Lesson 1
FOUNDATION IN CHEMISTRY

Many people shudder when they open the pages of a course and see the word CHEMISTRY. It may triggers memories of boring high school classes that really had nothing to do with their life. Others however, might find it a fascinating area of study. The reason why our ancestors started looking at chemistry in the first place is probably the same reason you are taking this course - to understand how the world around us works. What are some of the mechanisms underlying how these herbs work?

The chemistry of life can be exciting if you set out to make it an adventure. It is not just a bunch of stick figures with letters in between that you might remember from your younger years of study. Chemistry is an intricate flow of energy, always vibrating with its own dynamics; humming and sparkling in three dimensions, creating the miracles of life we see around us. If we could actually see all the interactions of the electrons of molecules, we would be amazed at the sheer beauty of their exotic nature.

For this lesson we will confine our study to a basic broad view of chemistry. If you want a more in-depth look at chemistry, you might want to visit your local library or bookstore. Auditing a university course is also an option.

*Read the Textbook of Advanced Herbology, p. 35 - 39 (down to ‘Hydrogen, H’)*
Atoms: The Building Block Of Chemistry

All substances are made up of tiny particles called atoms. There are billions of atoms in the head of a pin. These atoms are the smallest unit of a substance that can retain the property of that substance. There are over 100 different types of atoms known individually as elements (a substance containing only one type of atom). Each element has its own name and chemical symbol. We usually refer to the element by the short hand symbol such as H for hydrogen. Sometimes the symbol doesn't seem straightforward because some symbols are based on the element's Latin name (e.g., gold has the symbol Au from its Latin name aurum.)

![Atom Structure](image1)

Every atom contains an equal number of electrically charged protons and electrons and a number of uncharged neutrons. (Fig 1.1 and 1.2) The neutrons and the positively-charged protons make up the nucleus. The negatively-charged electrons surround the nucleus and are the dynamic portion that takes part in bonding, an important topic we will be discussing later. The electrons make up the outer shell(s) of the element. (Fig 1.1)

A list of elements can be found in the Periodic Table (page 3). Elements are listed in order of their atomic number. The atomic number is the number of protons in the nucleus of an atom. Each element is represented in a block in the table containing its symbol, atomic number and its approximate atomic mass. (Fig 1.4)

The atomic mass is the number of protons and neutrons found in the nucleus. The horizontal rows in a periodic table are called periods. All elements in a period have the same number of shells of electrons. Each period has one more shell than the previous one. The vertical columns are called groups. Elements within the same group have the same number of electrons in their outer shell. This makes them have similar chemical
properties. For example, group I elements all have one electron in their outer shells, tending to make them very reactive.

The electrons travel in orbitals that make up the shell. These shells are more like clouds then specific orbits that we think of in terms of planets around the sun. Remember this is all taking place in three dimensions. There are four type of shells $s$, $p$, $d$, and $f$. (Fig 1.5). Isotopes are atoms of the same element, which have different numbers of neutrons.

All isotopes of the same element have the same atomic number, but a different atomic mass. There can be three different isotopes of hydrogen ($\text{H}$). (Fig 1.3)
In this last reading assignment we looked at the eight elements H, He, Li, Be, B, C, N, and O. Through this process you can see how the various elements make up the periodic table. Remember these atoms and thus molecules are extremely small. A drop of water has a billion, billion molecules of H₂O in it. This becomes quite important when you start looking at vibrational medicine such as Flower Essences and Homeopathy.

From a textbook “university” point of view, carbon is just that – an element, but if we sprinkle in a little bit of mystical dust from our alchemical ancestors, we can add in the four elements of Earth, Air, Fire and Water. We can think of carbon as the quintessential Earth element in the living system of phytochemicals. Of course we can see graphite (pencil ‘lead’), coal and diamonds as nearly pure carbon representatives of this, but from a biological perspective carbon forms the backbone of earth bound carbon-based life forms. Remember carbon creates four bonds producing a tetrahedron.

Oxygen is very important to supporting our life. If there isn’t enough O₂ in our environment, we can’t breath the ‘prana’ of life and we will die. At the same time oxygen can be quite toxic, creating free radicals that can easily kill us if in excess. We need to thank the plant kingdom, especially the small algae for providing the right balance of O₂ to support our life. We can think of oxygen as being both the elements of Air and Fire. We need oxygen for the slow, controlled metabolic fire inside our cellular mitochondria that supply adenosine triphosphate (ATP), one of the major currencies of life.

Hydrogen is the smallest, lightest and simplest known atom in the universe. It is our Air element. This ephemeral gas is a fundamental component of water.
Nitrogen is a curious element that as a gas makes up 78% of Earth’s atmosphere. In this state it is quite neutral and unreactive. Plants can’t use atmospheric nitrogen. They depend on tiny nitrogen-fixing bacteria in the soil that turn the nitrogen into nitrates that can easily be absorbed. Even through nitrogen is not quite as prominent in human or phytochemical compounds as carbon, hydrogen, or oxygen, it is an important aspect of amines, alkaloids, proteins, enzymes and DNA. As you saw in your reading, even though nitrogen has three bonds, it can often have a fourth hydrogen bond as seen in betanidin the powerful purple antioxidant alkaloid found in beets, spinach, swiss chard, purslane, prickly pear fruit and pokeberry. Nitrogen is another element with an Airy character. We also have to acknowledge it has a sprinkle of Earth element in it - being part of the backbone of DNA, amino acids.

Water is the flowing molecule on earth that encompasses the matrix in which all biochemical processes of life occur. It is the lifeblood of our planet. It continuously recycles, flowing through every living and nonliving being of our planet. Rather than take this abundant substance for granted, we should be respectful of and thankful for its life-supporting gift. It is an important solvent we will discuss later.

Sulfur is a Fire element, which spews from volcanoes, suffuses the water in hot springs, and is part of the flammable coating on the tip of a match. In phytochemicals, we see it as the hot pungent activity in garlic, onions, and wasabi. Allicin has two sulfur atoms (with both four and two bonds), one bonded to oxygen giving an extra fiery quality.

Phosphorus is a Fiery element whose name means ‘light bearer’. Some elemental phosphorus actually glows in the dark. This reactive element can be found in matches, fireworks and explosives. In plants, it is used to transfer energy as seen in adenosine triphosphate (ATP).

You can find fun representatives of the periodic table at: http://theodoregray.com/periodictable/ or the iPad application The Elements from iTunes. Or maybe a bit more scholarly source on: http://www.webelements.com/

Now we come to the important and dynamic role of bonding. We can have simple bonding as seen in water (H₂O), or the more complex bonding in biochemistry.

The next reading assignment will deal with simple bonding.

Read p. 44 - 46 (down to Inorganic and Organic Chemistry)
Bonding

Atoms are more stable when the outer shell is full. In an attempt to fill the outer shell many elements attempt to join chemically with other atoms via bonding. There are two basic types of bonding:

1. Ionic where a metal and a non-metal combine together.
2. Covalent where two non-metal elements bond.

There is a third type of bonding called a metallic bond when atoms of a metal form a lattice. Other non-metal forms of lattice are the giant carbon molecules, which form a huge latticework in diamond.

Ionic Bonding

When an atom loses or gains electrons it becomes electrically charged and is known as an ion. A positive ion is a cation; a negative ion is called an anion. This is an atom’s valence. When ions join together we get an ionic bond. They usually come from opposite ends of the periodic table.

Oppositely charged ions pull toward each other in a process called electrostatic attraction. For example, a sodium atom can easily lose one electron to form a positive ion (Na⁺). A chlorine atom can easily accept an electron to form a negative ion (Cl⁻). They now both achieve complete outer shells. These ions are drawn together to produce sodium chloride (NaCl). These can grow together to form a macromolecule or a salt crystal (fig 1.7)
Properties of Ionic and Covalent compounds

<table>
<thead>
<tr>
<th>Ionic</th>
<th>Covalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Formed by swapping electrons</td>
<td>• Formed by sharing electrons</td>
</tr>
<tr>
<td>• High melting and boiling points</td>
<td>• Often lower melting and boiling points</td>
</tr>
<tr>
<td>• Form lattices</td>
<td>• No lattices, except diamond and graphite</td>
</tr>
<tr>
<td>• Dissolve in water</td>
<td>• Do not dissolve in water</td>
</tr>
<tr>
<td>• Do not dissolve in organic solvents</td>
<td>• Dissolve in organic solvents</td>
</tr>
<tr>
<td>• Conduct electricity when melted or dissolved in water</td>
<td>• Do not conduct electricity (graphite is the only exception)</td>
</tr>
<tr>
<td>• Strong forces holding whole compounds together</td>
<td>• Atoms in molecule held by strong forces</td>
</tr>
<tr>
<td></td>
<td>• But forces between molecules weak</td>
</tr>
</tbody>
</table>

Table 1.1 Properties of Ionic and Covalent compounds

Covalent Bonding

The atoms in the middle of the Periodic Table do not lose or gain electrons easily. Instead, they use a strategy of sharing electrons in order to satisfy their need to have a stable outer shell. The atoms in a carbon dioxide molecule covalently bond through each oxygen atom sharing two pairs of electrons with the carbon atom. This produces a double bond.

Read p. 46 - 50 (down to Shape of Organic Compounds)
Inorganic And Organic Chemistry

While inorganic chemistry deals with a full array of the 103 elements, organic chemistry is the study of compounds containing carbon. It is called organic because at one time chemists thought that these compounds could only be found in, or as products of, living systems. Today we know that carbon can also be found in man-made substances such as plastic. Of course the word "organic" here is quite different from the word "organic" in the natural food industry. We can find the results of organic chemistry around us abundantly in the form of herbs, medicine, plastic, fuel and food.

Organic molecules are made up of covalently-bonded carbon. We see single- and double-bonding quite commonly in organic chemistry. On rare occasions, we can find a triple bond between carbons as can be seen in isobutylamide that give the pungent (tingly) taste to some Echinacea and Spilanthes plants. We can also see this with the hydrogen cyanide (HCN) connection of the cyanogenic glycoside prunasin found in apples, cherries, apricots, plums and Bitter Almonds.

Alkanes And Alkenes

Alkanes are the simplest type of hydrocarbon. They all contain carbon atoms with each one singly bonded to four other atoms. The simplest alkane is methane (CH₄). Each alkane in a series has one more carbon and two more hydrogens (e.g. ethane C₂H₆). The general formula for alkanes is CₙH₂n+2. The nomenclature for alkanes is to end in ‘-ane’ (e.g., methane, ethane, propane etc.)
Alkenes, like alkanes, are made up of carbon and hydrogen atoms. They differ from alkanes in that they have at least one double bond in the chain. This makes alkenes more reactive as it enables other atoms to be added to them. Alkenes are therefore called unsaturated. The nomenclature for alkenes is to end in ‘-ene’ (e.g. ethene, propene, etc.)

Organic molecules tend to form cyclic structures. In cyclic structures the sharing of electrons (bonding) is distributed over the whole ring. Benzene is an example. We can find no ‘real’ double bonds as they are always shifting. This is called a resonance. (fig 1.9) In chemistry, these compounds are called aromatic – which refers to their electron sharing characteristic rather than any smell. I realize this might cause a bit of confusion at first due to the idea of aromatic herbs with volatile compound in essential oils. They are quite

Table 1.2 Alkanes

<table>
<thead>
<tr>
<th>Number of 'C' atoms</th>
<th>Word root</th>
<th>IUPAC name</th>
<th>Structure</th>
<th>Molecular Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Meth</td>
<td>Methane</td>
<td>CH₄</td>
<td>CH₄</td>
</tr>
<tr>
<td>2</td>
<td>Eth</td>
<td>Ethane</td>
<td>CH₃ - CH₃</td>
<td>C₂H₆</td>
</tr>
<tr>
<td>3</td>
<td>Prop</td>
<td>Propane</td>
<td>CH₃ - CH₂ - CH₃</td>
<td>C₃H₈</td>
</tr>
<tr>
<td>4</td>
<td>But</td>
<td>Butane</td>
<td>CH₃ - (CH₂)₂-CH₃</td>
<td>C₄H₁₀</td>
</tr>
<tr>
<td>5</td>
<td>Pent</td>
<td>Pentane</td>
<td>CH₃ - (CH₂)₃-CH₃</td>
<td>C₅H₁₂</td>
</tr>
<tr>
<td>6</td>
<td>Hex</td>
<td>Hexane</td>
<td>CH₃ - (CH₂)₄-CH₃</td>
<td>C₆H₁₄</td>
</tr>
<tr>
<td>7</td>
<td>Hept</td>
<td>Heptane</td>
<td>CH₃ - (CH₂)₅-CH₃</td>
<td>C₇H₁₆</td>
</tr>
<tr>
<td>8</td>
<td>Oct</td>
<td>Octane</td>
<td>CH₃ - (CH₂)₆-CH₃</td>
<td>C₈H₁₈</td>
</tr>
<tr>
<td>9</td>
<td>Non</td>
<td>Nonane</td>
<td>CH₃ - (CH₂)₇-CH₃</td>
<td>C₉H₂₀</td>
</tr>
<tr>
<td>10</td>
<td>Dec</td>
<td>Decane</td>
<td>CH₃ - (CH₂)₈-CH₃</td>
<td>C₁₀H₂₂</td>
</tr>
</tbody>
</table>
different. These rings share electrons in rough doughnut-shaped clouds, which can also be considered a torus from sacred geometry.

In 1890, the German Chemical Society organized an elaborate appreciation celebrating the twenty-fifth anniversary of Professor Kekulé's first benzene paper by. At the celebration, Kekulé spoke of the creation of the theory. He said that he had discovered the ring shape of the benzene molecule after having a reverie or day-dream of a snake seizing its own tail (this is a common symbol in many ancient cultures known as the Ouroboros or Endless knot).

Two other members of the benzene series that will become important later in our studies are naphthalene (C\textsubscript{10}H\textsubscript{8}) and anthracene (C\textsubscript{14}H\textsubscript{10}). (fig 1.10)

Read p 50 - 53 (Functional Groups in Organic compounds)
Shapes Of Organic Compounds

The importance of an organic compound’s shape in a three dimensional plane is very significant to biological systems. Isomers are two or more molecules that have the same empirical formula but have their atoms connecting in different ways producing different shapes. Many biological functions rely on the shape of the molecules involved more than the molecular weight of the molecule.

From an herbal medicine point of view this can be quite significant. Most often the isomers of a chemical found in plant material are ones that response to our biological system. Man-made chemicals often come in many isomers, thus do not have the same biological activity. We will be seeing more information on this as we go through the course. A good example is the difference between a cis and trans configuration of a molecule. The trans form has the chemical groups on opposite sides of the double bond, while the cis form has them on the same side. In large molecules, such as fatty acids, this can have great significance on the therapeutic value or even toxicity of the fatty acid.

Read pg 53 - 54 (down to Oxidation-Reduction Reaction)
### Functional Groups In Organic Compounds

When one of the functional groups is incorporated into a molecule it usually forms a class. Some examples are alcohols, carbonyl compounds, carboxylic acid, and amines.

#### Alcohols

Alcohols are hydrocarbon derivations in which one or more of the hydrogen atoms have been replaced by the \(-\text{OH}\) (hydroxyl) group. The general formula is \(R\text{-OH}\). The nomenclature standard is to replace the \('-\text{e}'\) ending of the corresponding alkane with the suffix \('-\text{ol}'\) (e.g. Table 1.2).

To represent functional groups and the generic carbon groups they are attached to, the generic carbon groups are often replaced with an "R" in chemical diagrams. E.G. alcohol is a hydroxyl (OH) attached to a generic carbon group. \(R \rightarrow \text{OH}\)

#### Carboxylic Acid

This group has a carbonyl with an OH attached to it (HO-C=O). This gives it an acid hydrogen (OH) along with an electropositive carbonyl carbon (C=O). The nomenclature is to take the longest chain carrying the carboxyl group as the parent structure and replace the \('-\text{e}'\) ending with \('-\text{oic acid}'\).
Amines
The simplest way to conceptualize an amine is to view it as a derivative of ammonia where the hydrogens are replaced with alkyl or aryl groups. The normal way to name amine is to drop the last ‘-e’ and replace it with ‘-amine’.

Read Advanced Herbology, pg. 64 – 66

Biochemistry And Life

All chemicals in the known universe have to obey the two laws of thermodynamics:

1. Energy can be gained or lost in a chemical process it can be shifted from one form to another, but it cannot be created or destroyed. Income and expenditures of energy have to balance.

2. Energy inevitably disperses, dissipates and scatters — that is, it’s transformed from a more usable form, like photons, to a less usable form such as heat.

The tendency of energy to disperse and dissipate ordered structures to become disorderly is called entropy.

Biological energy or life is the only function that we know of that creates order out of disorganized matter. Even though the laws of thermodynamics are not broken to ‘run life’ they appear to be temporarily suspended. Some feel that this suspension of the second law of thermodynamics is the definition of life itself. Others take a more esoteric point of view of life. Herbal medicine is usually based on what, in the introduction, was called vitalism. The utilization of Qi, prana, vital force, or an energy that is representative of the basic life energy of the universe is considered by some to ‘run the chemistry’ of life.

In this process biological systems create four groups of macro-molecules: carbohydrates, lipids, proteins and nucleic acids. It is these building blocks that make up the structures of our bodies and the bodies of the botanicals we will be studying.
Summary

In this lesson we looked at the atom: made up of protons, neutrons and electrons. We saw how elements are arranged in the Periodic Table and how they created ionic and covalent bonds. The field of organic chemistry deals with the chemistry of carbon. Here, shape and configuration are quite important.

Functional groups have an important role in how a molecule will behave.

The process of oxidation and reduction helps transform these structures and passes the energy along to different molecules.