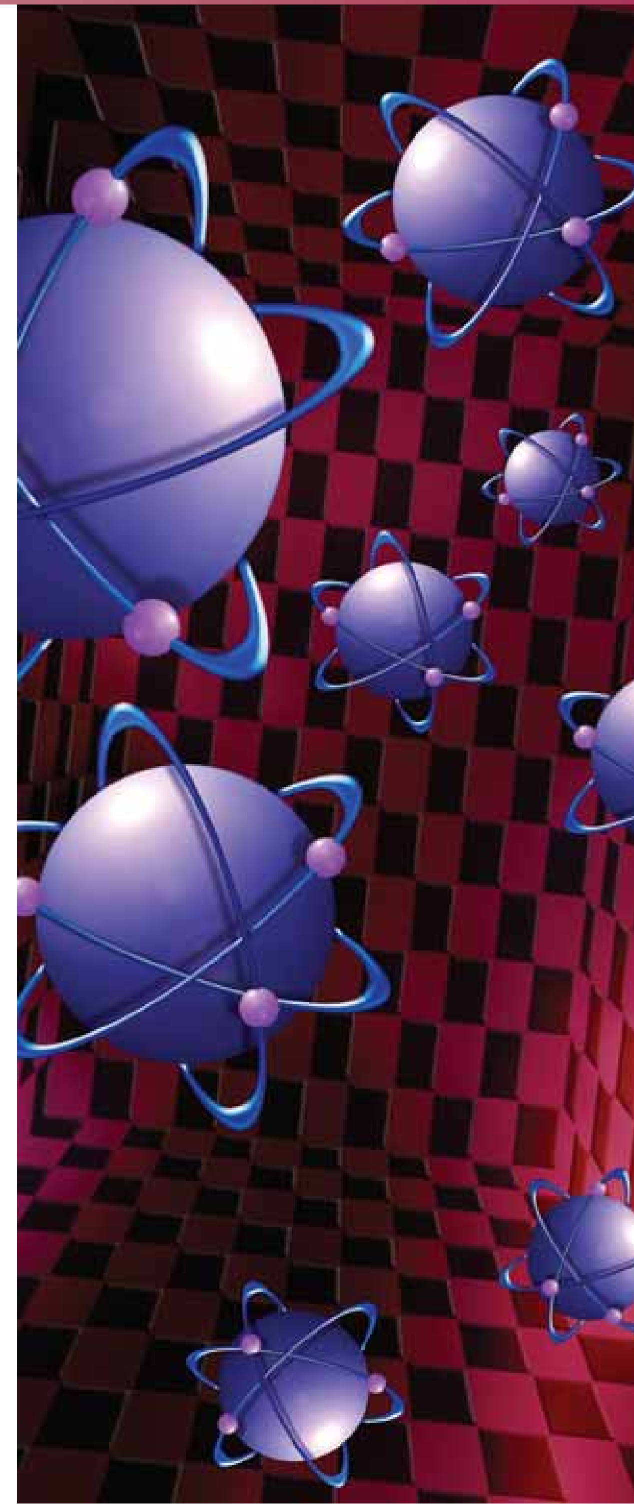
Chapter 6

The Atom

There is something more to wintergreen-flavored candy (the kind with the hole in the middle) than the refreshing taste. When you bite and crush one of these candies, blue sparks jump out of your mouth! You can only see the sparks if you hold a mirror up to your mouth in a very dark place, like a closet. You will be able to see the light even better if you crush one of the candies with a pair of pliers (no mirror required). To understand why the blue sparks appear, you must know what an atom is and what it is made of. After reading this chapter on atoms, you can do an Internet search on the term triboluminescence to find out why this candy sparks when you crush it.

Key Questions

1. *How did scientists figure out what atoms are like if they couldn't see them?*
2. *What makes atoms of different elements different?*
3. *What are atoms themselves made of?*



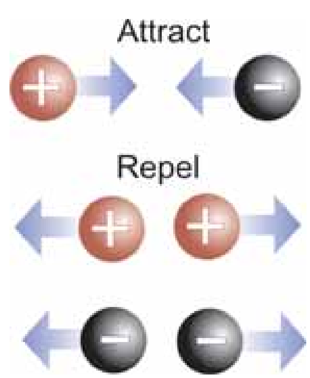
6.1 Fundamental Particles and Forces

Scientists once believed that 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 all atoms are made of three basic particles: the proton, electron, and neutron. Astonishingly, the incredible variety of matter in universe can be constructed using just these three subatomic particles!

Electric charge

Electric charge is a property of matter

Along with mass and volume, matter has another fundamental property that we call **electric charge**. In order to understand atoms, we need to understand electric charge because one of the forces that hold atoms together comes from electric charge.



We know of two different kinds of electric charge and we call them *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

We use the letter *e* to represent the **elementary charge**. On the atomic scale, 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, +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. Electric charge only appears in units of the elementary charge.

VOCABULARY

electric charge - a fundamental property of matter that comes in two types called positive and negative.

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

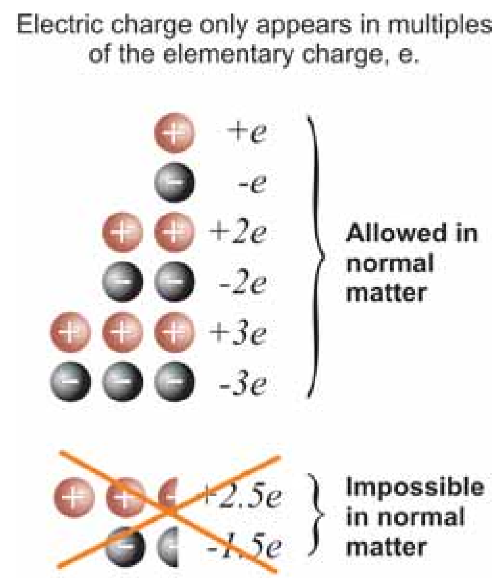


Figure 6.1: *Just as normal matter is divided into atoms, electric charge appears only in units of the elementary charge, e.*

Static electricity

Neutral means zero charge

We say an object is electrically **neutral** when its total electric charge is zero (Figure 6.2). Your pencil, your textbook, even your body are electrically neutral, at least most of the time. These forms of matter are made up of charged particles, which you don't usually notice because there is perfect cancellation between positive and negative, leaving a net charge of precisely zero.

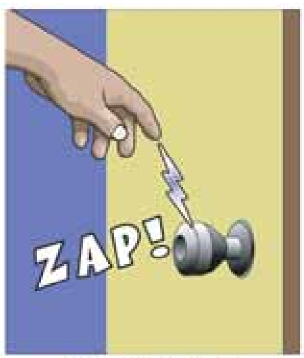
Charged objects

An object is **charged** when its total electric charge is *not* zero. Objects become charged when they have an excess of either positive or negative electric charge.

Static electricity and charge

A tiny imbalance of positive or negative charge is the cause of **static electricity.** If two neutral objects are rubbed together, the friction often pulls some charge off one object and puts it temporarily on the other. This is what happens to clothes in the dryer and to your socks when you walk on a carpet. The static electricity you feel when taking clothes from a dryer or scuffing your socks on carpet typically results from an excess charge of less than one part in a hundred trillion!

What causes shocks



Static electricity

The forces between electric charges are incredibly strong. That is why charged objects do not stay charged very long. An object with excess positive charge strongly attracts negative charge until the object becomes neutral again. When you walk across a carpet on a dry day, your body picks up excess negative charge. If you touch a neutral door knob your negative charge repels negative charge in the door knob causing the doorknob to become slightly positive. The negative charge on your skin is now attracted to the positive charge on the doorknob. The shock you feel is the energy released when your excess negative charge jumps the gap between your skin and the door knob.

VOCABULARY

neutral - a condition where the total positive charge is canceled by the total negative charge. Matter is neutral most of the time.

charged - a condition where there is an excess of positive or negative charge.

static electricity - the buildup of either positive or negative charge; made up of isolated, motionless charges.

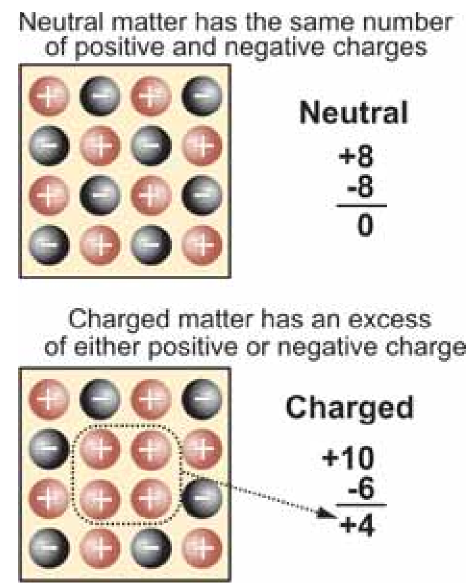


Figure 6.2: *An object is neutral if it has an equal number of positive and negative charges.*

Inside an atom: solving the puzzle

The electron identified The first strong evidence that something existed smaller than an atom 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. Thomson's new particles also had negative electric charge while atoms have zero electric charge. Thomson called his particles *corpuscles*, which were eventually named **electrons**, and proposed that they came from the inside of atoms.

The proton and the nucleus discovered In 1911, Ernest Rutherford, Hans Geiger, and Ernest Marsden did a clever experiment to test Thomson's model of the atom. They launched positively-charged helium ions (a charged atom is called an *ion*) at extremely thin gold foil (Figure 6.3). They expected the helium ions to be deflected a small amount as they passed through the foil. However, a few bounced back in the direction they came! The unexpected result prompted Rutherford to remark "*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 the gold atoms were mostly empty space, allowing most of the helium ions to go through virtually undeflected. 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. Further experiments confirmed Rutherford's ideas and we know that every atom has a tiny **nucleus**, which contains more than 99% of the atom's mass.

The neutron The positively charged **proton** was soon discovered and shown to be the particle in the nucleus. But there still was a serious problem with the atomic model. Protons could only account for about half the observed mass. This problem was solved in 1932 by James Chadwick. Chadwick's experiments revealed another particle in the nucleus which has no electric charge and similar mass as the proton. Chadwicks neutral particle was named the **neutron**.

VOCABULARY

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

proton - a particle with an electric charge (+e) found in the nucleus of atoms.

neutron - a particle with zero charge found in the nucleus of atoms.

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

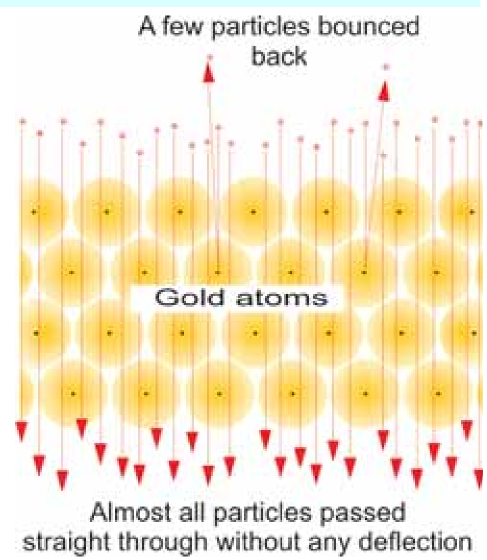


Figure 6.3: *Rutherford's famous experiment led to the discovery of the nucleus.*

Three subatomic particles make up an atom

Protons, neutrons, and electrons

Today we know that atoms are made of three tiny *subatomic* particles: protons, neutrons, and electrons. Protons have positive charge. Electrons have negative charge. Neutrons add mass but have zero charge. The charge on a proton (+e) and an electron (-e) are exactly equal and opposite. Atoms that have the same number of protons and electrons have a total charge of precisely zero.

The nucleus

The protons and neutrons are grouped together in the nucleus, which is at the center of the atom. The mass of the nucleus determines the mass of an atom because protons and neutrons are much larger and more massive than electrons (Figure 6.4). In fact, a proton is 1,836 times heavier than an electron. All atoms have both protons and neutrons in their nuclei except the simplest type of hydrogen, which only has one proton and no neutrons. The chart below compares electrons, protons, and neutrons in terms of charge and mass.

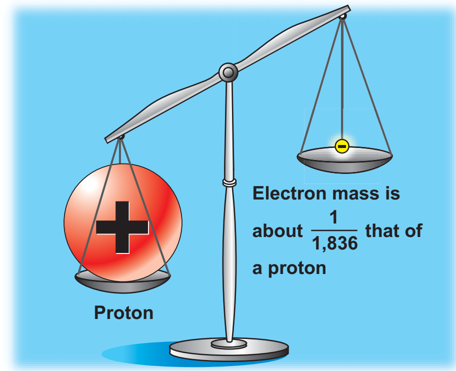


Figure 6.4: *The mass of at atom is mostly in the nucleus because protons and neutrons are much heavier than electrons.*

	Occurrence	Charge	Mass (g)	Relative Mass
Electron	found outside of nucleus	-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 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 6.5). 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 extremely high speed. Can you visualize how much empty space there would be in the stadium? The atom is mostly empty space!

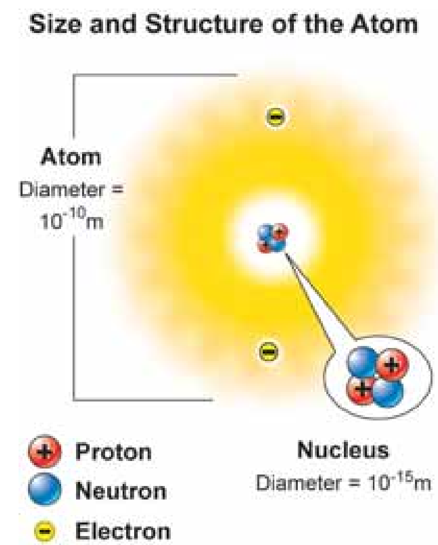


Figure 6.5: *The overall size of an atom is the size of its electron cloud. The nucleus is much, much smaller.*

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. The energy of an electron causes it to move around the nucleus instead of falling in (Figure 6.6). A good analogy is Earth orbiting the sun. Gravity creates a force that pulls the 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.

Strong nuclear force Because of electric force, all the positively charged protons in the nucleus *repel* each other. 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 6.7). 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.

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 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. But there are many unanswered questions. Understanding how gravity works inside atoms is an unsolved mystery in science.

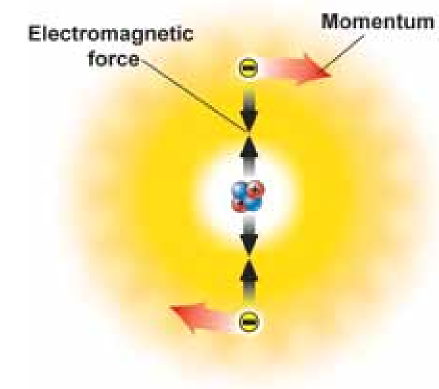


Figure 6.6: *The negative electrons are attracted to the positive protons in the nucleus, but their momentum keeps them from falling in.*

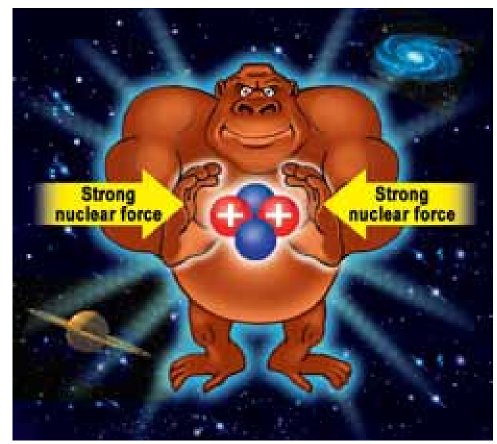


Figure 6.7: *When enough neutrons are present the strong nuclear force wins out over the repulsion between positively charged protons and pulls the nucleus together tightly. The strong nuclear force is the strongest force in the universe that we know.*

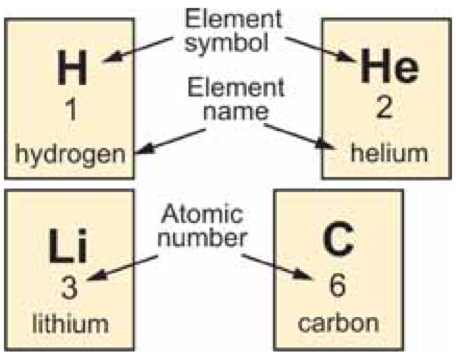
How atoms of different elements are different

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 6.8). 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.

Atoms of the same element always have the same number of protons in the nucleus.

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 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.

VOCABULARY

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

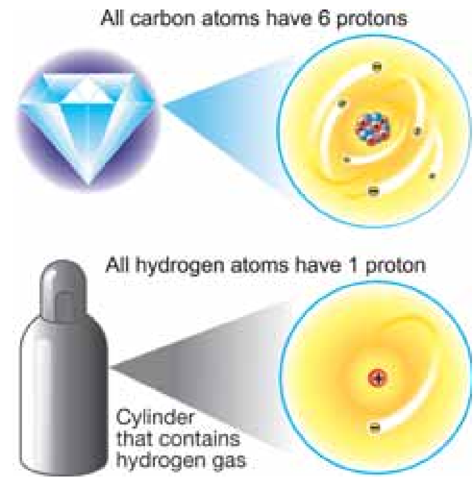


Figure 6.8: *Atoms of the same element always have the same number of protons.*

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 6.9 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.

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? *Answer: 12*

b. Find the number of neutrons in a calcium atom that has a mass number of 40. *Answer: 20*

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.

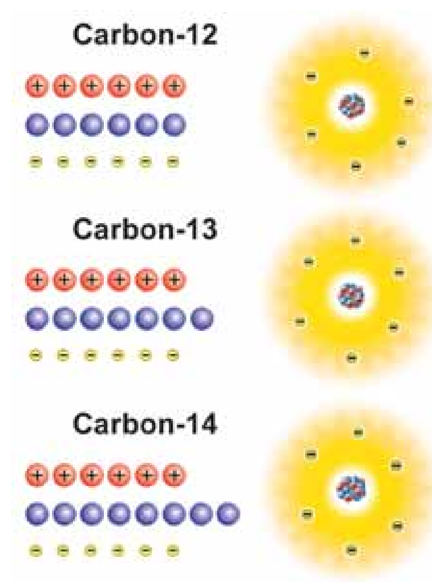


Figure 6.9: *The isotopes of carbon.*

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. For example carbon 14 is radioactive and eventually becomes nitrogen 14.

Alpha decay

In *alpha decay*, the nucleus ejects two protons and two neutrons (Figure 6.10). Check the periodic table and you can quickly show that two protons and two neutrons are the nucleus of a helium-4 (^4He) atom. Alpha radiation is actually fast-moving ^4He 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 and 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.

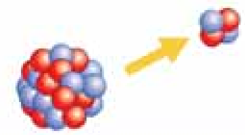
VOCABULARY

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

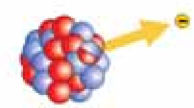
Nucleus ejects a helium-4 nucleus



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

Beta decay

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



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

Figure 6.10: *Two common radioactive decay reactions.*

6.1 Section 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 6.11 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 strongest first, second strongest second, and so on.
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 6.12 shows three isotopes of the element carbon. Which one is radioactive?
9. Radioactivity 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.

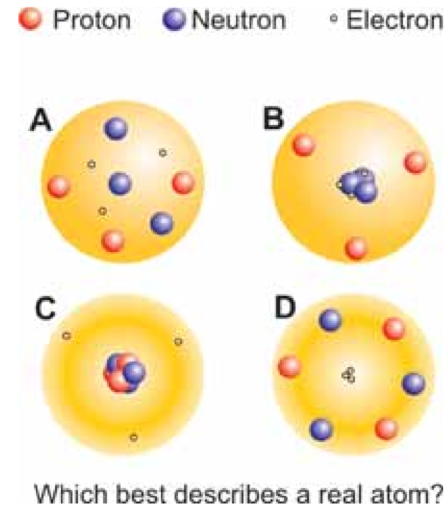


Figure 6.11: *Question 3*

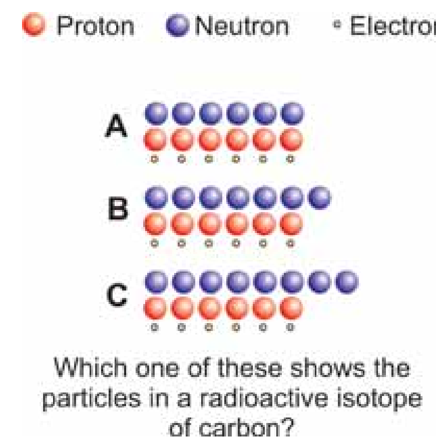


Figure 6.12: *Question 8*

6.2 Electrons in the Atom

Virtually all the properties of the elements (except mass) are due to the electrons outside the nucleus. Atoms interact with each other through their electrons. Chemical bonds involve only electrons so electrons determine how atoms combine into compounds. The rich variety of matter we experience comes directly from the complex behavior of electrons inside atoms. Exactly how electrons create the properies of matter was a puzzle that took bright scientists a long time to figure out!

VOCABULARY

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

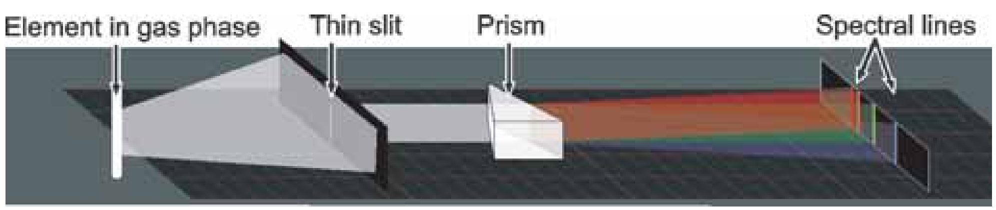
spectroscope - an instrument that separates light into a spectrum.

spectral line - a bright colored line in a spectroscope.

The spectrum

The spectrum 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 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 6.13). 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 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 spreads light into its different colors. The diagram below shows a spectroscope made with a prism. The spectral lines appear on the screen on the right.



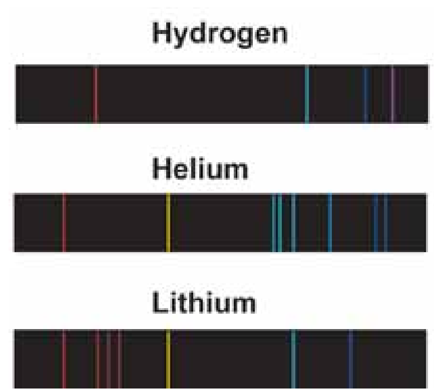


Figure 6.13: *When light from energized atoms is directed through a prism, spectral lines are observed. Each element has its own distinct pattern of spectral lines.*

The Bohr model of the atom

Energy and color

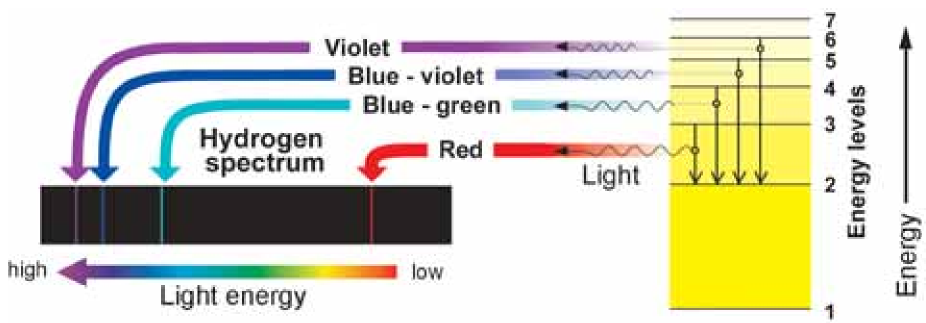
Light is a form of pure energy. The amount of energy determines the color of the light. Red light has low energy and blue light has higher energy. Green and yellow light have energy between red and blue. The fact that atoms only emit certain colors of light tells us that something inside an atom can only have certain values of energy.

Neils Bohr

Danish physicist Neils Bohr 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 6.14).

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.



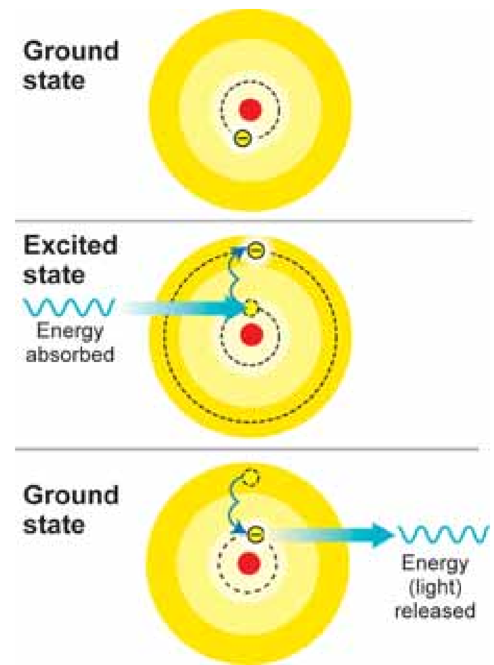


Figure 6.14: *When the right amount of energy is absorbed, an electron in a hydrogen atom jumps to a higher energy level. When the electron falls back to the lower energy, the atom releases the same amount of energy it absorbed. The energy comes out as light of a specific color.*

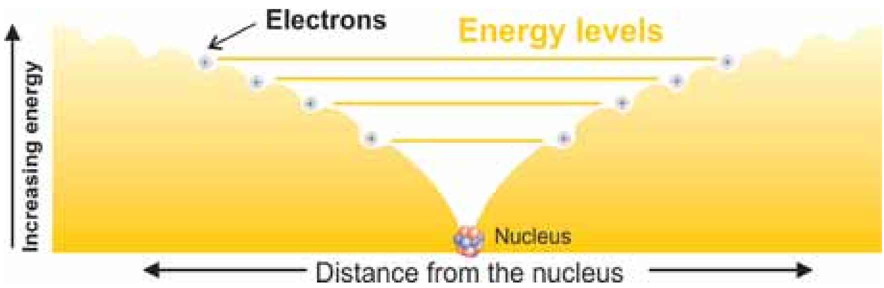
Electrons and energy levels

The electron cloud

Bohr's model of electron energy levels was incomplete. Electrons are so fast and light that their exact position within an atom cannot be defined. In the current model of the atom, we think of the electrons in an atom 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.

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 to the nucleus.



Rules for energy levels

Inside an atom, electrons behave in certain ways:

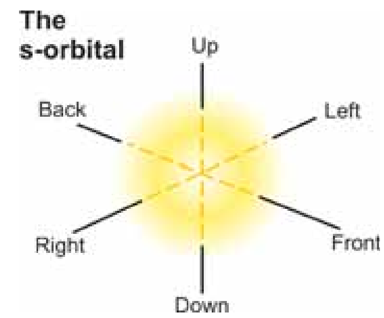
- The energy of an electron must match one of the energy levels in the atom.
- Each energy level can hold only a certain number of electrons, and no more.
- As electrons are added to an atom, they settle into the lowest unfilled energy level.

Quantum mechanics

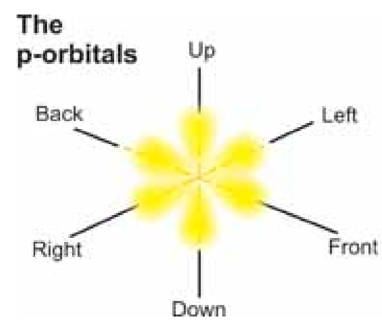
Energy levels are predicted by *quantum mechanics*, the branch of physics that deals with the microscopic world of atoms. While quantum mechanics is outside the scope of this book, you should know that it is a very accurate theory and it explains energy levels.

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.

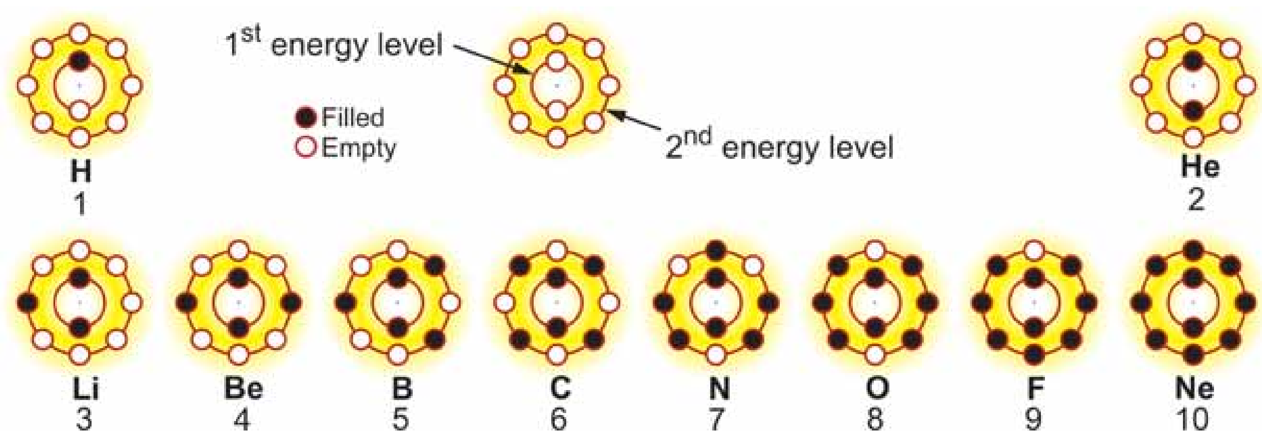
The energy levels in an atom

How electrons fill in the energy levels

The first energy level can accept up to two electrons. The second and third energy levels hold up to eight electrons each. The fourth and fifth energy levels hold 18 electrons (Figure 6.15). A good analogy is to think of the electron cloud like a parking garage in a crowded city. The first level of the garage only has spaces for two cars, just as the first energy level only has spaces for two electrons. The second level of the garage can hold eight cars just as the second energy level can hold eight electrons. Each new car that enters the garage parks in the lowest unfilled space, just as each additional electron occupies the lowest unfilled energy level.

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 different point. For example, a helium atom has two electrons (Figure 6.16). The two electrons completely fill up the first energy level (diagram below). The next element is lithium with three electrons. Since the first energy level only holds two electrons, the third electron must go into the second level. The diagram shows the first 10 elements which fill the first and second energy levels.



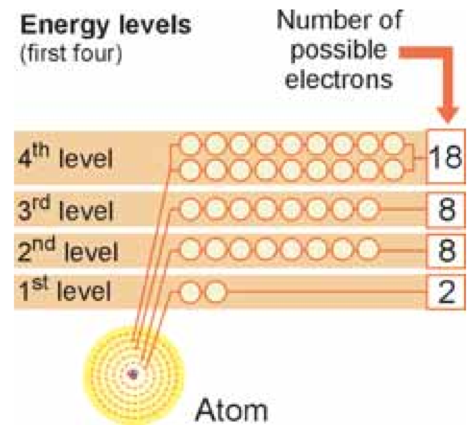


Figure 6.15: *Electrons occupy energy levels around the nucleus. The farther away an electron is from the nucleus, the higher the energy it possesses.*

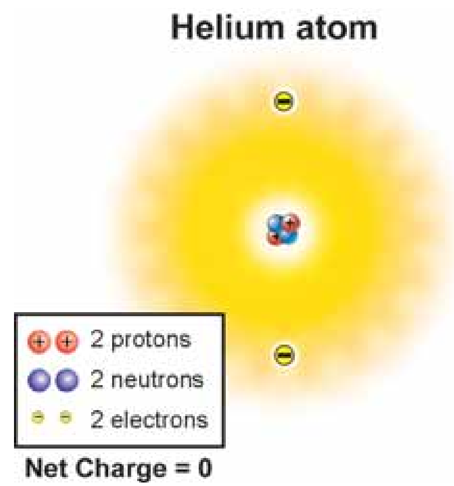


Figure 6.16: *A helium atom has two protons in its nucleus and two electrons.*

6.2 Section 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 6.17 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 these?
5. How many electrons can fit in the fourth energy level?
6. The element beryllium has four electrons. Which diagram in Figure 6.18 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.

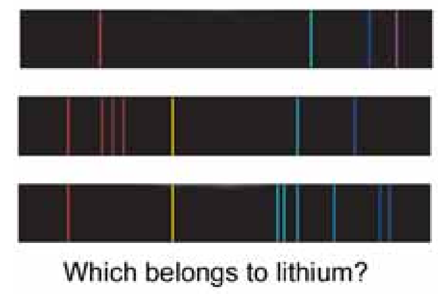


Figure 6.17: *Question 2*

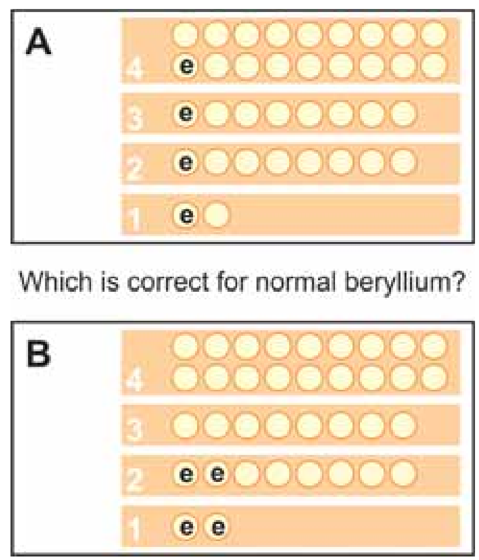


Figure 6.18: *Question 6*

BIOLOGY CONNECTION

Bioluminescence

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.

Photos by Garth Fletcher

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?

Light is a form of energy. To make light, an atom must first absorb enough energy to promote an electron up to a higher-energy state. When the electron falls back to its original state, the energy is given off as light.

Atoms can absorb energy from a number of sources. Electrical energy is used in 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 electrons you pumped up fall back down. You 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

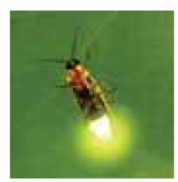
Like a glow stick, living things produce their own light using a chemical reaction. We call this process *bioluminescence* (*bio-* means “living” and *luminesce* means “to glow”). Bioluminescence is “cold light” because it doesn’t produce a lot of heat. While it takes a lot of energy for a living thing to produce light, almost 100% of the energy becomes visible light. In contrast, only 10 percent of the used by an “incandescent” electric light bulb is converted to visible light. 90 percent of the energy is wasted 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 and luciferase are categories of chemicals with certain characteristics. 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.

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. They can also be used 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 around the fungus spores.

Bioluminescent ocean creatures use their lights in amazing ways. The deep-sea angler fish has a glowing lure attached to its head. When a smaller fish comes to munch on the lure, it instead is gobbled up by the angler fish.

Photo by E. Widder

Comb jellies are some of the ocean's most beautiful glowing creatures. When threatened, they release a cloud of bioluminescent particles into the water, temporarily blinding the attacker.

Recently, scientists have begun to realize that some deep-ocean creatures make their own light, too. Perhaps someday you will be part of a research team that discovers new uses for bioluminescence.

Questions:

1. Find out more about what is inside a glow stick. Make a poster to explain how glow sticks work, or prepare a demonstration for your classmates
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?

CHAPTER ACTIVITY

Atoms and Radioactivity

Radioactivity is how we describe any process where the nucleus of an atom emits particles or energy. All radioactive elements have a half-life. This means that there is a certain length of time after which half of the radioactive element has decayed. Radioactive elements have an unstable nucleus, which decays into an different type of atom with a more stable nucleus. As it decays, it releases radiation.

Materials:

can of pennies, graph paper

What you will do

Your teacher has given you a can of pennies to represent the atoms of a sample of a newly discovered, radioactive element. You will use the pennies to simulate the process of radioactive decay. Upon completion of the simulation, you will construct a graph of your data.

Shake your can of pennies and spill them out onto a tray or table.

1. Remove all pennies that are “heads” up and count them.
2. Record these as decayed atoms in a table like the one below.

Trial	Sample Number	# of decayed atoms
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

3. Put the rest of the pennies back into the can and shake them again.
4. Spill them out onto the tray or table, and again, remove and count the “heads”.
5. Repeat this process until there are no pennies left.

Applying your knowledge

a. Graph your data. The sample number will be on the *x*-axis and the number of decayed atoms per sample will be on the *y*-axis. Label the axes clearly and provide a title for the graph.
b. Describe what your graph looks like.
c. How many trials did it take for half of your original number of pennies to decay to “heads up”?
d. How many trials did it take for all your pennies to decay?
e. Would it make a difference if you graphed the number of “tails” up instead?
f. If you were to put a sticker on one of the pennies and repeat the activity, could you predict in which trial the marked penny would decay?
g. Another student did this activity, and on the third shake 12 pennies decayed. Can you tell how many pennies the other student started with?

Vocabulary

Select the correct term to complete the sentences.

nucleus	spectroscope	neutral
spectral line	atomic number	isotopes
spectrum	neutron	radioactive
elementary charge		

Section 6.1

1. A particle with zero charge, found in the nucleus of an atom, is the ____.
2. The smallest unit of electric charge that occurs in ordinary matter is a(n) ____.
3. The tiny core of an atom containing most of the atom's mass and all of its positive charge is called the ____.
4. Atoms having the same atomic number but different mass numbers are called ____.
5. When an object has a net charge of zero, it is described as ____.
6. The number of protons in the nucleus of an atom is known as the ____.
7. A nucleus that spontaneously breaks up or emits particles may be called ____.

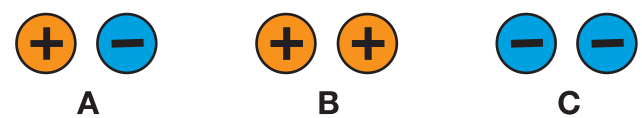
Section 6.2

8. A bright colored line viewed in a spectroscope is called a ____.
9. The characteristic pattern of colors iven off by an element is called a(n) ____.
10. The instrument used to separate the light from electrons into different colors is called a(n) ____.

Concepts

Section 6.1

1. When matter is observed closely, different electric charges may be seen. Of the following charges, which are NOT observed in matter on the atomic scale? There may be more than one answer.
   a. +2.3e
   b. -6.0e
   c. -3.5e
   d. +9.0e
2. How do forces between electrical charges differ from forces between masses?
3. Most objects are electrically neutral. Describe how an object may become charged.
4. Charges are attracted or repelled by one another. Use the words **attract** or **repel** to describe how the following combinations would react.



5. Which two particles are electrically attracted to each other?
   a. proton and neutron
   b. electron and neutron
   c. proton and electron
6. A neutral atom has:
   a. zero electrons.
   b. the same number of protons and neutrons.
   c. the same number of protons and electrons.
7. Why would an atom become radioactive?

8. Describe the three subatomic particles that make up an atom by completing the chart below.

Particle	Place in Atom	Charge	Relative Mass
electron			
proton			
neutron			

9. List the four fundamental forces of nature in order from strongest to weakest.

10. Describe the terms:
    a. alpha decay
    b. beta decay
    c. gamma decay

Section 6.2

11. When electricity passes through a gas it may become hot enough to give off light. How could a scientist determine the element(s) from which the gas is made?

12. How does the energy of an electron relate to its distance from the nucleus?

13. Correctly complete the following statements concerning electrons and energy levels:
    a. The energy of an electron in an atom must be _______________ (the same as, more than, less than) one of the energy levels in the atom.
    b. As electrons are added to an atom they must occupy the _______________ (highest, lowest) unfilled energy level.
    c. Each energy level can hold ____________________ (one, a specific number of, all available) electrons.

Problems

Section 6.1

1. One of the isotopes of the element of carbon is an atom with 6 electrons, 6 protons and 6 neutrons.
    a. What is the atomic number of this isotope?
    b. What is the mass number of this isotope?
    c. What is the charge on this isotope?

2. One atom has 12 protons and 12 neutrons. Another has 13 protons and 12 neutrons. Are they the same or different elements?

3. Of the following atoms, which are isotopes of the same element? There may be more than one correct answer.
    a. An atom with 11 protons, 11 electrons and 13 neutrons
    b. An atom with 12 protons, 11 electrons and 12 neutrons
    c. An atom with 13 protons, 13 electrons and 13 neutrons
    d. An atom with 13 protons, 13 electrons and 14 neutrons

4. Identify the following nuclear changes as alpha decay or beta decay.
    a. A radium atom with 88 protons and 138 neutrons becomes a radon atom with 86 protons and 136 neutrons.
    b. A sodium atom with 11 protons and 13 neutrons becomes a magnesium atom with 12 protons and 12 neutrons.

Section 6.2

5. Electrons “X” and “Y” are temporarily on different energy levels. As they fall back toward ground state, X emits red light and Y emits blue light. Which electron had more energy before falling?