INORGANIC CHEMISTRY

Today, biology involves cloning, genetic engineering, DNA analysis, antibody research, and many other concepts not even discovered 30 to 40 years ago. Underlying the foundations of modern biology is chemistry and physics. In order to understand later material in the course, you must develop a basic understanding of biochemistry. In order to understand biochemistry, you need a working knowledge of inorganic and organic chemistry.

It is not the intent of a biology course to teach you inorganic and organic chemistry. We will simply lay the foundation for understanding the new biology. In this course, I will assume you know no chemistry. Let's get started.

Assume you are on a scavenger hunt. Your assignment is to find as many naturally occurring pure substances in, on, and around the planet earth. Before you begin, perhaps it would be wise to know what a pure substance is. A pure substance may be defined as a single kind of *matter.*

Matter

Matter, as you may remember from high school, is anything which has mass and occupies space. That pretty much defines everything in the universe, because everything seems to have mass and occupy space. Those of you who had physics may point out energy is not matter. You would be correct, but Albert Einstein, through his equation $E = mc^2$, tells us that if we accelerate a small amount of mass at the speed of light squared, a huge amount of energy will be released. That's the principle behind nuclear reactions. However, $E = mc^2$ is an equation and what is found on the left side must equal what is found on the right side of an equation. That means we could take a large amount of energy and theoretically convert it into a small amount of mass. Therefore, pretty much everything in the universe does have mass and occupy space or it can be converted to matter.

Mass *vs* Weight

Many students (and teachers) often use the term mass and weight interchangeably when in reality, we are talking about mass. Mass is defined as the quantity of matter. Weight is the gravitational attraction on that mass. For example, if I weigh 180 lbs on earth, on the moon, I would weigh 30lbs. Remember the moon has 1/6 the gravitational influence as that of earth. Have I changed my quantity of matter, however? No. Often you will hear the expression atomic weight. To be completely accurate, we should say atomic mass.

Back to the scavenger hunt. You need to find as many naturally occurring pure substances in, around, and on the earth as possible. Another name for a pure substance is an element. In other words, you need to find naturally occurring elements.

Elements

Elements are pure substances, or a single kind of matter. To save you time and energy on a scavenger hunt, there are 92 naturally occurring elements. We've even arranged them for your convenience. It's called the periodic table of elements.

Periodic Table of the Elements
You can tell a great deal about elements with a simple glance at the periodic table of the elements. Note the majority of the elements are in black. This means they are solids *at room temperature.* Other elements are in red. This indicates they are gases *at room temperature.* Those in blue are liquids *at room temperature.* We have to stipulate room temperature because solids may be heated and converted to liquids, liquids can be heated further and converted to gases.

If you look at a periodic table, you will immediately notice there are more than 92 elements. This means there are some elements not naturally occurring. Those elements are called synthetic elements. They were created in the laboratory. Look at element # 43 on the periodic table of elements. That's the element Technetium. Notice the element is in outline. This indicates it is a synthetic element. Also, note it is outlined in black. This indicates when it was created, it was created as a solid at room temperature.

Also notice there seems to be a heavy line separating element 5 from the left of the table, and also elements 13 and 14. This line zig-zags down through the chart. To the left of this heavy line are metals. To the right are nonmetals.

Metals *vs* Nonmetals
There are certain physical properties of the elements which separate them into metals or nonmetals. Metals are those materials that typically are shiny (said to be lustrous), conduct heat and electricity, and are malleable (can be hammered into sheets or drawn into wires). Nonmetals exhibit the opposite physical traits: typically non-lustrous, don't typically conduct heat or electricity, and are non-malleable.

Synthetic Elements
There are several synthetic elements and more are created periodically (no pun intended). Look next at element 93. That's Neptunium, named after the planet Neptune. Element 94 was named after the planet Pluto while element 95 was named for the country that created the element – America. We honor Marie Curie with element 96. Elements 97 and 98 were created by the University of California at Berkeley, and so on.

Naming the Elements and Assigning Their Abbreviations
Most of the earlier discovered elements are fairly simply named. There can be a story behind each. For example, helium, element # 2, was first discovered as an element in our sun and only later discovered on earth. The Greek word for sun is *helios,* hence, helium.

The short-hand notation or abbreviations of the elements can become a little confusing. It's easy to see why hydrogen, element # 1 is abbreviated H. Helium is abbreviated He, and so on. However, what do you do when you come to the element Iron? Iron is element # 26 and yet its abbreviation is Fe, not I, not Ir. Iron's abbreviation comes from the Greek word for iron, *Ferrum.*

Don’t worry, you’ll learn most of the abbreviations simply by using them over and over.

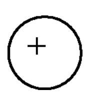
Gold!
Let’s look at an element …gold. The abbreviation of gold is Au, from the Greek word *Aureum.* Think of a block of gold in the shape of a cube. Imagine cutting the block in half. Now, half the half. Now half the half of the half. Keep halving the gold. Is there a point at which you can no longer subdivide the block of gold and still retain the properties of that element?

An ancient Greek philosopher, Democritis (460 - 370 B.C.) was thinking about this and he decided, yes, there is a point at which you can no longer subdivide matter and still retain the characteristics of that matter. He called that point an *atoma,* from whence we get the word atom. The ancient Greeks, must have been pretty smart. They theorized the existence of an atom some 2300 years before we had definite proof.

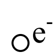
Atoms
Another way of stating the definition of an atom is an atom is the smallest unit of matter indivisible by <u>ordinary chemical means.</u> In this atomic age, you should realize we can divide atoms. However, splitting the atom is no ordinary chemical reaction.

So what makes up an atom? Atoms are composed of smaller particles of matter (have mass and occupy space). In particular, this course will look at three of those particles: protons, neutrons, and electrons. Atoms are composed of many types of particles. There are leptons, hadrons, mesons, quarks, etc., but we will stick to just protons, neutrons, and electrons.

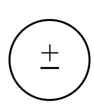
Protons
Protons are positively charged particles. We often represent protons by a sphere with a positive sign inside it.



Electrons
Electrons are particles which carry a negative charge. They are often represented by a much smaller sphere with a minus sign (-).



Neutrons
Neutrons are particles that carry no charge. Just as in mathematics, when you add a +1 to a –1, the answer is zero, neutrons are often represented with a positive and minus sign written together + inside a sphere a little larger than a proton.



Since these are particles, they have mass and occupy space. However, atoms themselves are exceptionally small and light, so the particles that make up atoms must be even smaller and lighter. How much mass does a proton have?

Look at your Sargent-Welch© periodic table of the elements. You should see an inset on the table, (side two) that is labeled "Data Concerning the More Stable Elementary (Subatomic) Particles". Look for the column labeled "Rest mass in (kg)". Note the mass of a proton is listed as $1.67265 \text{ X } 10^{-27}$. In essence, that number, represented as a decimal is 0.00000000000000000000000000167265 kg! As you can tell, that's a pretty small number.

For all practical purposes, scientists decided this mass was too small to work with for every day chemistry. As a consequence, they decided to arbitrarily assign a mass of 1 for a proton. So what is the mass of a proton? It's one. One what? One proton. However, it's most often referred to having a mass of 1 atomic mass unit (amu).

What is the mass of a neutron? Again, referring to the table, it states the resting mass of a neutron is $1.67495 \text{ X } 10^{-27}$ kg. Note the neutron is slightly more massive than a proton. However, do you think if someone placed a neutron in your right hand and a proton in your left, you could tell the difference? No. Therefore, scientists said neutrons also have a mass of 1 amu. (Remember, neutrons, in actuality, are slightly more massive.)

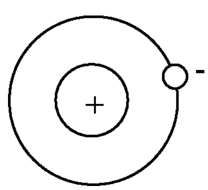
What about electrons. Electrons have a mass of $9.1095 \text{ X } 10^{-31}$kg. These are very small particles. Therefore, scientists arbitrarily assigned the mass of 0 to electrons. Remember, they do have a mass but for our purposes, we say they have a mass of zero.

Arrangement of Particles

The subatomic particles of protons, neutrons, and electrons are arranged in the atom in a particular order. Protons and neutrons are found together in the *nucleus* of the atom. Electrons are found orbiting around the nucleus.

Diagrammatic Representation of Atoms

To envision an atom, you can diagrammatically represent one as shown below. This particular atom has one proton, zero neutrons, and one electron.

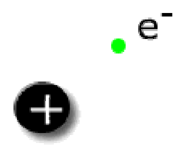


Let's look at hydrogen, the first element on the periodic chart. It's a gas at room temperature. In the upper right hand of the element on the chart, you should see the number 1.00797. This is the atomic number.

Round off 1.00797 to the nearest whole number. That's 1. This means there is one atomic mass unit in the nucleus. The question is, what is the particle that makes up that mass unit. Remember, electrons have a mass of zero, protons and neutrons have a mass of one each. The particle in the nucleus, by definition, could be either a neutron or proton. In our case, it is a proton. To represent hydrogen, there is a single proton in the nucleus with one electron orbiting the proton. This form of hydrogen does not have a neutron in its nucleus.

What is the charge on this atom of hydrogen?

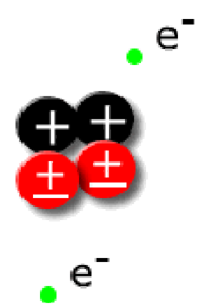
Protons = 1 (+)
Neutrons = 0 (±)
Electrons = 1 (-)
Total charge = zero



We say hydrogen, in its *naturally occurring form,* has a zero charge because the number of protons = the number of electrons (neutrons have no charge). The positive charge cancels the negative charge.

Helium (He)

Helium is a gas at room temperature. As mentioned earlier, it was first discovered as a component of our sun and then discovered on earth. Helium contains two protons and two neutrons in its nucleus and is orbited by two electrons. The count on helium is:

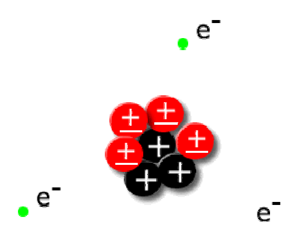


Protons 2 (+)
Neutrons 2 (±)
Electrons 2 (-)
Total charge = zero.

Again, helium in its naturally occurring form has a zero overall charge of particles.

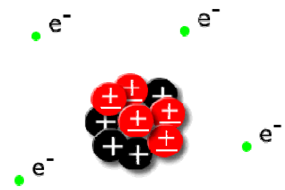
Lithium (Li)

Lithium is a solid at room temperature. It contains 3 protons and 4 neutrons in its nucleus and there are 3 electrons orbiting that nucleus. The count on Lithium is:



Protons 3 (+) Neutrons 4 (±) Electrons 3 (-)
Total charge = zero.

Lithium, in its naturally occurring form has a zero overall charge on its particles. Get the idea? **What is the overall charge found on any atom in its naturally occurring form?** Zero. For this to occur, the positive charges *must* equal the negative charges. For that to happen, the number of *protons* must equal the number of *electrons.*

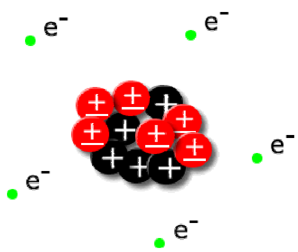


beryllium

Beryllium (Be)
Beryllium is element # 4. It’s a solid at room temperature and there are four protons (therefore, 4 electrons). In addition, there are 5 neutrons in its nucleus. The count is:

Protons 4 (+)
Neutrons 5 (±)
Electrons 4 (-)

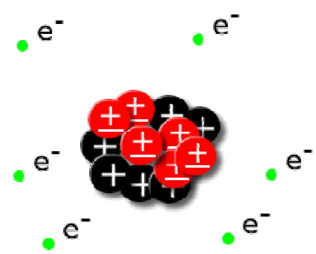
Total charge on any atom in its naturally occurring form = zero.



boron

Boron (B)
Boron has 5 protons, 6 neutrons, and 5 electrons.

Carbon (C)
Carbon has 6 protons, 6 neutrons and 6 electrons.



carbon

Summary

Atom	**Protons**	**Neutrons**	**Electrons**	**Overall charge**
Hydrogen	1	0	1	0
Helium	2	2	2	0
Lithium	3	4	3	0
Beryllium	4	5	4	0
Boron	5	6	5	0
Carbon	6	6	6	0

Do you see any pattern?

You should notice atoms in *naturally occurring forms,* have a zero charge on the atom. This means the number of protons *must* equal the number of electrons. You should also deduce there may be occasions when atoms are not in their naturally occurring forms. More about that later.

Protons = Atomic Number
Have you noticed the correlation between the atomic number of an atom and the number of protons? It’s no coincidence. Therefore, if I tell you to look at element # 92, Uranium, you should know that Uranium has 92 protons in its nucleus (as well as 92 electrons orbiting that nucleus).

Protons Are the Fingerprints of the Elements
Protons are like fingerprints. They determine the identity of the element. For example, Uranium has 92 protons in its nucleus. No other element in the universe has that number. If it has 92 protons, it must be Uranium.

What About Neutrons?
Can you see any pattern in the neutrons? Not really. Then how do you determine the number of neutrons in an atom. Look again at the mass of the atom.

Hydrogen has a mass of 1.00797. Rounded off to the nearest whole number, that is “1”. Remember protons have a mass of 1, neutrons have a mass of 1 and electrons, for all practical purposes have no mass. This means all of the mass of an atom is concentrated in its nucleus. Since hydrogen *must* have 1 proton to be hydrogen, all the mass of hydrogen is found in its single proton.

A Chemical Convention
There is a standard way chemists indicate mass and atomic number of elements. For hydrogen with a mass of 1 and an atomic number of 1, it is as follows.

$${}^{1}_{1}H$$

The number in red is the atomic mass unit and is written as a superscript on the *left* side of the hydrogen symbol. The number in blue is the atomic number and is written as a subscript on the *left* hand side of the hydrogen symbol. It’s important to recognize superscripts and subscripts and which side of the symbol you find them. On the right side, they mean something totally different.

Look at Helium. The shorthand way of describing the atom is:

$${}^{4}_{2}He.$$

Helium has an atomic mass of 4 (rounded to the nearest whole number). Therefore, at there are four mass units *in the nucleus.* Two of those mass units must be protons (atomic # of 2). That means 2 mass units are unaccounted for. Those are neutrons.

${}^{4}He$
$_{-2}$ protons
= $_{2}$ neutrons

Lithium has an atomic mass of 7 (rounded to the nearest whole number). Seven mass units are in the nucleus. Since Lithium’s atomic number is 3, that means there are 3 protons. This leaves 4 mass units unaccounted for, and those must be neutrons. Lithium has 4 neutrons in its nucleus.

What about Uranium?
Uranium has 238 atomic mass units. 92 of those must be protons. How many neutrons? Simply subtract the atomic number from the atomic mass and you will come up with 146 neutrons.

Element X
Now that you know that you determine the number of neutrons in an atom by subtracting the atomic number from the atomic mass, let's try something different. Suppose someone tells you they found an element with 114 *neutrons* and an atomic mass of 190. Can you determine the element? Think. All the mass of an atom is in the nucleus. The nucleus is composed of protons and neutrons. If there are 190 mass units in the nucleus and 114 of them are neutrons, then the other 76 must be protons. Protons determine the fingerprint of the element. Element # 76 is Osmium.

Hydrogen Again
Hydrogen is the most abundant element in the universe. The sun is composed primarily of hydrogen. All stars are primarily composed of hydrogen. The atomic mass of hydrogen is reported as 1.00797. Why would we report the mass of hydrogen to 5 decimal places when we are dealing with relative numbers? Remember, we arbitrarily said protons have a mass of 1. The answer to the "five decimal places" question lies in the fact there are three forms of hydrogen.

Protium
The first form of hydrogen – and the most abundant – is protium. 99.44% of the hydrogen in our universe in protium. Our diagrammatic representation of hydrogen earlier is this form. Protium has 1 proton, 0 neutrons, and 1 electron with an overall charge of zero. However, there are two additional forms of hydrogen.

Deuterium
Deuterium is a form of hydrogen that has one proton – it must or it is not hydrogen. However, deuterium has one neutron. The number of neutrons does not alter the fact that the element is hydrogen, it simply adds mass to the nucleus. There is also one electron. For deuterium, the count is: 1 proton, 1 neutron, 1 electron, with an overall charge of zero. Note how the atom is represented below. The mass of deuterium is 2.

$$^{2}_{1}\mathrm{H}$$

Since deuterium is more massive (by one neutron) than protium, it is sometimes referred to as "heavy" hydrogen. When you make water with heavy hydrogen, the result is "heavy" water. It is often used as a controlling agent in nuclear reactions. Deuterium is fairly rare in nature.

Tritium
Tritium is the third form of hydrogen. It has one proton, two neutrons, and one electron, for an overall charge of zero. The mass of tritium is thus 3. Tritium is exceptionally rare. Today, it is often used as a radioactive tracer in research.

If you take the relative abundance of protium and multiply by its mass of 1; then take the relative abundance of deuterium and multiply by its mass of 2; then take the relative abundance of tritium and multiply by its mass of three; add them together and divide by three, you obtain the number 1.00797, the average mass of hydrogen and its forms.

How do protium, deuterium, and tritium differ? Only in the number of neutrons. *Any atom with varying numbers of neutrons is called an isotope.*

Isotopes
Isotopes are atoms with varying numbers of neutrons. When you look at the Periodic Table of the Elements, you will notice most of the elements have masses expressed to decimal places. This should indicate to you that most of the elements have isotopic forms.

When you look at the masses of synthetic elements, note most are reported to whole numbers. This must mean when created in the laboratory, we created a single isotopic form of that element.

Atoms to Compounds
Depending on which periodic chart you have, there are 119 elements. In today's society, you probably have more television channels from which to choose. Chemists would be bored pretty quickly if they only had 119 "toys" to play with. What is exciting about chemistry is the ability to combine atoms into compounds or molecules. We can make combinations of atoms to form other substances. This increases the "playing field" significantly.

Molecules and Compounds
When we combine atoms chemically, they form either molecules or compounds. What's the difference between a molecule and compound?

Molecules
Molecules are two or more atoms chemically combined.

Compounds
Compounds are two or more *different* atoms chemically combined.

At first glance, there doesn't seem to be much difference. In reality, there is. Take the combination of hydrogen combined with hydrogen. We represent the substance formed from that combination as H_2. (Again, pay attention to where subscripts and superscripts are located – on the left or right hand side of the atoms.) Is H_2 a molecule, compound, or both?

H_2 is a molecule but not a compound. It is two or more atoms combined chemically (molecule), but the atoms are *not* different, they are the same, therefore, it is *not* a compound.

What about water (H_2O)? Is it a molecule, compound or both? Water is both. It is both a molecule (two or more atoms) and a compound (two or more different atoms).

Catch 22
All compounds are also molecules, but not all molecules are compounds.

Electrons
In order to combine atoms chemically to form molecules or compounds, we need to know something about how atoms react when placed together. There are some atoms you would do well *not* to try to react with others. You may not be around to tell about your experiment. In order to predict the reactivity of atoms, we need to know something about electrons.

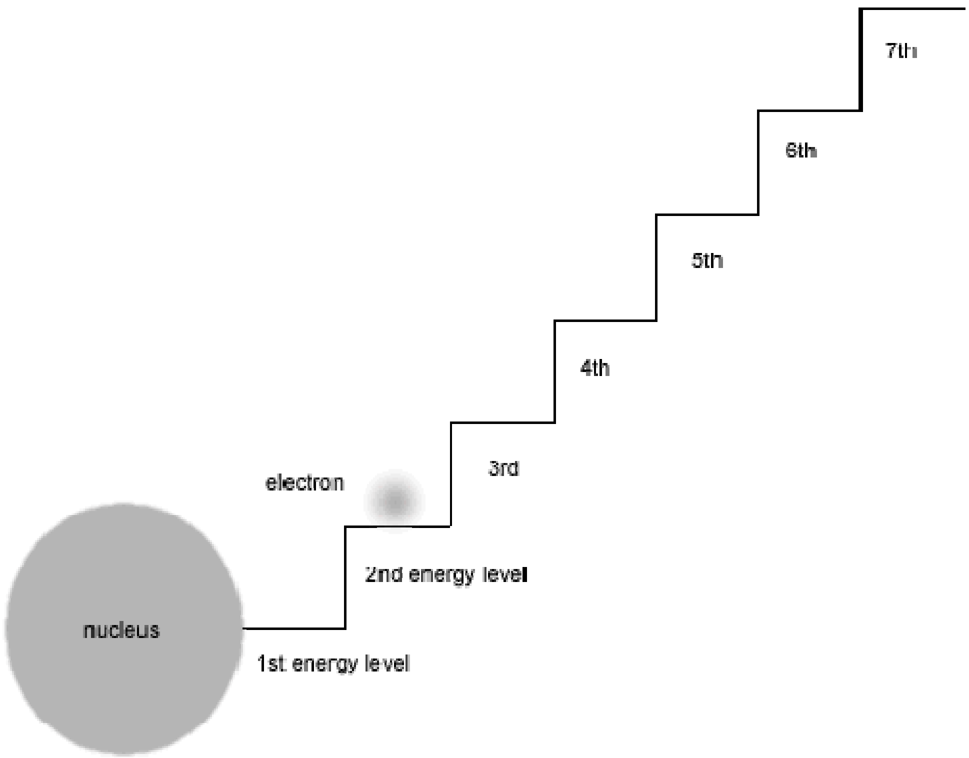
Up until this point, we've short-changed electrons. We haven't really said a whole lot about them. Electrons are important because they determine the chemistry of atoms.

So far, you've learned that the number of electrons is equal to the number of protons in an atom in its naturally occurring form. You've also learned the electrons of an atom are found orbiting somewhere around the nucleus of the atom. Let's take that a little further.

To predict the chemistry of atoms, you need to know both the position and movement of an electron. How do you determine the position of a particle in motion? A German physicist named Heisenberg said you cannot, with any degree of accuracy, predict both the movement and position of an electron. I just told you you need to know that. Heisenberg says you cannot. We are at a road block! However, there is a way to *adequately* predict both motion and position of an electron. It's through the use of four quantum numbers.

Quantum numbers
We will use a series of numbers to describe the position and movement of an electron in order to predict the atom's chemistry. Numbers are a language in their own right and can be very descriptive. The four numbers we will use to describe the electron are "n", "l", "m", and "s". I said numbers and just gave you letters. Remember, however, that in algebra, "x" can stand for any number. We will assign numbers to the four letters.

Quantum number "n"
The quantum number "n" represents the distance from the nucleus you may find an electron. An electron can be found 1 distance, 2 distances, 3 distances, 4 distances, etc. In theory, "n" can be any number from 1 to infinity. However, by the time we reach n = 7, we have accounted for all the electrons in all the known atoms.

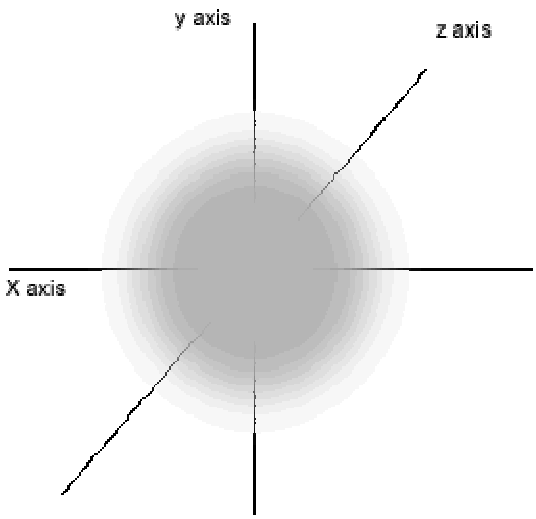


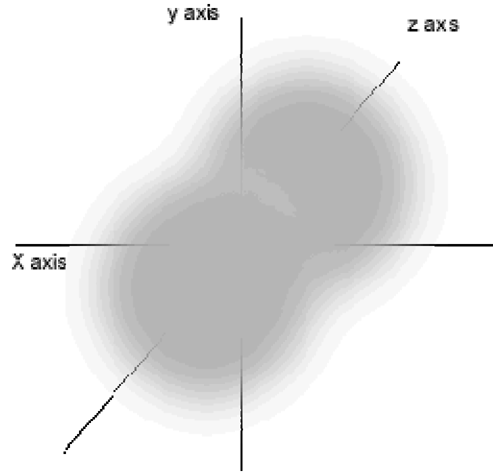
Sometimes, we refer to those distances as energy levels. Another way of saying it is an electron may be found in the first energy level, the second, etc. An electron has enough energy to be either in one level or another. It cannot be found between levels. We say the electron has a *discrete* amount of energy, called a *quantum.* Electrons with the greatest amount of energy are found in the energy levels farther away from the nucleus while those with the least energy are found closer to the nucleus.

Quantum number "ℓ"
The quantum number "ℓ" represents the shape of the orbit of the electron. In other words, what is the pattern of orbit of the electron around the nucleus? If n=1, then ℓ=1, there is one possible shape for the orbit. If n = 2, then ℓ = 2, there are two possible shapes for the orbit. If n = 3, ℓ = 3, there are 3 possible shapes. You get the idea.

One of the shapes is a simple sphere. Think of a tennis ball as the nucleus of an atom. Then think of that tennis ball suspended within the center of a basketball. Anywhere between the tennis ball and the inner surface of the basketball, you can find an electron orbiting in the spherical shape. Another shape is like a three dimensional figure eight.

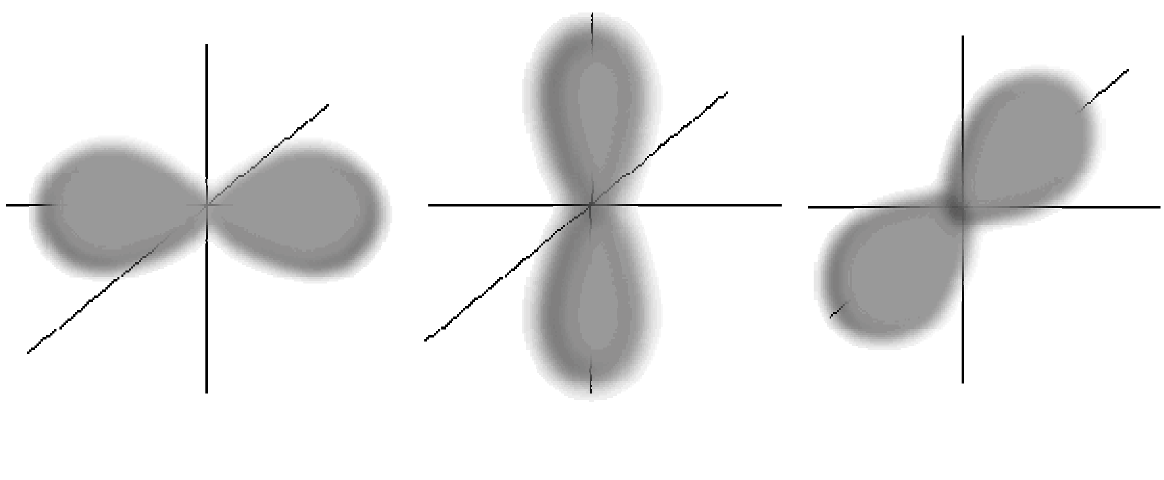
Quantum number "m"
The quantum number "m" represents the orientation in space in which you find the shape. From high school, you should remember something called the Cartesian plot; you plotted on an x-y axis straight lines, parabolas, circles, etc. The Cartesian plot is a two dimensional plot. Life is three dimensional. There is an x-y-z axis. The question becomes – how do we place any of the possible shapes of the orbitals along an x-y-z axis. For a sphere, the answer is simple. There is only one way to place a sphere along an x-y-z axis – dead center.



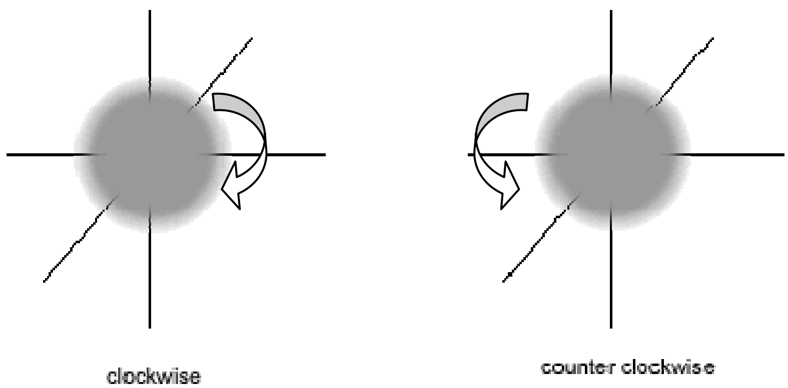


p_z orbital

What about the "dumbbell" shape? You can orient the dumbbell along either the "x" axis, or the "y" axis, or even the "z" axis; therefore, there are three possible orientations in space for the dumbbell shape.



Quantum number "s"
The quantum number "s" is the spin on the electron. Just as the planet earth rotates on its axis once every 24 hours, electrons rotate on their axis. There are two possible rotations of planets: clockwise (like the hands of a clock) or counterclockwise. Electrons, like planets, may rotate either clockwise or counterclockwise. Imagine, just like our solar system where the earth revolves around the sun at the same time it rotates on its axis, electrons are doing the same thing.



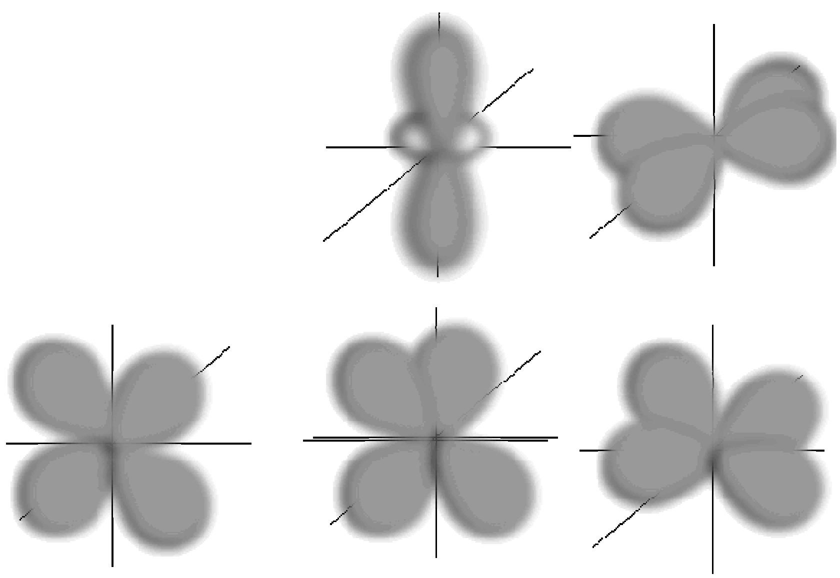
What's Next?
Where do we go from here? Let's place in tabular form the above information and expand it through all 7 energy levels. Before we do this, we need to concern ourselves with how many electrons may fit in any given energy level, orbit, etc. A German physicist named Pauli came up with what is known as **Pauli's Exclusion Principle.** No more than two electrons may occupy any single *orientation in space.*

Quantum *n*	**Quantum ℓ**	**Shapes of the Orbit**	**Orientations in Space**	**Maximum # of Electrons**
1	1	s	1	2
2	2	s p (dumbbell)	1 3	2 6

For the p orbital, there are three possible orientations in space (p_x, p_y, p_z) with 2 electrons for each orientation. Therefore, according to Pauli, you may have a maximum of 2 electrons per orientation or 6 total possible electrons for all three orientations.

For the d orbital, there are 5 possible orientations in space. This seems impossible since there are only 3 dimensions, however, it is *how* you place the orbits around the x,y,z axes.

Quantum *n*	**Quantum ℓ**	**Shapes of the Orbit**	**Orientations in Space**	**Maximum # of Electrons**
1	1	s	1	2
2	2	s p (dumbbell)	1 3	2 6
3	3	s p d	1 3 5	2 6 10



I think you can see a pattern. As we increase the number of electrons, you have to increase the shapes of the orbits and therefore you increase the number of orientations by two and the electrons by four. Here's the summary.

Quantum *n*	**Quantum ℓ**	**Shapes of the Orbit**	**Orientations in Space**	**Maximum # of Electrons**
1	1	s	1	2
2	2	s p (dumbbell)	1 3	2 6
3	3	s p d	1 3 5	2 6 10
4	4	s p d f	1 3 5 7	2 6 10 14
5	5	s p d f g	1 3 5 7 9	2 6 10 14 18
6	6	s p d f g h	1 3 5 7 9 11	2 6 10 14 18 22
7	7	s p d f g h i	1 3 5 7 9 11 13	2 6 10 14 18 22 26

There are several important things to remember about this table. First, you must remember the names of the orbits, s, p , d, f, g, h, i. The actual shapes are far too complicated to learn in a beginning biology course, however, you do need to know the names. Secondly, you need to remember the orientations in space for each: s = 1, p = 3, d = 5, f = 7, g = 9, h = 11, i = 13. Lastly, you need to know the maximum number of electrons: s = 2, p = 6, d = 10, f = 14, g = 18, h = 22, i = 26. Note that the orientation in space increases by two for every energy level you go up and the maximum number of electrons increases by four.

How Do We Use This?
Using the tabular information above, we can, in a short-hand way, represent the electron configuration of an atom that gives us a pretty good idea of both position and movement. For example, hydrogen has 1 proton, 0 neutrons in its most common isotope, and 1 electron. Where do we find that electron? Is it in the first energy level or the 7^{th}? The answer is the first; so n = 1. If n = 1, then ℓ = 1, there is one possible shape of the orbit (consult the table). That is the spherical shape designated "s". There is only one way to place a sphere on an "x/y/z" axis and that is dead center, so there is only 1 orientation in space. Pauli tells us there can be a maximum of two electrons per orientation in space, therefore we can put up to two electrons in the "s" shape. We only have one.

To represent the electron configuration of hydrogen, we would write the following:

$1s^1$.

The coefficient of 1 is the quantum number n (n=1). The small letter "s" is the shape of the orbit. The superscript 1 tells us the number of electrons found in that "s" orbit.

Check the following electron configurations and try to understand how they were determined.

Helium $1s^2$

Lithium $1s^22s^1$

Beryllium $1s^22s^2$

Boron $1s^22s^22p^1$

Carbon $1s^22s^22p^2$

Look at Neon with 10 electrons.

Neon $1\ s^22s^22p^6$

This should be fairly easy to understand. However, what do you do when you get to very large atoms, such as uranium (92). The logical answer would be to follow the table, fill the electrons until you reach the number of 92. In other words,

$1\ s^22s^22p^63s^23p^63d^{10}4s^24p^64d^{10}4f^{14}5s^25p^65d^{10}5f^{14}$.

Unfortunately, physicists figured out the system and forgot to experiment to see if the electrons follow their system. They don't. However, after experimentation, the proper sequence of filling was determined for each electron. *Most* of the elements follow the sequence shown below. However, it's very difficult to memorize the proper sequence of filling. There's a way you can determine the sequence of filling without memorizing the information. See below.

1s
2s 2p
3s 3p 3d
4s 4p 4d 4f
5s 5p 5d 5f 5g
6s 6p 6d 6f 6g 6h
7s 7p 7d 7f 7g 7h 7i

Notice we've placed "s" under "s", "p" under "p", etc. to form kind of a ramp.
Now draw a line through the "1 s" level as shown below.

1s
2s 2p
3s 3p 3d
4s 4p 4d 4f
5s 5p 5d 5f 5g
6s 6p 6d 6f 6g 6h
7s 7p 7d 7f 7g 7h 7i

That means the "1 s" level fills first.

Next draw a diagonal *parallel* to the first. It goes through the "2s" level.

1s
2s 2p
3s 3p 3d
4s 4p 4d 4f
5s 5p 5d 5f 5g
6s 6p 6d 6f 6g 6h
7s 7p 7d 7f 7g 7h 7i

Another diagonal parallel to the first two goes through *first* the "2p" and then the "3s".
These fill next.

1s
2s 2p
3s 3p 3d
4s 4p 4d 4f
5s 5p 5d 5f 5g
6s 6p 6d 6f 6g 6h
7s 7p 7d 7f 7g 7h 7i

Continue drawing diagonals and as each arrow cuts through a letter, that's the one that fills next.

1s
2s 2p
3 s 3p 3d
4s 4p 4d 4f
5s 5p 5d 5f 5g
6s 6p 6d 6f 6g 6h
7s 7p 7d 7f 7g 7h 7i

The proper sequence of filling is:
1s 2s 2p 3s 3p 4s 3d 4p 5s 4d 5p 6s 4f 5d 6p 7s 5f 6d 7p 5g 6f 7d 6g 7f 6h 7g 7h 7i.

So what is the "real" electron configuration of Uranium (92)?

$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^{10} 5p^6 6s^2 4f^{14} 5d^{10} 6p^6 7s^2 5f^4$

Notice the last energy level and orbit, the 5f, has only 4 electrons. It can hold 14, but we have reached the magic number of 92 by simply adding 4 electrons.

Outermost Energy Level Electrons

By understanding where the electrons orbit around the atom, you can predict the reactivity of the atoms. It was a little misleading to say "electrons determine the chemistry" of atoms earlier. In reality, *it 's the outermost energy level electrons that determine the chemistry of atoms.* When you write the notation for the electron configuration, it allows you to determine the outermost energy level electrons and how they fill up the levels.

Look on your periodic table of the elements at the far right-hand side. You will see a column of gases. These are Helium, Neon, Argon, Krypton, Xenon, and Radon. They are sometimes referred to as the Noble Gases. These gases tend to be very unreactive. They do not readily combine chemically with other atoms to form compounds and molecules. As a result, they are very stable. What makes them so stable? Look at their electron configuration.

He	$1s^2$
Neon	$1s^2 2s^2 2p^6$
Argon	$1s^2 2s^2 2p^6 3s^2 3p^6$
Krypton	$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6$

What is the *outermost energy level* of each?

He 1 s^2 - the 1 st energy level is the outermost with 2 electrons.

Neon 1 $s^2 2s^2 2p^6$ - the second energy level is the outermost with 8 electrons.

Argon $1s^2 2s^2 2p^6 3s^2 3p^6$ – the third energy level is the outermost with 8 electrons.

Krypton $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6$ – the fourth energy level is the outermost with 8 electrons.

You get the idea. You could write the electron configuration notation for xenon and radon, but

Xenon - has 8 electrons in its outermost energy level.

Radon -has 8 electrons in its outermost energy level.

Octet Rule

Except for helium, with two electrons, the most stable configuration an atom may have is eight electrons in its outermost energy level.

Look at sodium. Sodium is element number 11 on the periodic chart. The chemical symbol for sodium is Na, from the Greek word *natrium*. It is a metal. The characteristics of sodium are it is very shiny and very soft. Sodium is so soft you can gouge out a piece with your thumbnail. The lustrous nature of sodium would make you think it would be an excellent material for making jewelry. However, it has a problem. Not only is it soft, but it is quite reactive. It reacts with the oxygen in the air to form a powdery white material on the shiny metal called sodium oxide. Pure sodium reacts vigorously with water to form hydrogen gas and sodium hydroxide. The hydrogen gas often ignites during the process.

The electron configuration for sodium is $1s^2 2s^2 2p^6 3s^1$. The outermost energy level electrons in this case are found in the third energy level (only 1 is present). According to the octet rule, sodium wishes eight. Will sodium take on 7 additional electrons to reach 8? For example, $1s^2 2s^2 2p^6 3s^2 3p^6$. The adding of 7 additional electrons to make 8 is a possibility for sodium. However, where will it obtain the 7?

Another possibility for sodium would be to give up one electron. This would make the electron configuration of sodium $1s^2 2s^2 2p^6$ with the second energy level becoming the outermost level of electrons with 8.

Given the choice, sodium will give up one electron. However, this has consequences. Normally, sodium has 11 protons, 12 neutrons, and 11 electrons. If it gives up one, it is losing one negative charge. That means the atom becomes positively charged.

11 protons (+)
12 neutrons ($\pm$)
11 electrons (-)
Overall charge = zero

When it gives up an electron the following results.

11 protons (+)
12 neutrons ($\pm$)
10 electrons (-)
Overall charge = positive 1

We denote this by showing the atom with a positive charge (Na^{+1}). (Notice it is a superscript on the right hand side.) This is still sodium. Why? We have lost electrons, not protons. Remember, protons are the fingerprints of the elements.

The name of this new form of sodium is the sodium *cation.* A cation is any atom that loses one or more electrons and becomes positively charged. To name a cation, simply state the name of the atom and add *cation.*

Look at calcium. Calcium as an atomic number of 20. That means 20 protons and 20 electrons. The electron configuration of calcium is: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2$. The outermost energy level is the 4^{th} with 2 electrons. Calcium will give up 2 electrons to become the Ca^{+2} cation.

Chlorine

Chlorine, element # 17, has 17 protons, 18 neutrons and 17 electrons. Chlorine is normally found as a green colored gas. It is exceptionally deadly. If you write the electron configuration for chlorine, it is $1s^2 2s^2 2p^6 3s^2 3p^5$. The outermost energy level is the third level. There are 7 electrons in energy level 3. It wants 8. Will it give up 7 (to make the 2^{nd} energy level the outermost level) or will it take on 1 to make the third energy level have 8? The answer, of course, is it will take on one electron. However, that has consequences.

Normally, chlorine is as follows:

17 protons (+)
18 neutrons ($\pm$)
17 electrons (-)
Overall charge = zero

If chlorine does take on one electron, it becomes:

17 protons (+)
18 neutrons ($\pm$)
18 electrons (-)
Overall charge = -1

We indicate this by writing chlorine as Cl^{-1}. This is the chlor*ide* anion. An *anion* is any atom that has gained one or more electrons to become negatively charged. For example, Oxygen (element # 8) has an electron configuration of 1 $s^2 2s^2 2p^4$. The outer most energy level has 6 electrons. It needs 8 to obey the octet rule. Oxygen thus will *add* 2 electrons to become the –2 anion. We write is as O^{-2}. This is called the oxide anion.

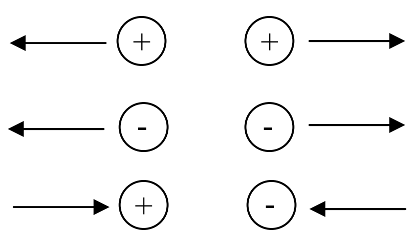
Note how we name cations and anions.
To name a cation, simply name the atom and add the word cation. Anions are different. You take name of the atom, drop the ending and add the suffix "ide". That's why it is called the chlor*ide* anion and the ox*ide* anion.

Both cations and anions have in common the suffix "ion". We can define an ion as any atom that loses or gains electrons and becomes charged.

From where does chlorine obtain the electron to make 8? If you place sodium in the presence of chlorine, sodium *will* donate an electron to chlorine. The result will be a sodium cation and a chloride anion in close proximity.

Na^{+1} Cl^{-1}

There is a law of physics that states "like charges repel, unlike charges attract." This means if you place two positive particles together, they repel. The same for two negative particles. However, if you place a positive and negative particle together, they attract.



The result in the case of sodium cation and chloride anion is:

NaCl.

We have now formed something totally different from sodium metal and chlorine gas. We now have sodium chloride, better known as table salt. Both sodium metal and chlorine gas are very dangerous materials. However, by combining them into the compound sodium chloride, they are no longer dangerous but the new compound is actually essential for life. Also notice there is no overall charge on the compound even though the compound was made from charged particles. The positive sodium cation cancels out the negative chloride anion.

We have combined atoms chemically to form compounds (or molecules). The way this occurred was to *bond* the atoms together chemically by their electrostatic attraction of unlike charges. This type of bond is called an **ionic bond.** Would you consider NaCl a compound or molecule or both?

Bonds

There are four major types of chemical bonds with which we will be concerned:

- Ionic,
- Covalent,
- Hydrogen, and
- Van der Waals (sometimes called London Forces).

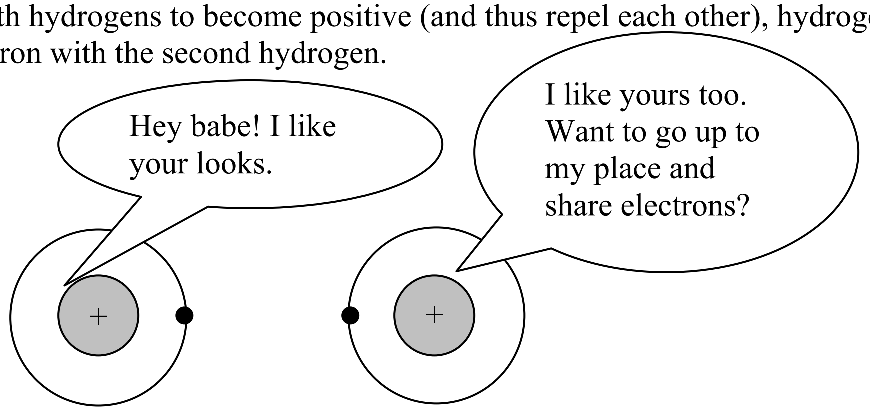
Ionic Bonds

Ionic bonds are formed from the electrostatic attraction of unlike charges due to a transfer of electrons from one atom to another. Our example is sodium chloride, but there are many different ionic bonds.

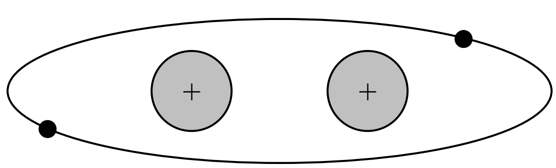
Covalent Bonds

Atoms do not necessarily transfer electrons to form ions in order to bond. Take hydrogen, for example. Hydrogen has the electron configuration of $1s^1$. There is no way hydrogen can aspire to be like the noble gas Neon (with 8 electrons in its outermost shell). Instead, it can try to become as stable as Helium with 2 electrons in the outermost energy level.

Place two hydrogen atoms in close proximity and instead of forming ions (which would cause both hydrogens to become positive (and thus repel each other), hydrogen shares its one electron with the second hydrogen.



Now both think they have two electrons and both think they are like the noble gas Helium. The electrons actually orbit both nuclei.



The result is the molecule H_2. Note the subscript on the right hand side. This denotes a molecule of hydrogen gas in a covalent bond. What is the overall charge on this molecule?

This sharing of electrons between atoms results in a covalent bond. In the case of hydrogen, the electrons are evenly shared. We refer to a covalent bond that shares electrons equally between the atoms as **nonpolar** covalent.

Diatomic Molecules

The molecule of hydrogen is composed of two atoms of hydrogen chemically combined. This type of molecule is referred to as a diatomic molecule. Earlier, it was stated hydrogen is the most abundant element in the universe. That is certainly true, but it is not the atomic form of hydrogen which is the most abundant - it is the molecular form of hydrogen that forms the stars. When you find hydrogen gas naturally occurring on earth, you find it in the diatomic state.

There are many diatomic molecules. These exist on earth most commonly in the diatomic form. For example, Nitrogen exists naturally on earth as N_2 as a nonpolar covalently bonded molecule. Approximately 78% of the air you breathe is diatomic nitrogen. Other diatomic molecules are

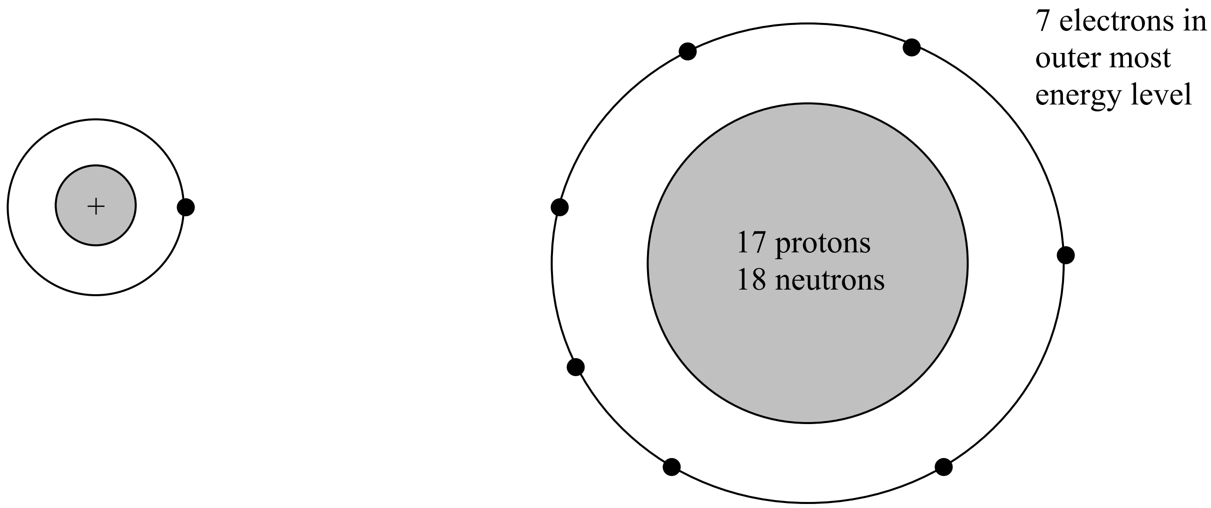
Oxygen (O_2) – 21 % of the air you breathe is diatomic oxygen.
Chlorine (Cl_2)
Fluorine (F_2)
Bromine (Br_2)
Iodine (I_2) and
Astatine (At_2).

Polyatomic Molecules

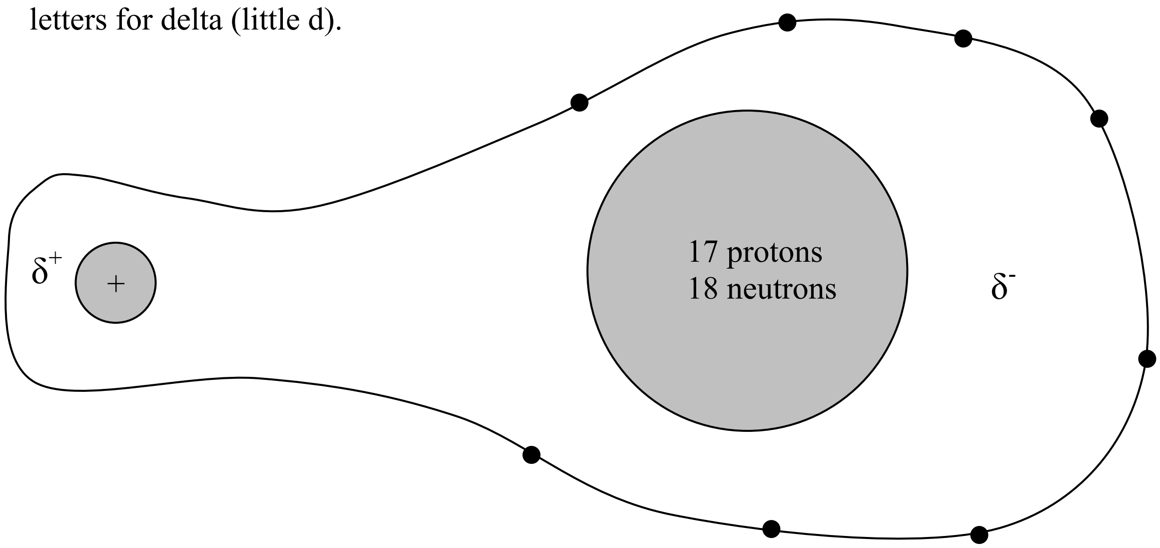
Some atoms naturally occur, not as atoms, not as diatomic molecules, but as polyatomic molecules (composed of more than two atoms). Examples include Phosphorus (P_4). Another is Sulfur (S_8). This means when you find sulfur naturally occurring, you find it as a polyatomic molecule with 8 atoms per molecule.

Polar Covalent Bonds

Hydrogen doesn't have to share electrons with itself. It can share electrons with any atom which needs one or more electrons to obey the octet rule. Remember, chlorine has 7 electrons in its outermost energy level ($1s^22s^22p^63s^23p^5$). Why not have hydrogen share its one electron with chlorine which needs one more to have a 8 electrons in its outermost energy level (the third level)?

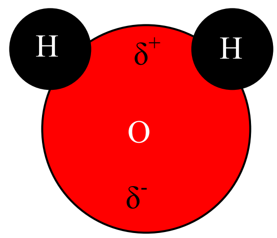


Hydrogen will share electrons, but since chlorine is a much larger atom than hydrogen (17 protons, 18 neutrons and 17 electrons), chlorine keeps hydrogen's electron orbiting around it more often than hydrogen gets its electron back and one of chlorines. The result is an unequal sharing of electrons. This means chlorine has a negative *region* and hydrogen has a positive *region.* Even though the molecule has zero charge associated with it, there is a definite positive/negative orientation. This is called a polar covalent bond. The positive and negative regions are often designated as δ^+ or δ^-. These are the Greek letters for delta (little d).

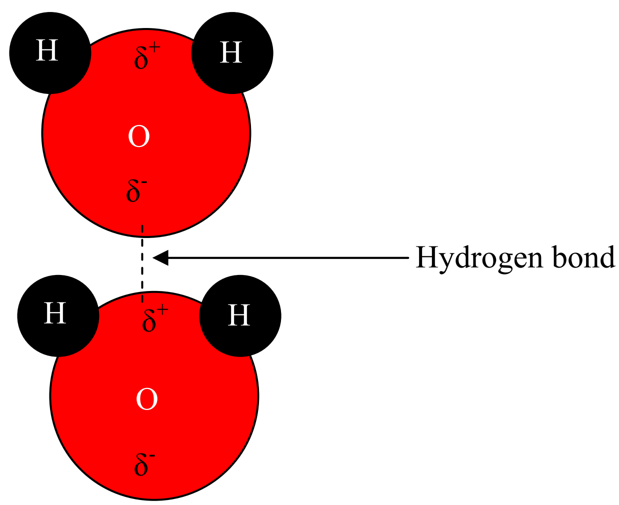


This bond results in the formation of hydrogen chloride (HCl), a gas. Many people assume this is hydrochloric acid, but only when the gas hydrogen chloride is bubbled through water does hydrochloric acid form.

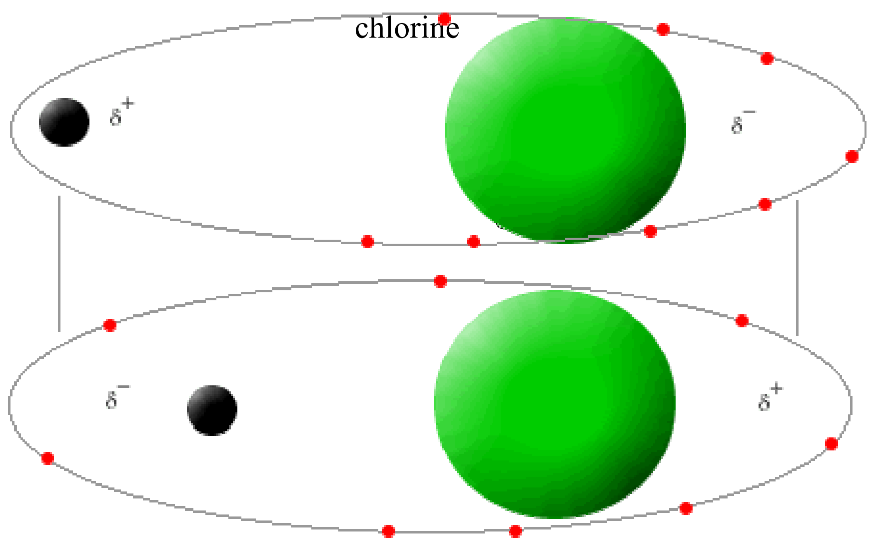
Hydrogen Bonds
To understand hydrogen bonds, you need to understand the water molecule, H_2O. You already know hydrogen can share electrons to form either polar or nonpolar covalent bonds. Oxygen, with 6 electrons in its outermost energy level, needs two additional electrons. Hydrogen can share both locations and does in a water molecule. Notice that even with two hydrogens, oxygen is a larger atom and the sharing of electrons between oxygen and the two hydrogens is unequal. Water is a polar covalently bonded molecule.



When you place another water molecule around the first, since both have positive and negative *regions,* the positive region of the hydrogen atom attracts the negative region of the other molecule. There is a weak bond between two water molecules. This is the hydrogen bond.



Van der Waals (London Forces)
Earlier, hydrogen chloride was discussed as a polar covalent molecule where chlorine kept hydrogens electron around it more than hydrogen got to borrow one from chlorine (and keep its own electron). Regardless, hydrogen, on occasion, does get to use its own electron and one of chlorines. This causes the positive/negative region of the polar molecule to shift position towards hydrogen. This shifting of regions of charge within a molecule is called a dipole moment.



Dipole moments resulting in a Van der Waals bond.

If you place two hydrogen chloride molecules together, one on top of the other, and they are out of phase with each others dipole moment (hydrogen area is more positive in one, more negative in the other) there is a weak attraction between the two molecules due to the dipole moment in both. This is a Van der Waals bond.

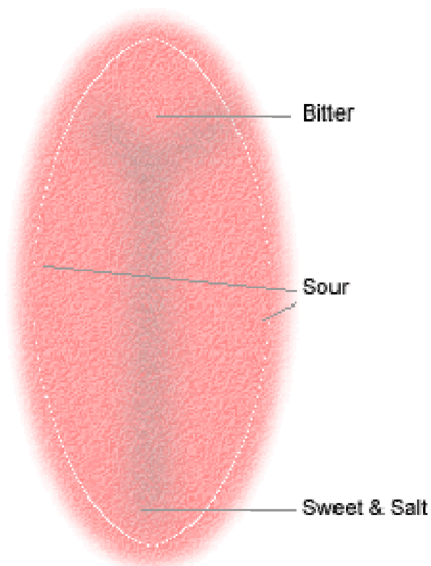
Relative Bond Strengths
Of these four bonds, covalent bonds are the strongest and require the most energy to break apart. Ionic are next, followed by hydrogen and then Van der Waals. The bond strength in descending order is:

Covalent
Ionic
Hydrogen
Van der Waals.

Some Important Compounds and Molecules
Now that you know how atoms combine chemically to form compounds and molecules, it is time to look at three special types: acids, bases, and salts.

Acids
Acids are characterized by four traits. They:
1) taste sour,
2) turn blue litmus red,
3) are indicated by the presence of hydrogen ions, and
4) neutralize bases.

Taste
You are capable of only four taste sensations: sweet, salt, sour, and bitter. Many people will tell you they "taste" chocolate. The overall gastronomical sensation associated with chocolate is actually smell. Chocolate, by itself, is extremely bitter. We add sugar to it to make it taste sweet. Below is a representation of the areas of taste on the tongue. The front of the tongue detects salt and sweet. The sides detect sour and the back part of the tongue determines bitter tastes.



Acids Taste Sour
Tasting an acid is not a wise thing to do since they are corrosive. Acids dissolve holes in table tops and people. If you could dilute an acid to the point it would be harmless to taste, you would get a distinct sour taste.

Acids Turn Blue Litmus Red
Litmus is an indicator. Litmus paper is simply a piece of paper impregnated with a chemical that undergoes a color change in the presence of an acid – thus the ability to turn "blue" litmus red.

Acids Are Indicated by the Presence of Hydrogen Ions
When acid salts are dissolved in water, they split apart into ions. One of those ions is the hydrogen ion (technically the hydronium ion). A hydrogen ion is simple a hydrogen atom without the electron and is indicated by the symbol H^+. All that is left is the nucleus of the atom and since hydrogen (in its most common isotopic form) is a single proton with no neutrons, another way of expressing an acid is to say it is a proton donor.

Acids Neutralize Bases

Acids have the ability to counteract the nature of bases. If you spill a strong base (which also dissolves holes in table tops and people), you can neutralize that base by spraying it with large quantities of a dilute acid. More about neutralization later.

Some Examples of Acids

*Acid	Formula	Dissociation Products	Negative Ion Name
Hydrochloric Acid	HCl	$H_+ + Cl^-$	Chloride
Sulfuric Acid	H_2SO_4	**$H^+ + SO_4{}_{-2}$	Sulfate
Hydrofluoric	HF	$H_+ + F-$	Fluoride
Carbonic Acid	H_2CO_3	$H_+ + HCO_3^-$	Bicarbonate

* Technically HCl is hydrogen chloride (a gas at room temperature) . When hydrogen chloride is bubbled through water, it dissociates into the hydrogen ion and the chloride ion, the form of hydrochloric acid. This is true with almost all the acids.

** Up until this time you have studied ions composed of a single atom. Just as there may be polyatomic molecules (remember S_8), there may be polyatomic ions. The sulfate ion ($SO_4{}^{-2}$) is an example.

Bases

Bases also have four characteristics. They taste bitter, turn red litmus blue, are indicated by the presence of hydroxide ions, and they neutralize acids.

One caveat on the characteristics of bases. Not all bases have the hydroxide ion (OH^-). However, if it does have a hydroxide ion, it is definitely a base. Some bases, such as ammonia (NH_3) do not produce hydroxide ions when dissociated, yet they are still a base. Ammonia is a very weak base, but a base none-the-less.

Example of A Base

One example of a base is sodium hydroxide (NaOH). This is a very strong base that is commonly referred to as lye. It’s the main ingredient in the commercial product called Draino. Dissolve NaOH in water and it breaks apart into sodium ions and hydroxide ions.

Neutralization

One of the characteristics of acids is they neutralize bases. One of the characteristics of bases is they neutralize acids. This concept of neutralization is fundamental to understanding acids and bases, and the production of salts.

If you mix a strong acid (such as hydrochloric) with a strong base (such as sodium hydroxide), the result will be as indicated:

$$H_+ + Cl^- + Na^+ + OH^- \Leftrightarrow H_2O + Na^+ + Cl^-.$$

The hydrogen ion and the hydroxide ion combine to form water. What remains in solution are the sodium and chloride ions. Therefore, the result of mixing a strong acid with a strong base is the production of water and *a salt..* Notice that it is the formation of *a salt,* not *the salt* sodium chloride. If for example, you substituted hydrofluoric acid for hydrochloric, the salt would *not* be sodium chloride. Instead, it would be sodium fluoride.

Another example of a base is ammonia (NH_4). This base, however, does not have a hydroxide ion.

Salts
Salts can be very simply defined as the result of a neutralization reaction.

Relative Strengths of Acids and Bases
Hydrochloric acid is considered to be a strong acid. Hydrofluoric is considered as a weak acid. Ammonia is a weak base while sodium hydroxide is a strong base. How is this determined? You could do the finger test (dip you finger in and if it dissolves, it's a strong acid or base) but you are limited in the number of tests you may run. Instead, we determine the relative strengths and weaknesses of acids and bases based on pH.

pH
pH is defined as the negative logarithm of the hydrogen ion concentration, or expressed as a formula, pH = –log [H^+]. Common logarithms are numbers expressed to some power of ten. For example 100 may be expressed as 10^2. (Natural logarithms are an entirely different matter and are not considered here.)

pH in biological systems often runs from zero to 14. There may be pH's found above 14 and below zero, but the range of zero to 14 is common in biological life forms. We divide the range into increments.

```
0      1      2     3     4    5       6     7      8     9      10   11   12     13   14
|------|---- | ----|---- | ----|---- | ---- | ----|---- | ----|---- | --- | ---- | ----|
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A pH of 7 is considered neutral (neither acidic nor basic). Pure water has a pH of 7.0. On the other hand, anything below 7 is considered an acid. The closer to zero you get, the stronger the acid. Anything above 7 is considered a base. The closer to 14 you get, the stronger the base. A caution about pH. This is a logarithmic scale and as such a pH of 2 is 10 times stronger than a pH of 3!

Some common pH's are

- Blood 7.4
- Milk 6.8
- Soda pop 2.3.

The soda pop pH is significant and interesting. How can you drink something of such a strong pH and not be harmed? The answer is a buffering system.

Buffers
A buffer protects you against wide swings in pH. There are many buffer systems in the body, but a very common (and important one) is the carbonic acid buffer system. Carbonic acid is a weak acid. It often forms when carbon dioxide from the atmosphere combines with ground water. That's one reason there are so many caves and caverns in certain areas of the country. Caverns are mostly limestone in formation (calcium

carbonate) and limestone dissolves in the presence of acids such as carbonic acid.

The overall reaction of carbonic acid is as follows:

H_20 +	CO_2	⇔	H^+ +	HCO_3^-
water +	carbon dioxide		hydrogen ion +	bicarbonate ion

Human blood, which is mostly water, has carbon dioxide dissolved in it to the point some of it combines to form the "associated" form of carbonic acid. The associated form, in solution, dissociates to from the hydrogen ion and the bicarbonate ion. The amounts of each (water, carbon dioxide, associated carbonic acid, hydrogen ions and bicarbonate ions) are in balance or *equilibrium.*

Think of it as a seesaw. As one side gets out of balance, the other side will compensate to restore equilibrium. For example, if you add soda pop, a acid, and as such a donor of hydrogen ions, to your blood stream, then the excess addition of hydrogen ions combine with the bicarbonate ion to form the associated form of the acid. This breaks apart and fforms water and carbon dioxide, neither acidic nor basic. In other words, you shift the equation to the left when you add something to the right and *vice versa.* It is a method of protecting your body from wide swings in pH – thus a buffer.