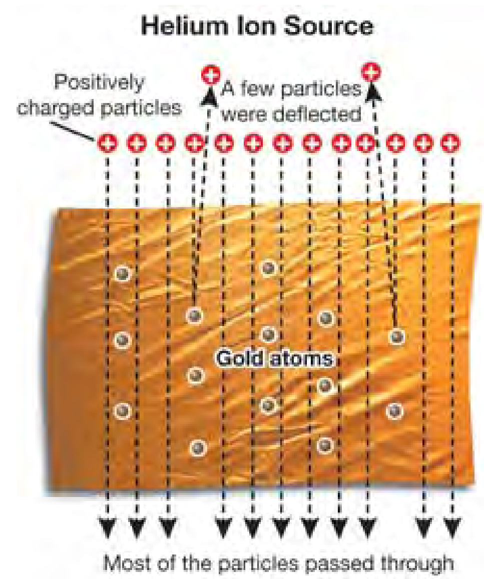


Figure 14.2: *Rutherford's famous experiment led to the discovery of the nucleus.*

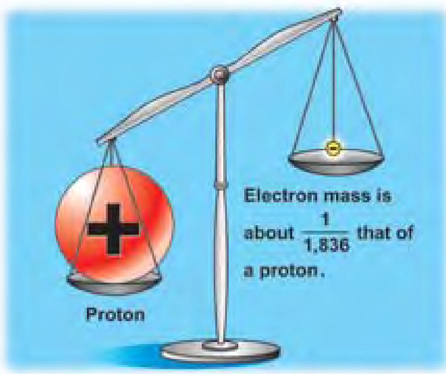
SC.912.N.2.5-Describe instances in which scientists' varied backgrounds, talents, interests, and goals influence the inferences and thus the explanations that they make about observations...
SC.912.P.8.4-Explore the scientific theory of atoms (also known as atomic theory) by describing the structure of atoms in terms of protons, neutrons and electrons, and differentiate among these particles in terms of their mass, electrical charges and locations within.

Three particles make up all atoms

Protons and neutrons

Today we know that the nucleus of an atom contains *protons* and *neutrons*. **Protons** have positive charge, opposite 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% of an atom's mass is in the nucleus.

	Occurrence	Charge	Mass (g)	Relative Mass
Electron	found outside of nuclei	−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)	0	1.675×10^{-24}	1,839

Electrons define the volume of an atom

Electrons occupy the space *outside* the nucleus in a region called the *electron cloud*. The diameter of an atom is really the diameter of the electron cloud (Figure 14.3). Compared to the tiny nucleus, the electron cloud is enormous, more than 10,000 times larger than the nucleus. As a comparison, 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 an extremely high speed. Can you imagine how much empty space there would be in the stadium? An atom is mostly empty space!

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.

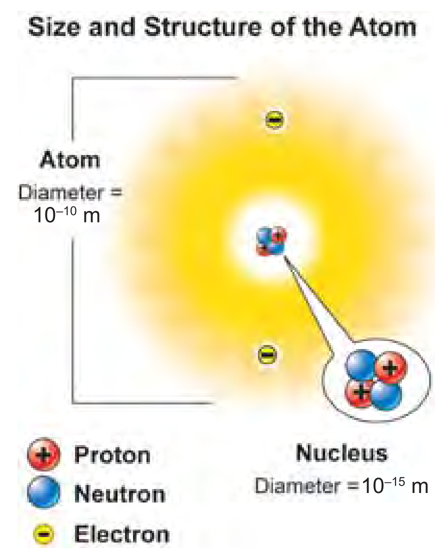


Figure 14.3: *The overall size of an atom is the size of its electron cloud. The nucleus is much, much smaller.*

SC.912.P.8.4-Explore the scientific theory of atoms (also known as atomic theory) by describing the structure of atoms in terms of protons, neutrons and electrons, and differentiate among these particles in terms of their mass, electrical charges and locations within.

Forces inside atoms

Electromagnetic forces

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 14.4). A good analogy is Earth orbiting the Sun. Gravity creates a force that pulls Earth toward the Sun. Earth's kinetic energy causes it to orbit the Sun rather than fall straight in. While electrons don't really move in orbits, the energy analogy is approximately right.

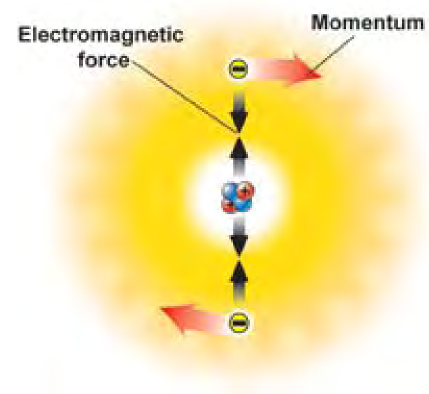


Figure 14.4: *The negative electrons are attracted to the positive protons in the nucleus, but their momentum keeps them from falling in.*

Strong nuclear force

Because of electric force, all the positively charged protons in the nucleus *repel* each other. So, what holds the nucleus together? There is another force that is even stronger than the electric force. We call it the *strong nuclear force*. The strong nuclear force is the strongest force known to science (Figure 14.5). This force attracts neutrons and protons to each other and works only at the extremely small distances inside the nucleus. If there are enough neutrons, the attraction from the strong nuclear force wins out over repulsion from the electromagnetic force and the nucleus stays together. In every atom heavier than helium, there is at least one neutron for every proton in the nucleus.

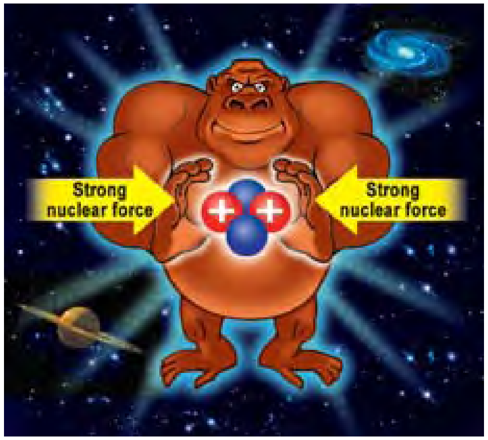


Figure 14.5: *When enough neutrons are present, the strong nuclear force wins out over the repulsion between positively charged protons and pulls the nucleus together tightly. The strong nuclear force is the strongest known force in the universe.*

Weak force

There is another nuclear force called the *weak force*. The weak force is weaker than both the electric force and the strong nuclear force. If you leave a single neutron outside the nucleus, the weak force eventually causes it 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 certain special cases when atoms break apart.

Gravity

The force of gravity inside the atom is much weaker than even 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. But there are many unanswered questions. Understanding how gravity works inside atoms is an unsolved scientific mystery.

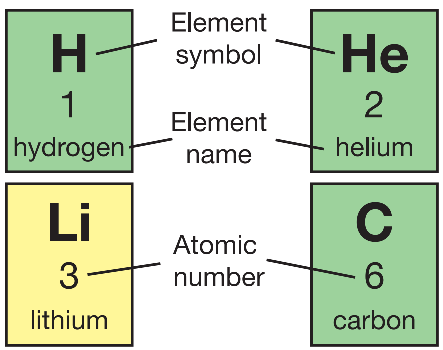
SC.912.P.10.10-Compare the magnitude and range of the four fundamental forces (gravitational, electromagnetic, weak nuclear, strong nuclear).

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 varying 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 14.6). 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 have unique atomic numbers



Each element has a unique atomic number. On a periodic table of elements, the atomic number is usually written above or below the atomic symbol. An atom with only one proton in its nucleus is the element hydrogen, atomic number 1. An atom with six protons is the element carbon, atomic number 6. Atoms with seven protons are nitrogen, atoms with eight protons are oxygen, and so on.

Complete atoms are electrically neutral

Because protons and electrons attract each other with very large forces, the number of protons and electrons in a *complete* atom is always equal. For example, hydrogen has one proton in its nucleus and one electron outside the nucleus. The net 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.

Ions

Ions are atoms that have a different number of protons than electrons and so have a net electric charge. Positively charged ions have more protons than electrons. Negatively charged ions have more electrons than protons. You will read more about ions in Chapter 16.

VOCABULARY

atomic number - the number of protons in the nucleus of an atom. The atomic number determines what element the atom represents.

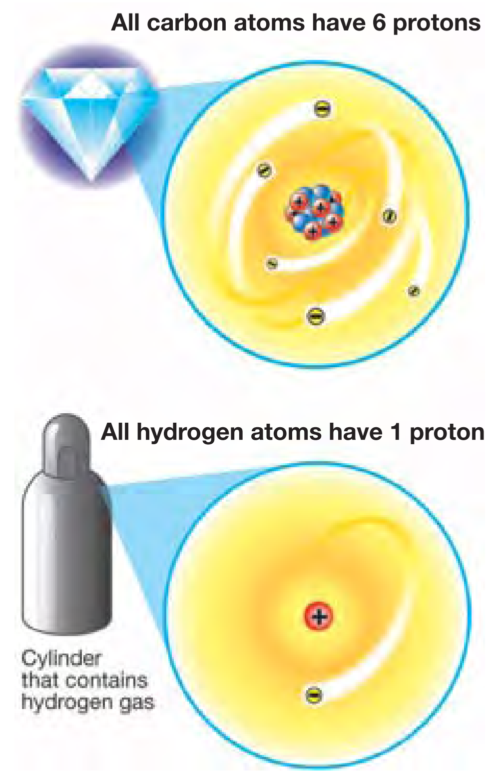


Figure 14.6: *Atoms of the same element always have the same number of protons in the nucleus.*

SC.912.P.8.4-Explore the scientific theory of atoms (also known as atomic theory) by describing the structure of atoms in terms of protons, neutrons and electrons, and differentiate among these particles in terms of their mass, electrical charges and locations within.
SC.912.P.8.5-Relate properties of atoms and their position in the periodic table to the arrangement of their electrons.

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 14.7 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.

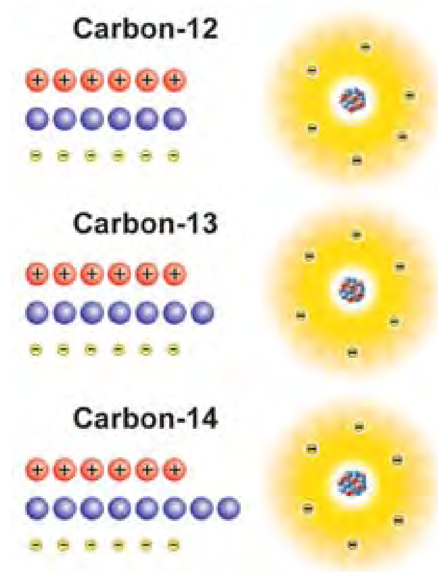


Figure 14.7: *The isotopes of carbon.*

Solving Problems: Isotopes

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: $13 + x = 27$; $x = 14$
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.

Solve first Look later

a. 12

b. 20

Radioactivity

What if there are too many neutrons?

Almost all elements have one or more isotopes that are **stable**. Stable means the nucleus stays together. For complex reasons, the nucleus of an atom becomes unstable if it contains too many or too few neutrons relative to the number of protons. If the nucleus is unstable, it breaks apart. Carbon has two stable isotopes, carbon-12 and carbon-13. Carbon-14 is **radioactive** because it has an unstable nucleus. An atom of carbon-14 eventually changes into an atom of nitrogen-14.

Radioactivity

If an atomic nucleus is unstable for any reason, the atom eventually changes into a more stable form. Radioactivity is a process in which the nucleus spontaneously emits particles or energy as it changes into a more stable isotope. Radioactivity can change one element into a completely different element.

Alpha decay

When *alpha decay* occurs, the nucleus ejects two protons and two neutrons (Figure 14.8). Check the periodic table and you can quickly find that two protons and two neutrons are the nucleus of a helium-4 (He-4) atom. Alpha radiation is actually fast-moving He-4 nuclei. When alpha decay occurs, the atomic number is reduced by two because two protons are removed. The atomic mass is reduced by four because two neutrons go along with the two protons. For example, uranium-238 undergoes alpha decay to become thorium-234.

Beta decay

Beta decay occurs when a neutron in the nucleus splits into a proton and an electron. The proton stays in the nucleus, but the high energy electron is ejected (this is called beta radiation). During beta decay, the atomic number increases by one because one new proton is created. The mass number stays the same because the atom lost a neutron but gained a proton.

Gamma decay

Gamma decay is how the nucleus gets rid of excess energy. In gamma decay, the nucleus emits pure energy in the form of gamma rays. The number of protons and neutrons stays the same.

VOCABULARY

stable - a nucleus is stable if it stays together.

radioactive - a nucleus is radioactive if it spontaneously breaks up, emitting particles or energy in the process.

Alpha decay

Nucleus ejects a helium-4 nucleus

Protons	Decrease by 2
Neutrons	Decrease by 2
Atomic number	Decreases by 2
Mass number	Decreases by 4

Beta decay

Nucleus converts a neutron to a proton and an electron, ejecting the electron.

Protons	Increase by 1
Neutrons	Decrease by 1
Atomic number	Increases by 1
Mass number	Stays the same

Figure 14.8: *Two common radioactive decay reactions.*

SC.912.P.10.11-Explain and compare nuclear reactions (radioactive decay, fission and fusion), the energy changes associated with them and their associated safety issues.
SC.912.P.10.12-Differentiate between chemical and nuclear reactions.

Section 14.1 Review

1. Which of the following statements regarding electric charge is TRUE?
   a. A positive charge repels a negative charge and attracts other positive charges.
   b. A positive charge attracts a negative charge and repels other positive charges.
2. Is electric charge a property of just electricity or is charge a property of all atoms?
3. Which of the drawings in Figure 14.9 is the most accurate model of the interior of an atom?
4. There are four forces in nature. Name the four forces and rank them from strongest to weakest.
5. There are three particles inside an atom. One of them has zero electric charge. Which one is it?
6. All atoms of the same element have (choose one):
   a. the same number of neutrons
   b. the same number of protons
   c. the same mass
7. 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
8. The diagram in Figure 14.10 shows three isotopes of the element carbon. Which one is radioactive?
9. *Radioactive* means:
   a. an atom gives off radio waves
   b. the nucleus of an atom is unstable and will eventually change
   c. the electrons in an atom have too much energy

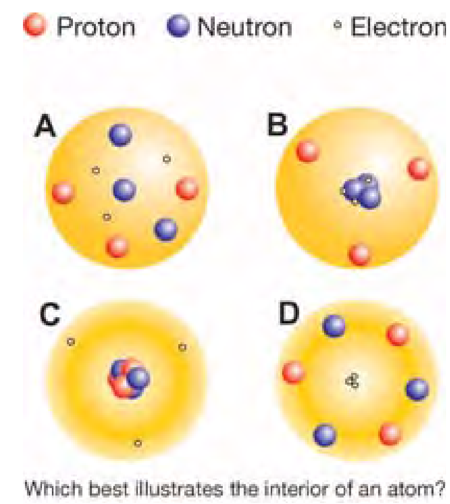


Figure 14.9: *Question 3.*

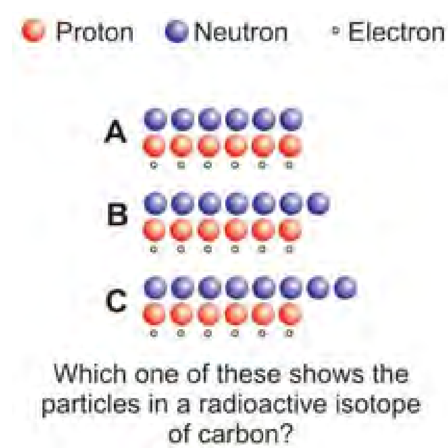


Figure 14.10: *Question 8.*

14.2 Electrons

Atoms interact with each other through their electrons. This is why almost all the properties of the elements (except mass) are due to electrons. Chemical bonds involve only electrons, so electrons determine how atoms combine into compounds. We find a rich variety of matter because electrons inside atoms are organized in unusual and complex patterns. Exactly how electrons create the properties of matter was a puzzle that took bright scientists a long time to figure out!

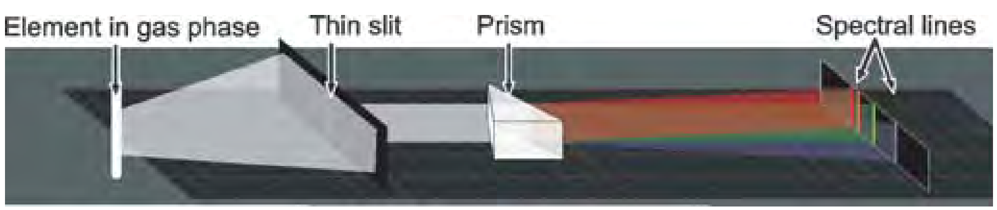
The spectrum

The spectrum is a pattern of colors

Almost all the light you see comes from atoms. For example, light is given off when electricity passes through the gas in a fluorescent bulb or a neon sign. When scientists look carefully at the light given off by a pure element, they find that the light does not include all colors. Instead, they see a few very specific colors, and the colors are different for different elements (Figure 14.11). Hydrogen has a red line, a green line, a blue, and a violet line in a characteristic pattern. Helium and lithium have different colors and patterns. Each different element has its own characteristic pattern of colors called a **spectrum**. The colors of clothes, paint, and everything else around you come from this property of elements that allows them to emit or absorb light of only certain colors.

Spectroscopes and spectral lines

Each individual color in a spectrum is called a **spectral line** because each color appears as a line in a **spectroscope**. A spectroscope is a device that separates light into its different colors. The illustration below shows a spectroscope made with a prism. The spectral lines appear on the screen at the far right.



VOCABULARY

spectrum - the characteristic colors of light given off or absorbed by an element.

spectral line - a bright, colored line in a spectroscope.

spectroscope - an instrument that separates light into a spectrum.

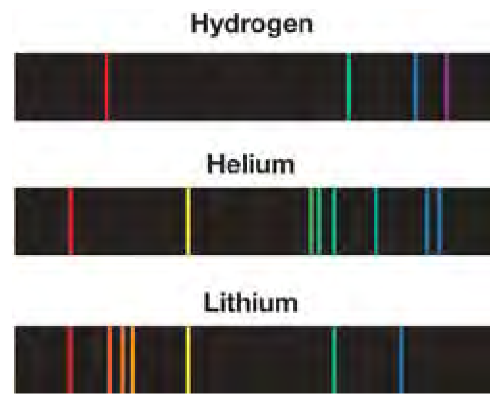


Figure 14.11: *When light from energized atoms is directed through a prism, spectral lines are observed. Each element has its own distinct pattern of spectral lines.*

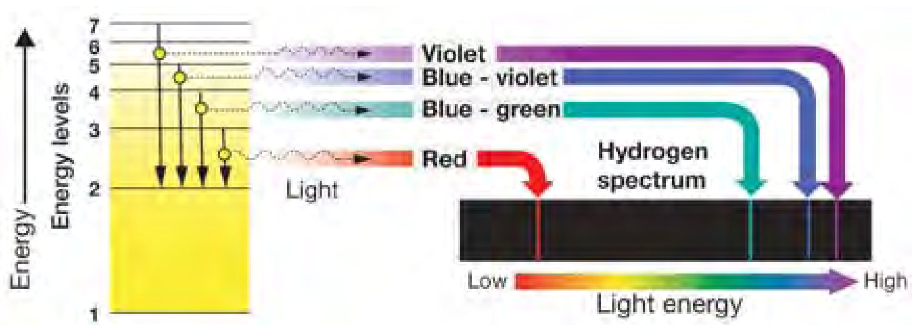
SC.912.P.10.18-Explore the theory of electromagnetism by comparing and contrasting the different parts of the electromagnetic spectrum in terms of wavelength, frequency, and energy, and relate them to phenomena and applications.

The Bohr model of the atom

Energy and color Light is a form of pure energy that comes in tiny bundles called *photons*. A photon is the smallest possible quantity of light energy. The amount of energy in a photon determines the color of the light. Red light has lower energy and blue light has higher energy. Green and yellow light have energy between red and blue. The fact that atoms only emit certain colors of light tells us that something inside an atom can only have certain values of energy.

Neils Bohr Danish physicist Neils Bohr (1885 - 1962) proposed the concept of **energy levels** to explain the spectrum of hydrogen. In Bohr's model, the electron in a hydrogen atom must be in a specific energy level. You can think of energy levels like steps on a staircase. You can be on one step or another, but you cannot be between steps except in passing. Electrons must be in one energy level or another and cannot remain in between energy levels. Electrons change energy levels by absorbing or emitting light (Figure 14.12).

Explaining the spectrum When an electron moves from a higher energy level to a lower one, the atom gives up the energy difference between the two levels. The energy comes out as different colors of light. The specific colors of the spectral lines correspond to the differences in energy between the energy levels. The diagram below shows how the spectral lines of hydrogen come from electrons falling from the 3^{rd}, 4^{th}, 5^{th}, and 6^{th} energy levels down to the 2^{nd} energy level.



VOCABULARY

energy level - one of the discrete allowed energies for electrons in an atom.

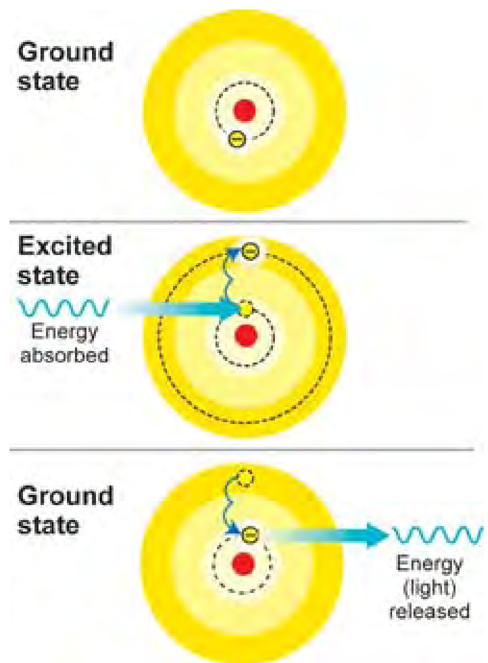


Figure 14.12: *When the right amount of energy is absorbed, an electron in a hydrogen atom jumps to a higher energy level. When the electron falls back to the lower energy level, the atom releases the same amount of energy it absorbed. The energy comes out as light of a specific color.*

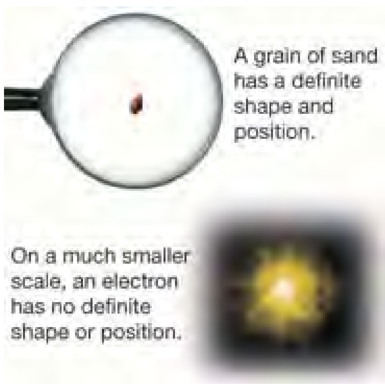
SC.912.N.3.5-Describe the function of models in science, and identify the wide range of models used in science.
SC.912.P.8.4-Explore the scientific theory of atoms (also known as atomic theory) by describing the structure of atoms in terms of protons, neutrons and electrons, and differentiate among these particles in terms of their mass, electrical charges and locations within.

The quantum theory

Quantum versus classical

Quantum theory says that when things get very small, like the size of an atom, matter and energy do *not* obey Newton's laws or other laws of *classical* physics. That is, the classical laws are not obeyed in the same way as with a larger object, like a baseball. According to the quantum theory, when a particle (such as an electron) is confined to a small space (such as inside an atom) then the energy, momentum, and other variables of the particle become restricted to certain specific values.

Everything is fuzzy in the quantum world



A particle like a grain of sand is small, but you can easily imagine it has a definite shape, size, position, and speed. According to quantum theory, particles the size of electrons are fundamentally different. When you look closely, an electron is "smeared out" into a wave-like "cloud."

The uncertainty principle

The work of German physicist Werner Heisenberg (1901–1976) led to Heisenberg's **uncertainty principle**. According to the uncertainty principle, in the quantum world, a particle's position, momentum, energy, and time can never be precisely known at the same time. For example, if you choose to measure the location of the electron, its momentum cannot be determined.

Understanding the uncertainty principle

The uncertainty principle arises because the quantum world is so small. To "see" an electron you have to bounce a photon of light off it, or interact with the electron in some way (Figure 14.13). Because the electron is so small, even a single photon moves it and changes its motion. That means the moment you use a photon to locate an electron, you push it, so you no longer know precisely how fast it was going. However, you know its position at that moment in time. In fact, any process of observing in the quantum world changes the very system you are trying to observe. The uncertainty principle exists because measuring any variable disturbs the others in an unpredictable way.

VOCABULARY

quantum theory - the theory that describes matter and energy at very small (atomic) sizes.

uncertainty principle - it is impossible to know variables precisely in the quantum world.

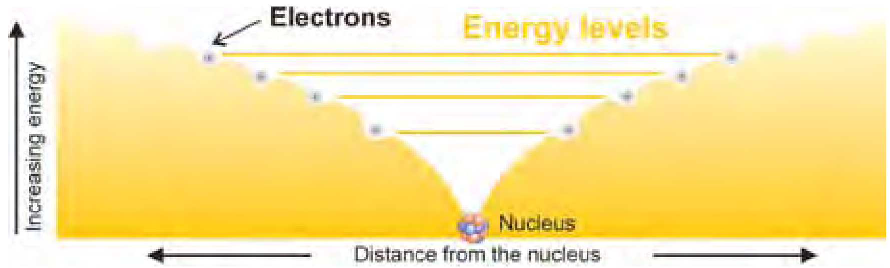
Figure 14.13: *The act of observing anything in the quantum world means disturbing in unpredictable ways the very thing you are trying to observe.*

SC.912.N.1.5-Describe and provide examples of how similar investigations conducted in many parts of the world result in the same outcome.

Electrons and energy levels

The energy levels are at different distances from the nucleus

The positive nucleus attracts negative electrons like gravity attracts a ball down a hill. The farther down the "hill" an electron slides, the less energy it has. Conversely, electrons have more energy farther up the hill, and away from the nucleus. The higher energy levels are farther from the nucleus and the lower energy levels are closer.



The electron cloud

While Bohr's model of electron energy levels explained atomic spectra and the periodic behavior of the elements, it was incomplete. Electrons are so fast and light that their exact position within an atom cannot be defined. Remember, in the current model of the atom, we think of the electrons as moving around the nucleus in an area called an electron cloud. The energy levels occur because electrons in the cloud are at different average distances from the nucleus.

Rules for energy levels

Inside an atom, electrons always obey these rules:

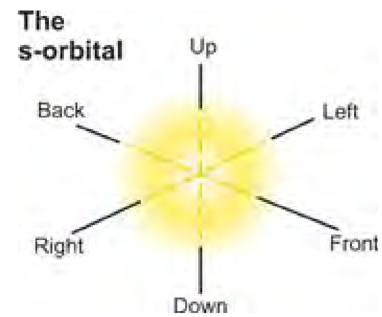
- The energy of an electron must match one of the energy levels in the atom.
- Each energy level can hold only a certain number of electrons, and no more.
- As electrons are added to an atom, they settle into the lowest unfilled energy level.

Quantum mechanics

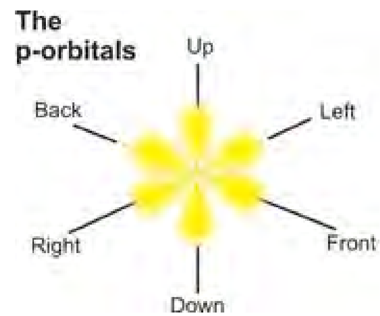
Energy levels are predicted by *quantum mechanics*, the branch of physics that deals with the microscopic world of atoms. While quantum mechanics is outside the scope of this book, you should know that it is a very accurate theory and it explains the characteristics of the energy levels.

Orbitals

The energy levels in an atom are grouped into different shapes called *orbitals*.



The s-orbital is spherical and holds two electrons. The first two electrons in each energy level are in the s-orbital.



The p-orbitals hold 6 electrons and are aligned along the three directions on a 3-D graph.

SC.912.P.8.4-Explore the scientific theory of atoms (also known as atomic theory) by describing the structure of atoms in terms of protons, neutrons and electrons, and differentiate among these particles in terms of their mass, electrical charges and locations within.

The energy levels in an atom

How electrons fill in the energy levels

In the Bohr model of the atom, the first energy level can accept up to 2 electrons. The second and third energy levels hold up to 8 electrons each. The fourth and fifth energy levels hold up to 18 electrons each (Figure 14.14). A good analogy is to think of the electron cloud like a parking garage. The first level of the garage only has spaces for 2 cars, just as the first energy level only has spaces for 2 electrons. The second and third levels of the garage can hold 8 cars each, and the fourth and fifth levels can each hold 18 cars. Each new car that enters the garage parks in the lowest level with an unfilled space, just as each additional electron occupies the lowest unfilled energy level in the atom.

How the energy levels fill

The number of electrons in an atom depends on the atomic number because the number of electrons equals the number of protons. That means each element has a different number of electrons and therefore fills the energy levels to a different point. For example, a helium atom (He) has two electrons (Figure 14.15). The two electrons completely fill up the first energy level (diagram below). The next element is lithium (Li) with three electrons. Since the first energy level only holds two electrons, the third electron must go into the second energy level. The diagram shows the first 10 elements which fill the first and second energy levels.

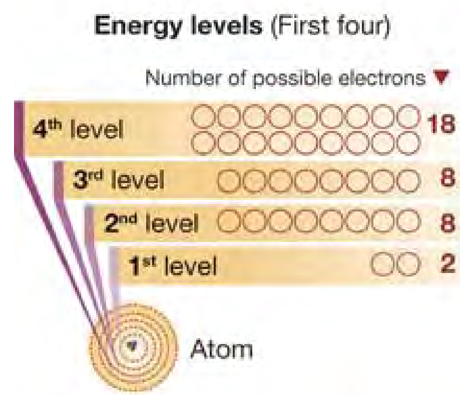


Figure 14.14: *Electrons occupy energy levels around the nucleus. The farther away an electron is from the nucleus, the higher the energy it possesses.*

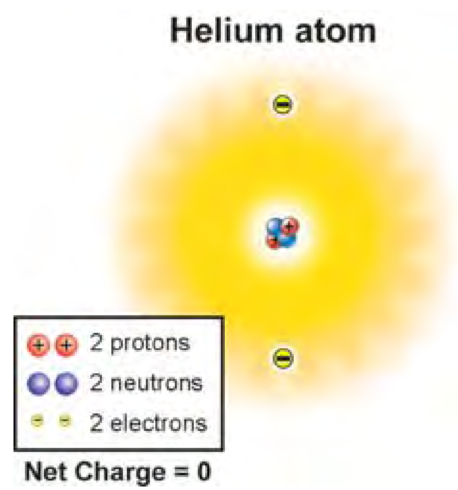
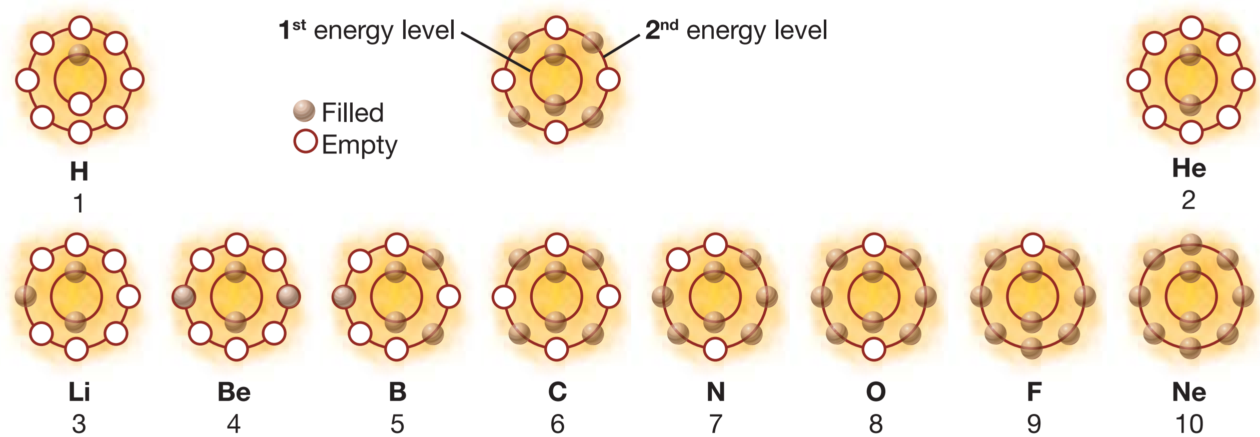


Figure 14.15: *A helium atom has two protons in its nucleus and two electrons.*



SC.912.P.8.5-Relate properties of atoms and their position in the periodic table to the arrangement of their electrons.

Section 14.2 Review

1. The pattern of colors given off by a particular atom is called:
   a. an orbital
   b. an energy level
   c. a spectrum
2. Which of the diagrams in Figure 14.16 corresponds to the element lithium?
3. When an electron moves from a lower energy level to a higher energy level, the atom:
   a. absorbs light
   b. gives off light
   c. becomes a new isotope
4. Two of the energy levels can hold eight electrons each. Which energy levels are they?
5. How many electrons can fit in the fourth energy level?
6. The element beryllium has four electrons. Which diagram in Figure 14.17 shows how beryllium's electrons are arranged in the first four energy levels?
7. Which two elements have electrons only in the first energy level?
   a. hydrogen and lithium
   b. helium and neon
   c. hydrogen and helium
   d. carbon and oxygen
8. On average, electrons in the fourth energy level are:
   a. farther away from the nucleus than electrons in the second energy level
   b. closer to the nucleus than electrons in the second energy level
   c. about the same distance from the nucleus as electrons in the second energy level

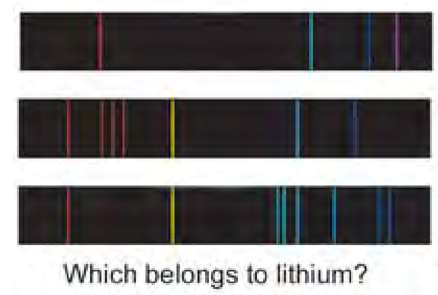


Figure 14.16: *Question 2.*

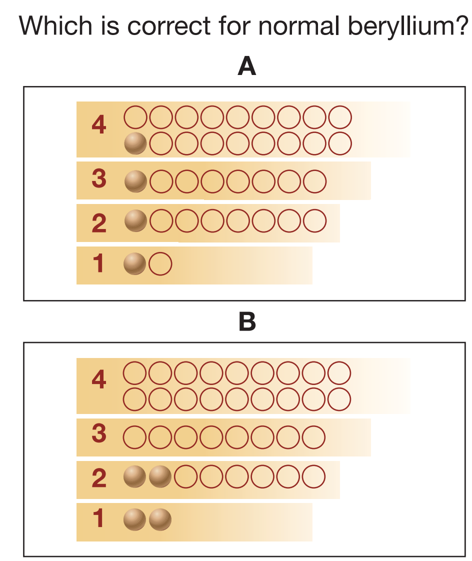
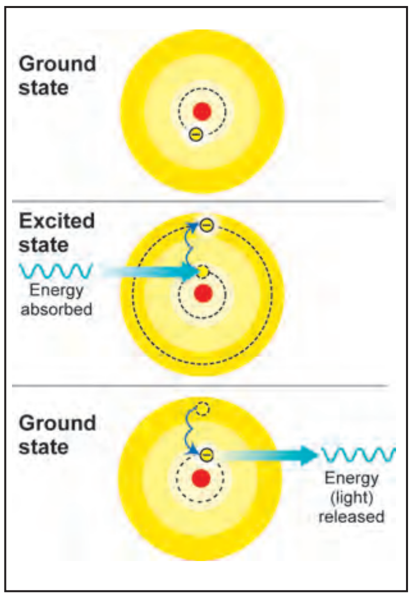


Figure 14.17: *Question 6.*

Bioluminescence Glow Live!

Imagine you could make your hands glow like living flashlights. No more fumbling around for candles when the power goes out! You could read in bed all night, or get a job directing airplanes to their runways.

Although a glowing hand might sound like something from a science fiction movie, many living things can make their own light. On warm summer evenings, fireflies flash signals to attract a mate. A fungus known as foxfire glows in decaying wood. While there are only a few kinds of glowing creatures that live on land, about 90 percent of the animals that live in the deep parts of the ocean make their own light!

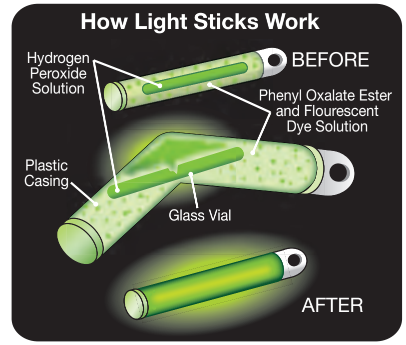


How Do They Do That?

Almost everything that creates light is made of atoms. If an atom absorbs energy, an electron can move to a higher energy level. When the electron moves back down to its original energy level, the atom may give off visible light.

Atoms can absorb energy from a number of sources. Electrical energy is used ito light ordinary light bulbs. Mechanical energy can be used, too. Hit two quartz rocks together in a dark room, and you'll see flashes of light as the energized electrons fall back down to lower energy levels.

Atoms can also use the energy from a chemical reaction. When you bend a glow stick, you break a vial inside so that two chemicals can combine. When they react, energy is released and used to make light.

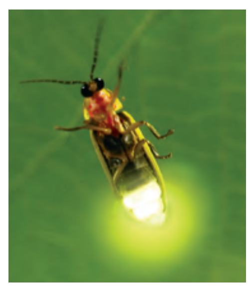


Bioluminescence

Like a glow stick, living things produce their own light using a chemical reaction. We call this process bioluminescence (bio- means "living" and luminesce means "to glow"). Bioluminescence is "cold light" because it doesn't produce a lot of heat. While it takes a lot of energy for a living thing to produce light, almost 100 percent of the energy becomes visible light. In contrast, only 10 percent of the energy used by an incandescent electric light bulb is converted to visible light. Ninety percent of the energy is lost as heat.

The Chemical Reaction

Three ingredients are usually needed for a bioluminescent reaction to occur: an organic chemical known as luciferin, a source of oxygen, and an enzyme called luciferase. Luciferin in a firefly is not exactly the same as the luciferin in foxfire fungus. However, both luciferin chemicals are carbon based and have the ability to give off light under certain conditions.



Firefly Light

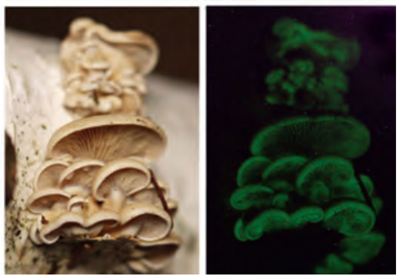
In a firefly, luciferin and luciferase are stored in special cells in the abdomen called photocytes. To create light, fireflies push oxygen into the photocytes. When the luciferin and luciferase are exposed to oxygen, they combine with ATP (a chemical source of energy) and magnesium. This chemical reaction drives some of the luciferin electrons into a higher energy state. As they fall back down to their "ground state," energy is given off in the form of visible light.

SC.912.P.8.4–Explore the scientific theory of atoms (also known as atomic theory) by describing the structure of atoms in terms of protons, neutrons and electrons, and differentiate among these particles in terms of their mass, electrical charges and locations within.

Why Make Light?

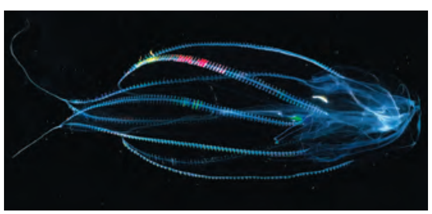
Living creatures don't have an endless supply of energy. Since it takes a lot of energy to make light, there must be good reasons for doing it.

Fireflies flash their lights in patterns to attract a mate. The lights also warn predators to stay away, because the light-producing chemicals taste bitter. Light can also be used as a distress signal, warning others of their species that there is danger nearby. The female of one firefly species has learned to mimic the signal of other types of fireflies. She uses her light to attract males of other species and then she eats them!



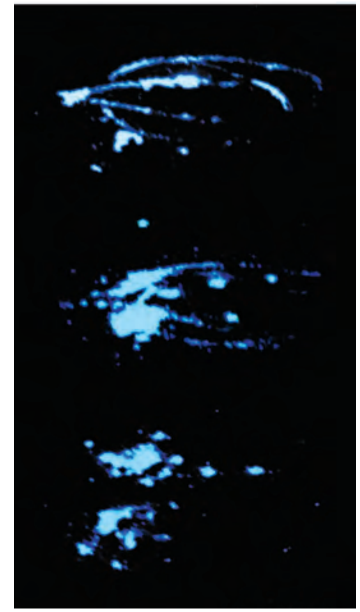
It's a little harder to figure out why foxfire fungus glows. Some scientists think that the glow attracts insects that help spread the fungus spores.

Bioluminescent ocean creatures use their lights in amazing ways. The deep-sea angler fish looks like it has a glowing lure attached to its head. It is actually a modified spine with a fleshy bulb (called an esca) at the tip. Bioluminescent bacteria grow in the esca, causing it to glow. When a smaller fish comes to munch on the "lure," it is gobbled up by the angler fish instead.



Comb jellies are some of the ocean's most beautiful glowing creatures. Comb jellies are mostly colorless, but they have iridescent plates that reflect sunlight. This picture (left) shows a comb jelly under reflected light. You are seeing iridescence, not bioluminescence.

Comb jellies can produce bright flashes of light to startle a predator. This photo set (right) shows the comb jelly's bioluminescence. When threatened, some comb jellies release a cloud of bioluminescent particles into the water, temporarily blinding the attacker.



So far, we know that living creatures use bioluminescence to attract mates, to communicate, to find food, and to ward off attackers. Perhaps someday you will be part of a research team that discovers even more uses for bioluminescence.

Questions:

1. Name three sources of energy that can be absorbed by atoms to produce light. Which source is used in bioluminescent organisms?
2. Bioluminescence is found in a wide range of living organisms, including bacteria, fungi, insects, crustaceans, and fish. However, no examples have been found among flowering plants, birds, reptiles, amphibians, or mammals. Why do you think this is so?
3. Use the Internet or a library to find out more about bioluminescent sea creatures. Here are some questions to pursue: What is the most common color of light produced? What other colors of bioluminescence have been found?

Angler fish and comb jelly photos by Edith Widder. Fungus photos by Garth Fletcher.

LA.910.4.2.2–The student will record information and ideas from primary and/or secondary sources accurately and coherently, noting the validity and reliability of these sources and attributing sources of information.
SC.912.N.1.4–Identify sources of information and assess their reliability according to the strict standards of scientific investigation.

Chapter 14 Assessment

Vocabulary

Select the correct term to complete the sentences.

atomic number	electron	elementary charge
energy level	isotopes	mass number
neutron	nucleus	spectral line
quantum theory	radioactive	spectroscope

Section 14.1

1. The sum of protons plus neutrons in the nucleus of an atom is known as the ____.
2. The smallest unit of electric charge in matter is called ____.
3. The core of the atom containing most of the atom's mass and all of its positive charge is called the ____.
4. A light particle with a negative charge, found in atoms, is called a(n) ____.
5. A neutral particle with nearly the same mass as the proton is the ____.
6. The number of protons in an atom, unique to each element, is known as the ____.
7. A nucleus that spontaneously breaks apart, emitting particles of energy is referred to as ____.
8. Atoms of the same element containing different numbers of neutrons are called ____.

Section 14.2

9. One of the allowed energies for electrons in an atom is known as a(n) ____.
10. The theory that describes matter and energy at atomic sizes is the ____.
11. A bright colored line produced by a spectroscope is a(n) ____.
12. An instrument that is used to separate light into spectral lines is a(n) ____.

Concepts

Section 14.1

1. Explain why Rutherford assumed most of the atom to be empty space.
2. Explain how Rutherford concluded that positive charge was concentrated in a small area.
3. How did Rutherford's model of the atom differ from Thomson's model?
4. Summarize the characteristics of the electron, proton, and neutron, comparing their relative mass, charge, and location within the atom by completing the table below.

Particle	Location in Atom	Charge	Relative Mass
electron	?	?	1
proton	?	+1	?
neutron	?	?	?

5. Name the four forces of nature and compare their relative strengths.
6. Explain the effect of the electromagnetic and strong forces on the structure of the atom.
7. What do the atomic number and mass number tell you about an atom?

8. Compare the number of protons and electrons in a neutral atom.
9. Compare the mass number and atomic number for isotopes of an element. Explain your answer.
10. Describe the radioactive disintegrations known as alpha, beta, and gamma decay.

Section 14.2

11. Which particle in an atom is most responsible for its chemical properties?
12. What is the source of the light you see?
13. How can a spectroscope be used to identify an element heated to incandescence?
14. Cite evidence that electrons are restricted to having only certain amounts of energy.
15. How did Neils Bohr explain spectral lines?
16. What is the difference between an electron in ground state and one in an excited state?
17. What would occur if an electron were to move from a certain energy level to a lower energy level?
18. Summarize the uncertainty principle.
19. Why can't the position of an electron be determined with certainty?
20. How is the location of an electron described?

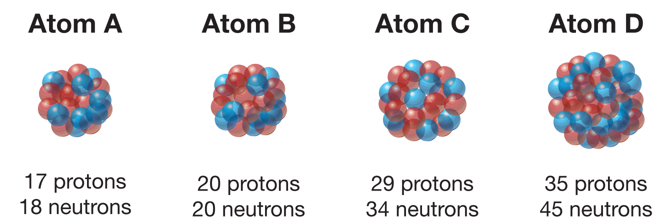
Problems

Section 14.1

1. Which of the following charges do *not* appear in normal matter?

a. +2e	d. –5.4e
b. +1/4e	e. +3/4e
c. –4e	f. –1e

2. What charge would an atom have if it lost one electron?
3. For each of the nuclei shown below, do the following.
   a. Name the element.
   b. Give the atomic number.
   c. Give the mass number.



4. A neutral atom has 7 protons and 8 neutrons. Determine its:
   a. mass number
   b. atomic number
   c. number of electrons
5. A carbon atom contains 6 protons in the nucleus. If an atom of carbon-14 were to undergo alpha decay, determine each of the following for the new element.
   a. mass number
   b. atomic number
   c. number of protons
   d. number of neutrons

6. A uranium atom contains 92 protons in the nucleus. If an atom of uranium-238 were to undergo alpha decay, determine each of the following for the new element.
   a. mass number
   b. atomic number
   c. number of protons
   d. number of neutrons

Section 14.2

7. If electrons in the hydrogen atom become excited and then fall back to the 2nd energy level from levels 3, 4, 5, and 6, four colors of light are emitted: violet, red, blue-violet, and blue-green.
   a. Which transition is responsible for the blue-violet light: 6 to 2, 5 to 2, 4 to 2, or 3 to 2?
   b. If an electron on the 2nd level were struck by a photon, then it could be excited to the 6th energy level. What color photon would be absorbed by the electron?
8. An atom has an atomic number of 6. Sketch a diagram that correctly represents the electron arrangement in energy levels around the nucleus. What is the name of this atom?

Applying Your Knowledge

Section 14.1

1. Make a poster illustrating the different models of the atom that scientists have proposed since the 1800s. Explain how each model reflects the new knowledge that scientists gained through their experiments. When possible, comment on what scientists learned about charge, mass, and location of subatomic particles.
2. Radioactive isotopes emit particles that can cause harm to our cells. However, scientists have figured out ways to use radioisotopes in ways that are beneficial to our health. Nuclear medicine is a branch of medicine that uses medical radioisotopes to diagnose and treat diseases. Research a disease that is either diagnosed or treated with medical radioisotopes. Create a pamphlet that provides information about the disease and how medical radioisotopes are used to diagnose and/or treat it.

Section 14.2

3. The element helium is a light gas that is very rare on Earth. In fact, helium was not discovered on this planet. It was discovered in the Sun. In Greek, *helios* means “sun.” Astronomers saw a series of spectral lines in the Sun that did not match any known element on Earth. Helium was first identified from its spectrum of light from the Sun. Researchers were then able to find it on Earth because they knew what to look for. Research and draw the visible spectrum for helium, labeling the wavelength of each spectral line. Rank the spectral lines from highest energy to lowest energy.
4. Choose an atom and make a three-dimensional model of its structure, using the Bohr model. Choose different materials to represent protons, neutrons, and electrons. Attach a key to your model that explains what each material represents.

LA.910.2.2.3-The student will organize information to show understanding or relationships among facts, ideas, and events.
LA.910.4.2.2-The student will record information and ideas from primary and/or secondary sources accurately and coherently, noting the validity and reliability of these sources and attributing sources of information.
SC.912.N.1.4-Identify sources of information and assess their reliability according to the strict standards of scientific investigation.
SC.912.N.1.5-Describe and provide examples of how similar investigations conducted in many parts of the world result in the same outcome.
SC.912.N.2.5-Describe instances in which scientists' varied backgrounds, talents, interests, and goals influence the inferences and thus the explanations that they make about observations of natural phenomena and describe that competing interpretations (explanations).
SC.912.N.3.5-Describe the function of models in science, and identify the wide range of models used in science.
SC.912.P.10.11-Explain and compare nuclear reactions (radioactive decay, fission and fusion), the energy changes associated with them and their associated safety issues.