12.2 Electrons

Atoms interact with one another 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!

VOCABULARY

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

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

spectrometer - an instrument that separates light into a spectrum.

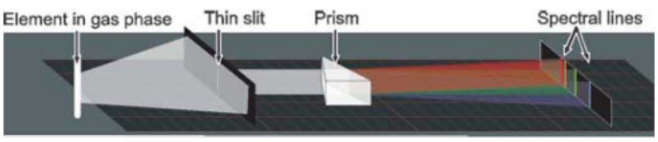
The spectrum

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 12.10). Hydrogen has a red line, a green line, a blue line, and a violet line in a characteristic pattern. Helium and lithium have different colors and patterns. Each 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.

Spectrometers and spectral lines

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



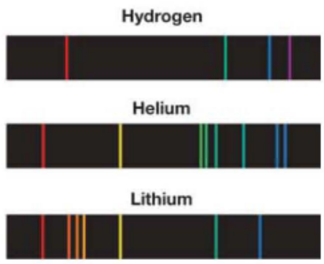


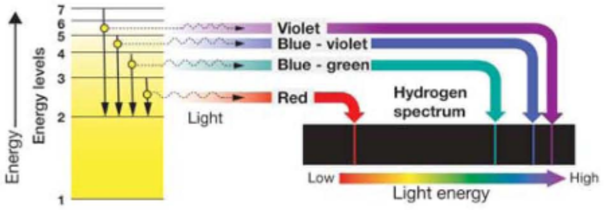
Figure 12.10: *When light from energized atoms is directed through a prism, spectral lines are observed. Each element has its own distinct pattern of spectral lines.*

The Bohr model of the atom

Energy and color Light is a form of pure energy 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 between energy levels. Electrons change energy levels by absorbing or emitting light (Figure 12.11).

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 3rd, 4th, 5th, and 6th energy levels down to the 2nd energy level.



VOCABULARY

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

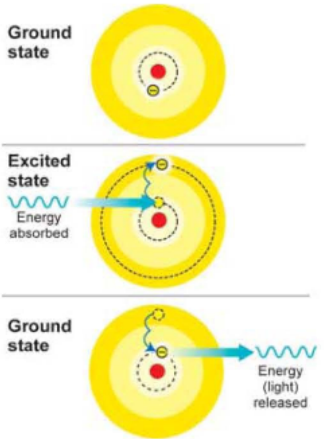


Figure 12.11: *When the right amount of energy is absorbed, an electron in a hydrogen atom jumps to a higher energy level. When the electron falls back to the lower energy level, the atom releases the same amount of energy it absorbed. The energy comes out as light of a specific color.*

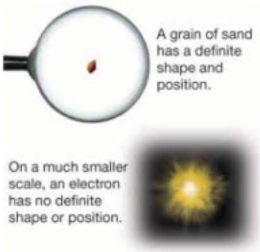
The quantum theory

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, such as 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), the energy, momentum, and other variables of the particle become restricted to certain specific values.

Everything is fuzzy in the quantum world

A particle, such as a grain of sand, is small, but you can easily imagine that 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, a particle's position, momentum, energy, and time in the quantum world 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 it in some way (Figure 12.12). 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.

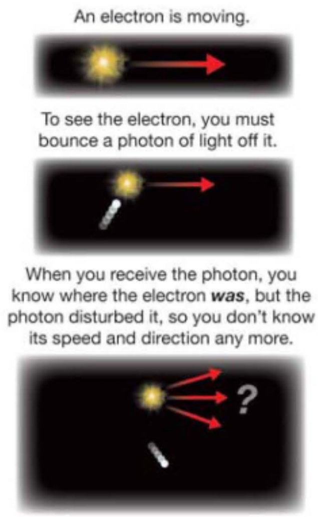
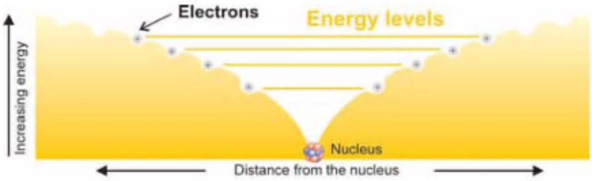


Figure 12.12: *The act of observing anything in the quantum world means disturbing in unpredictable ways the very thing you are trying to observe.*

Electrons and energy levels

The energy levels are at different distances from the nucleus

The positive nucleus attracts negative electrons the way 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 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 the following rules.

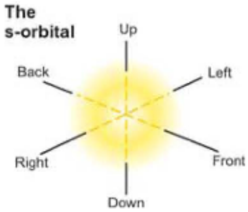
- The energy of an electron must match one of the energy levels in the atom.
- Each energy level can hold only a certain number of electrons, and no more.
- As electrons are added to an atom, they settle into the lowest unfilled energy level.

Quantum mechanics

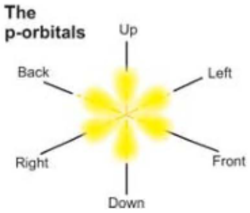
Energy levels are predicted by *quantum mechanics*, the branch of physics that deals with the microscopic world of atoms. While quantum mechanics is outside the scope of this book, you should know that it is a very accurate theory, and it explains the characteristics of the energy levels.

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.

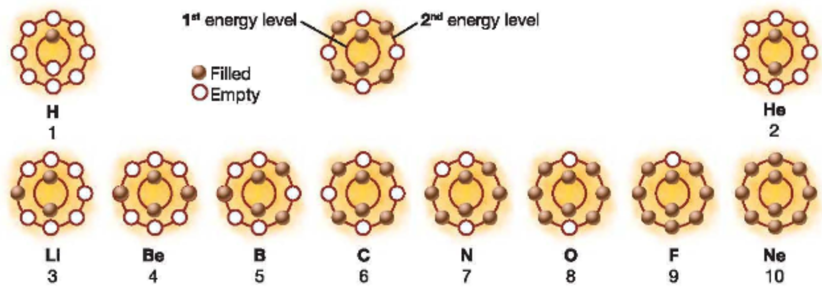
The energy levels in an atom

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 12.13). 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 12.14). The two electrons completely fill up the first energy level (see the 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.



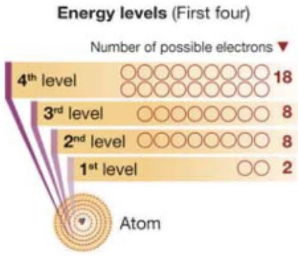


Figure 12.13: *Electrons occupy energy levels around the nucleus. The farther away an electron is from the nucleus, the higher the energy it possesses.*

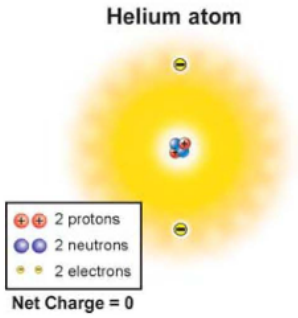


Figure 12.14: *A helium atom has two protons in its nucleus and two electrons.*

Section 12.2 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 12.15 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 12.16 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

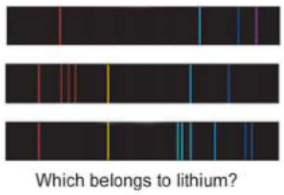


Figure 12.15: *Question 2.*

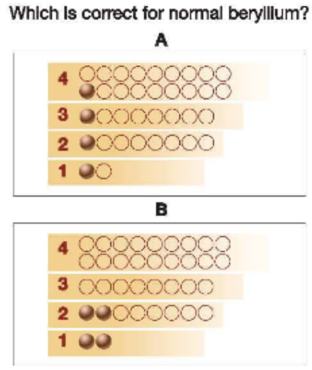


Figure 12.16: *Question 6.*