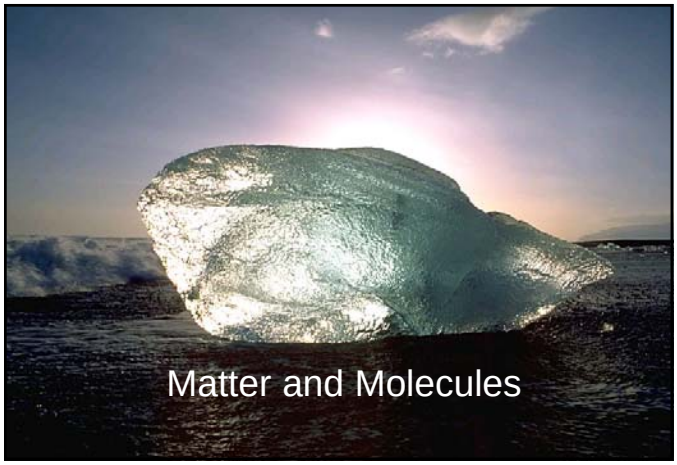


Essential Questions

1. What is the chemical basis of life?

2. Why is carbon important to life?

CONTENT KNOWLEDGE OBJECTIVES

How do chemical reactions impact organisms?

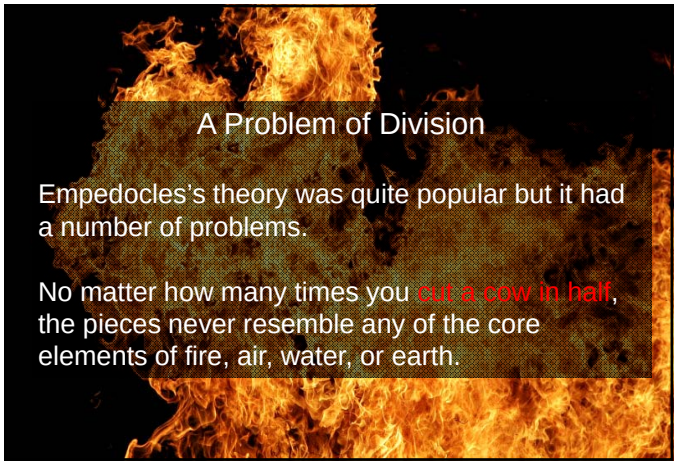
- Biological activities are based on chemical reactions
- Energy is used or produced by chemical reactions in the cell
- Carbohydrates, lipids, proteins, and nucleic acids are important biological molecules
- Enzymes control chemical reactions in the cell
- Enzymes promote chemical reactions

In the old days

- Early humans had to tell the difference between materials that were good for making clothes, shaping into tools, or good to eat
- We developed language and words to describe these things, such as “fur,” “rock,” or “cow.”
- People at the time did not have our current understanding of the substances that made up those objects.

Empedocles

- A Greek philosopher who lived in Sicily around 450 b.c., proposed one of the first theories that attempted to describe the things around us.
- Empedocles argued that all matter was composed of four elements: fire, air, water, and earth.



Even after being broken down into its smallest form the value meal does not yet resemble fire, air, water, or earth

- Despite being wrong Empedocles's theory was an important development in scientific thinking because it was among the first to suggest that some substances that looked like pure materials, like stone, were actually made up of a combination of different "elements."

Then along came Democritus who developed a new theory on matter.

One Material, Indivisible, with…

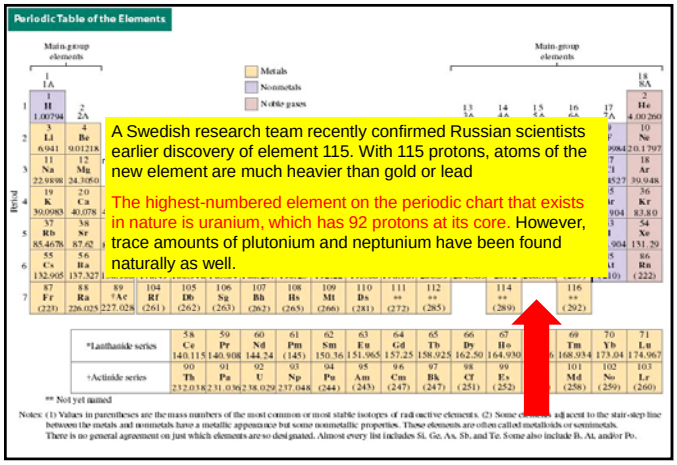
- Democritus reasoned that if you cut a stone into smaller and smaller pieces, at some point you would reach a piece so tiny that it could no longer be divided.
- Democritus called these infinitesimally small pieces of matter *atomos*, meaning "indivisible." He suggested that *atomos* were eternal and could not be destroyed.

Elements are the pure substances that act as the building blocks of the universe.

Elements are Made of Atoms

Elements

- Are pure substances that form all of the materials around us.
- There are approximately 117 elements. Which are organized using the periodic table.
- The elements most frequently found in biological systems are carbon, oxygen, hydrogen, nitrogen, phosphorus, and sulfur.



Elements Have Physical Properties

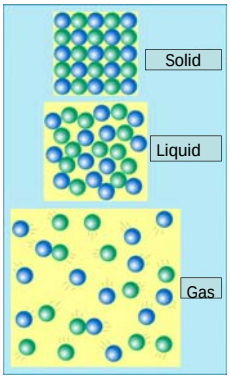
- **Like a certain bearded biology teacher, different chemical substances can be identified by their physical traits**
- **Matter can exist in different states**
  - **Liquid**
  - **Solid**
  - **Gas**
  - **Plasma**

States of Matter

- All atoms & molecules in any substance are in constant motion
- Rate which atoms or molecules move determines the state it is in:
  - Solid
  - Liquid
  - Gas

States of Matter

- Solids
  - Definite shape
  - Definite volume
  - Not compressible
  - Tightly packed particles
- Liquids
  - Indefinite shape
  - Definite volume
  - Not compressible
  - Medium packed particles
- Gases
  - Indefinite shape
  - Indefinite volume
  - Compressible
  - Loosely packed particles



Matter is Made of Atoms

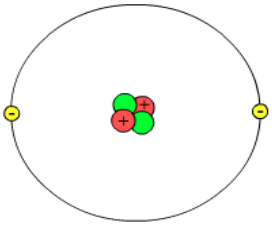
Elements are Made of Atoms

The single smallest unit of an element that retains all of the chemical and physical properties of its parent element is called an **atom**.

Elements are Made of Atoms

- The single smallest unit of an element that retains all of the chemical and physical properties is called an atom.

Atoms are made up of smaller, subatomic pieces called: protons, neutrons and electrons



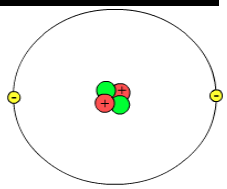
A Helium Atom

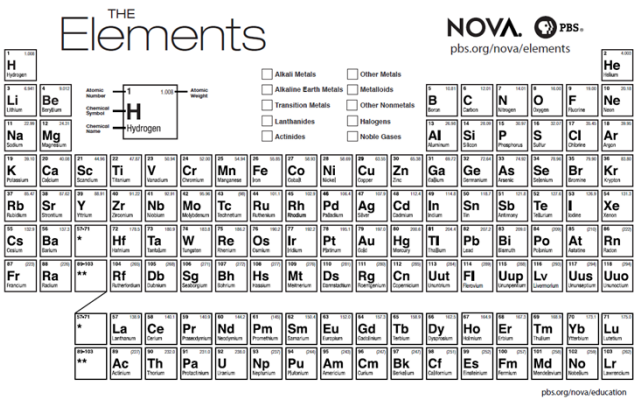
Atoms are composed of three types of subatomic particles

1. Electrons: have a negative charge and are the smallest part of an atom
2. Protons: have a positive charge
3. Neutrons: have no charge

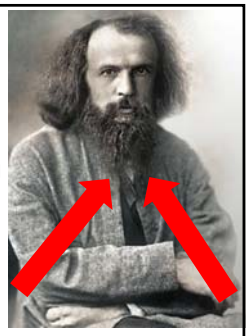
Protons and neutrons clump to make the nucleus

The electrons surround the nucleus and form the much larger electron cloud.





The periodic table of the elements is used to display the known chemical elements. The invention of the table is given to Russian chemist Dmitri Mendeleev in 1869. Mendeleev intended the table to illustrate recurring ("periodic") trends in the properties of the elements.

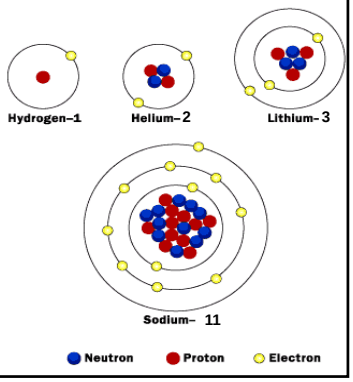


The periodic table provides an extremely useful tool for comparing all the many different forms of chemical behavior. The current standard table contains 117 confirmed elements (while element 118 has been synthesized, element 117 has not).

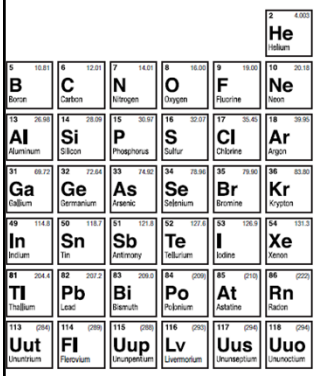
http://www.pbs.org/wgbh/nova/education/physics/developing-periodic-table.html

Atomic Number

- Atoms differ in the number of each of the subatomic particles they contain.
- The number of protons in an atom (called the atomic number) determines the element of that atom.



What is the atomic number of



- He
- Ne
- Ar
- P
- Pb
- AS

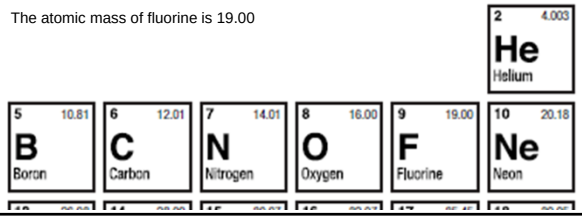
Atomic Mass

The atomic mass is the sum of the masses of the protons, neutrons, and electrons in an atom, or the average mass, in a group of atoms.

Electrons have so much less mass compared to protons and neutrons that they don't really factor into the calculation.

The atomic mass winds up being the sum of the masses of protons and neutrons.

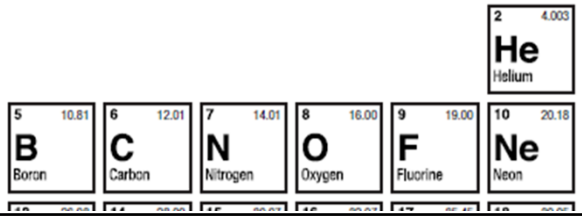
- The atomic mass of carbon is 12.01
- The atomic mass of fluorine is 19.00

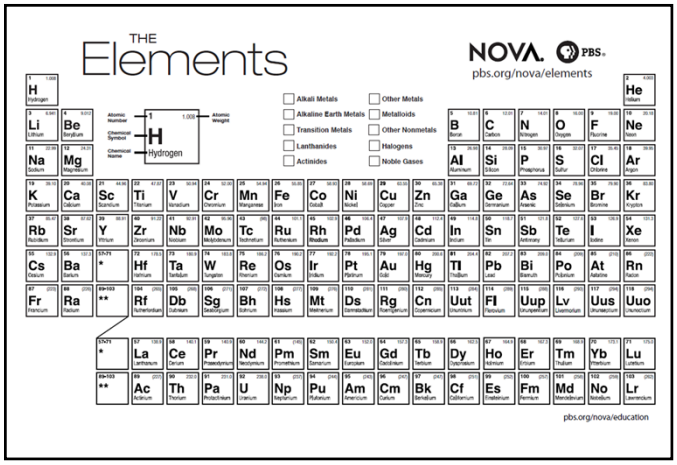


Atomic Mass – Atomic Number = Number of Neutrons

Because the atomic mass is the sum of the masses of protons and neutrons we can use it to find the number of neutrons by subtracting and rounding.

- If the atomic mass of carbon is 12.01 – the atomic number of 6 = 6 neutrons
- The atomic mass of fluorine is 19.00 – the atomic number of 9 = 10 neutrons





Electron Configuration

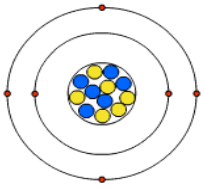
An element's ability to form bonds is determined by its valence (outer) electrons.

Since the outermost electrons determine chemical properties, those with the same number of valence electrons are grouped together on the periodic table.

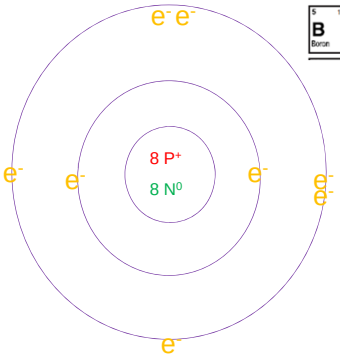
Shell	Electrons
1	2
2	8
3	8
4	18
5	18
6	32
7	32

Carbon is in group 4 (column 4) which means that it has 4 outer electrons.

It has an atomic number of 6 which means it has 6 protons.

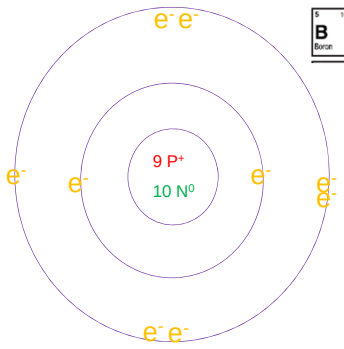


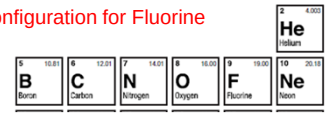
Draw the Electron Configuration for Oxygen



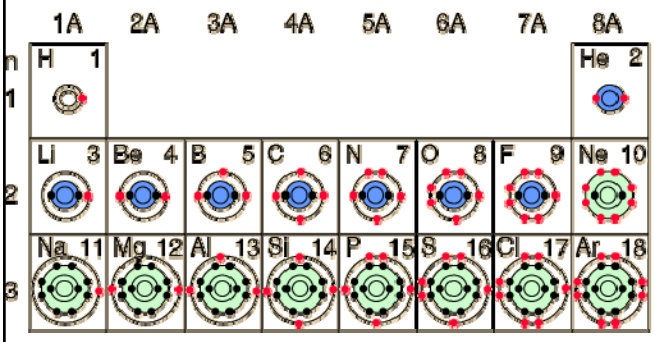
- Oxygen has an atomic number of 8
- That means it has 8 positive protons in the nucleus
- Atomic mass is 16
- 16 minus $8p^+$ = $8N^0$
- 8 p^+ = 8 e^-

Draw the Electron Configuration for Fluorine



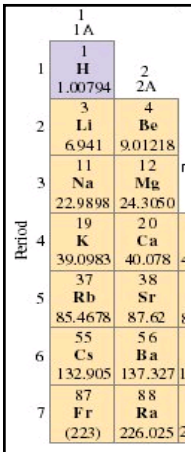


- Fluorine has an atomic number of 9
- That means it has 9 positive protons in the nucleus
- Atomic mass is 19
- 19 minus $9p^+$ = $10N^0$
- 9 p^+ = 9 e^-



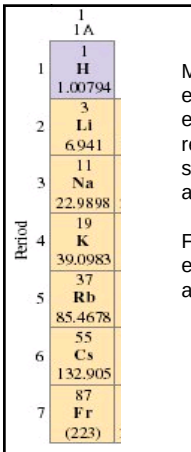
Groups and periods

- A group is a vertical column in the periodic table of the elements.
- In some groups, the elements have very similar properties
- A period is a horizontal row in the table



Period	1 1A	2 2A
1	1 H 1.00794	
2	3 Li 6.941	4 Be 9.01218
3	11 Na 22.9898	12 Mg 24.3050
4	19 K 39.0983	20 Ca 40.078
5	37 Rb 85.4678	38 Sr 87.62
6	55 Cs 132.905	56 Ba 137.327
7	87 Fr (223)	88 Ra 226.025

Elements with the same number of “outer” electrons are grouped together in the columns of the periodic table



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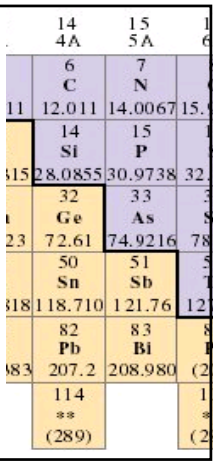
6	55 Cs 132.905
7	87 Fr (223)

Moving down through a group from the lightest element to heaviest element, the outer-shell electrons (those most accessible for chemical reactions) are all in the same type of orbital, with a similar shape, but with increasingly higher energy and average distance from the nucleus.

For instance, the outer-shell (or "valence") electrons of the first group, headed by hydrogen, all have one electron in an s orbital.

As another example, both carbon and lead have four electrons in their outer shell orbitals.



14 4A	15 5A
6 C 12.011	7 N 14.0067
14 Si 28.0855	15 P 30.9738
32 Ge 72.61	33 As 74.9216
50 Sn 118.710	51 Sb 121.76
82 Pb 207.2	83 Bi 208.980
114 ** (289)	

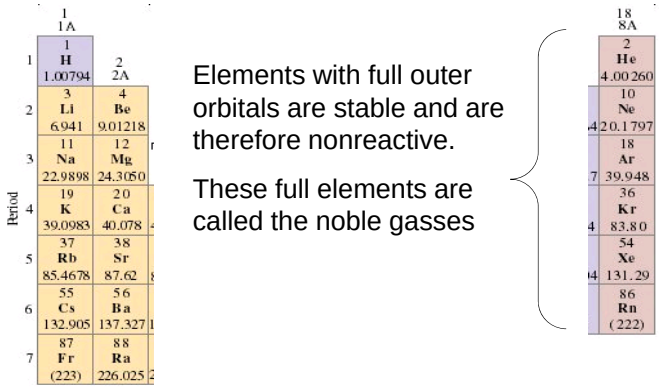
The Octet Rule

The octet rule is a simple chemical rule of thumb that states that atoms tend to combine in such a way that they each have eight electrons in their valence shells, giving them the same electronic configuration as a noble gas.

The rule is applicable to the main-group elements, especially carbon, nitrogen, oxygen, and the halogens, but also to metals such as sodium or magnesium.

In simple terms, molecules or ions tend to be most stable when the outermost electron shells of their atoms contain eight electrons.

Atoms are most stable with a full valence shell.



Elements with full outer orbitals are stable and are therefore nonreactive.

These full elements are called the noble gasses

http://www.pbs.org/wgbh/nova/education/physics/element-reactive.html

A consequence of the octet rule is that atoms generally react by gaining, losing, or sharing electrons in order to achieve a complete octet of valence electrons.
The reaction of atoms occurs primarily in two ways: ionically and covalently.

Exceptions to the Octet Rule

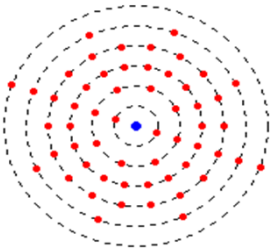
The duet rule of the first shell - the noble gas helium has two electrons in its outer shell, which is very stable.

Since shell 1 can only have at most 2 valence electrons.

Hydrogen only needs one additional electron to attain this stable configuration, while lithium needs to lose one.

Chemical Bonds

- The number of electrons in an atom's outermost shell (the valence shell) governs its bonding behavior.



Barium

Bonds are Strong

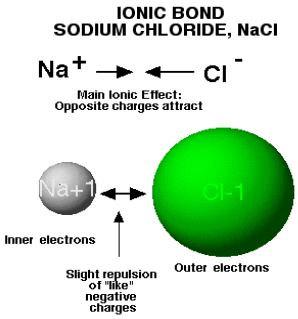
- The formation of a bond causes a strong attraction between two atoms, creating molecules or ionic compounds.
- An atom can **share** electrons with other atoms to form a **covalent bond**

or

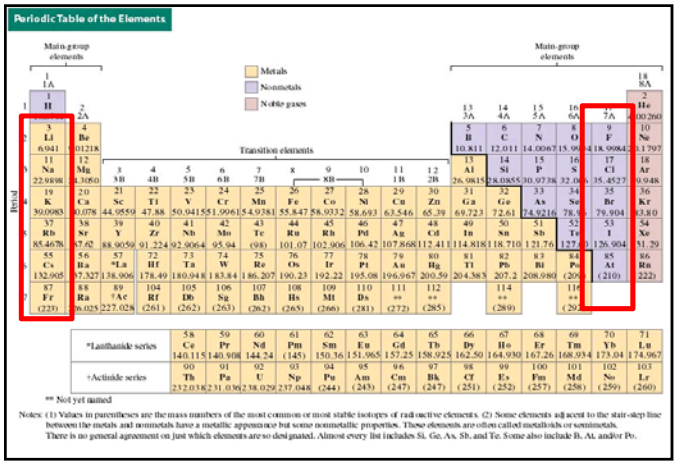
- An atom can **remove** electrons from other atoms to create an **ionic bond**.

Ionic Bonds (Salts)

- **The formation of an IONIC BOND is the result of the transfer of one or more electrons from a metal onto a non-metal.**
- The most common ionic compound in your kitchen is NaCl (table salt)



C. Ophardt, c. 20



Ionic Bonds

- Once an ionic bond is formed, as in Na^{+1} -- Cl^{-1}, the resulting molecule is highly polar.
- Polar molecules have positive and negative sides (like a north and south pole)
- Dipoles attract each other very strongly and so NaCl molecules readily attach to each other to form giant three dimensional crystals.

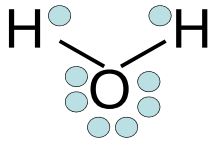
http://www.pbs.org/wgbh/nova/education/physics/elements-form-compounds.html

Covalent Bonds

A water molecule is made up of two hydrogen atoms and one oxygen atom. Oxygen is in the 6th column of the periodic table so we know it has 6 electrons in it's outermost shell.

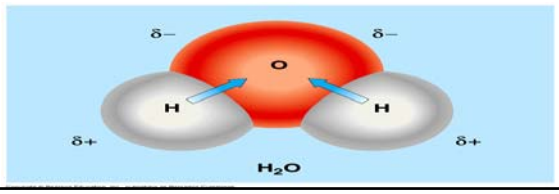
To be balanced Oxygen needs to gain two electrons or lose six. Hydrogen needs to gain one electron to be balanced. Each hydrogen can form a covalent bond and share its electron. A covalent bond exists when two electrons are shared by two non-metallic atoms

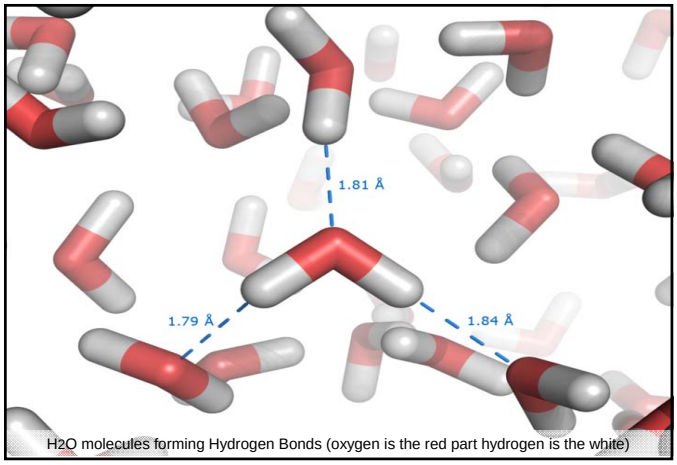
dihydrogen monoxide



The Amazing Properties of Water

- Polar Molecule
  - Uneven distribution of electrons between the 2 hydrogen atoms and the oxygen atom makes one region more negative and the other more positive.

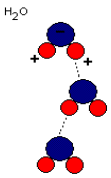




H_2O molecules forming Hydrogen Bonds (oxygen is the red part hydrogen is the white)

Water is polar

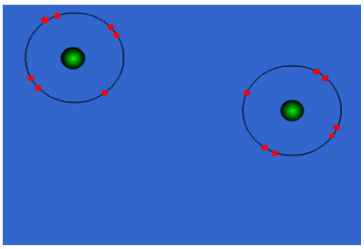
- Because water is polar it will form Hydrogen bonds between molecules
- Hydrogen bonding occurs when an atom of hydrogen is attracted to two atoms instead of only one acting as a bond between them
- Typically H bonds form where the partially positively charged hydrogen atom lies between partially negatively charged oxygen or nitrogen atoms



Liquid water contains by far the densest hydrogen bonding of any solvent with almost as many hydrogen bonds as there are covalent bonds.

Because of these attractive forces water will stick to itself (called cohesion) and stick to other surfaces (called adhesion)

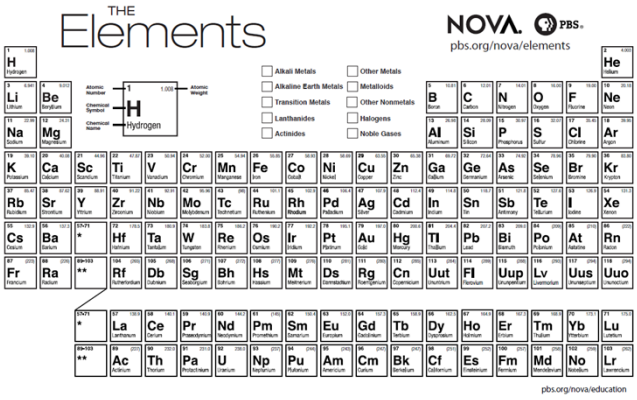
This animation is a schematic depiction of what happens in the formation of a covalent bond between to atoms of chlorine.



•Note that each chlorine atom has only **seven valence electrons**, but really wants eight.

•When each chlorine atom shares its unpaired electron, both atoms are tricked into thinking each has a full valence of eight electrons.

•Notice that the individual atoms have full freedom from each other, but once the bond is formed, energy is released, and the new chlorine molecule (Cl_2) behaves as a single particle.

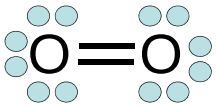


Types of Covalent Bonds

- (a) single bonds: in which a single pair of electrons, one from each atom, are shared, as in Cl_2.
- (b) double bonds: in which two pairs of electrons are trapped between the nuclei, as in O_2.
- (c) triple bonds: in which three pairs of electrons are trapped between the two nuclei, as in N_2.

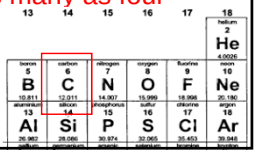
Oxygen is Diatomic

- Each oxygen atom needs to gain 2 electrons to be balanced.
- Instead of bonding with two separate atoms it can form a double bond with another oxygen and form O_2.
- In a double bond two electrons are shared.
- O_2 is the most common form of oxygen because it is stable (balanced)



CARBON IS SPECIAL

- The key to carbon's versatility lies in its atomic structure
- Carbon has four unpaired electrons in the outermost energy level
- These multiple bonding sites enable it to form strong covalent bonds with as many as four other atoms.



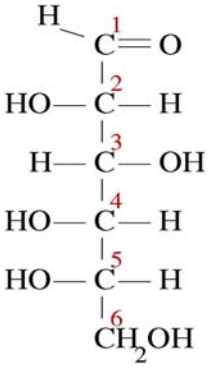
Carbon dioxide

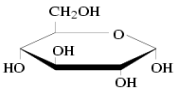
- Carbon has 4 electrons so it needs to gain 4 more to be balanced.
- Oxygen has 6 and needs 2 electrons

What kind of bonds will Carbon and Oxygen make to form CO_2?
Carbon forms a double bond (Covalent bonds) with each oxygen atom. Carbon will share 2 electrons with each oxygen and each oxygen will share 2 of its electrons with carbon.

Glucose

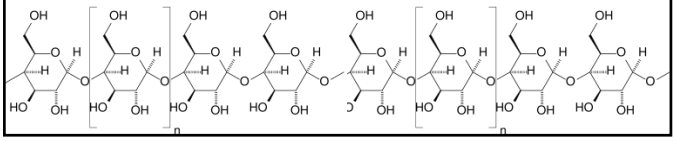
- A monosaccharide sugar, $C_6H_{12}O_6$, occurs widely in most plant and animal tissue.
- It is the principal sugar circulating in the blood and the major source of energy in the body.





Carbohydrates are Sugars

- Carbohydrates are an example of a special kind of molecule called a POLYMER
- Polymers are molecules that are made up of repeating subunits
- Simple sugars (monosaccharides like glucose) can be bonded to each other to make polysaccharides (like starch)



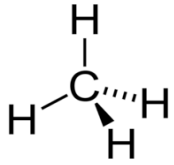
Sweet but what does mine say?

- Sugars can exist in one of two forms: **linear** or **cyclic** (rings).
- Although we often draw them as linear structures, they quickly fold up into ring shaped molecules in water.
- Sugars are important not just for energy but also as a building material.
  - Two 5-Carbon sugars: **ribose** , **deoxyribose** are found in RNA and DNA respectively.

Organic Molecules

- An organic compound is a member of a large class of chemical compounds whose molecules contain **carbon** and **hydrogen**
- Carbon oxides (like carbon dioxide) and elementary carbon are not organic compounds.

Methane is the simplest possible organic compound

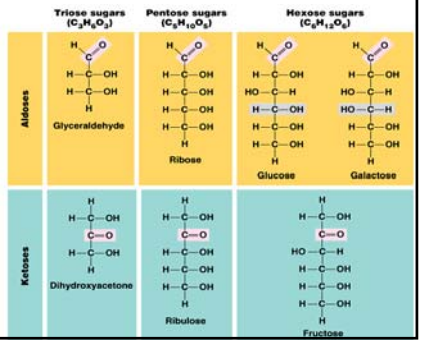


Monosaccharides

Monosaccharides are the simplest form of carbohydrates.

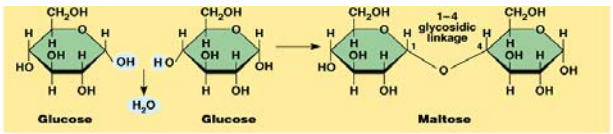
Examples include glucose, fructose, and ribose.

Monosaccharides are the building blocks of disaccharides like sucrose (common sugar) and polysaccharides (such as cellulose and starch).

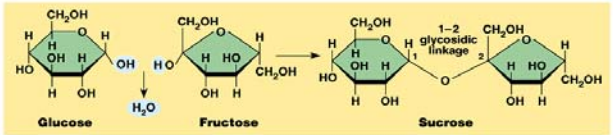


Dehydration Synthesis

Removing one molecule of water to bond 2 monomers together.



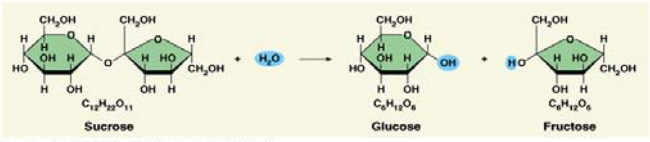
(a) Dehydration synthesis of maltose



(b) Dehydration synthesis of sucrose

Hydrolysis

Polymers can be split back to their simple monomer form by adding water.



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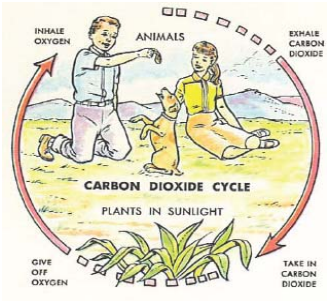
Matter can not be created nor destroyed… but it can be recycled

- Carbon, Hydrogen and Oxygen are continuously being recombined by organisms to make the materials needed for life.
- Energy, cannot be created or destroyed however energy can be converted from one form to another.



Energy is:

- The ability to do work or cause change.
- Energy cannot be created or destroyed
- Energy can be converted into another form
  - Light bulbs convert electrical energy → radiant energy (light) → thermal energy (heat)
- If energy can not be created where does the energy on Earth come from?

Where does energy come from if it can't be created?

- Energy on Earth comes as solar radiation (sunlight),
- Some of energy in light is captured by green plants via photosynthesis and is trapped in the chemical bonds of a glucose molecule.
- When glucose is used in cellular respiration some of the energy trapped in the chemical bonds is transferred to ATP and the rest of the energy is lost as heat.

Reduction-Oxidation Reactions

- Many chemical reactions that help transfer *energy* in living things involve the transfer of *electrons*
  - **Oxidation reactions:** reactant loses one or more electrons becoming more positively charged
  - **Reduction reactions:** reactants gain one or more electrons becoming more negatively charged
  - Redox reactions always occur together
  - **OILRIG**: Oxidation Is Loss Reduction Is Gain (of electrons)

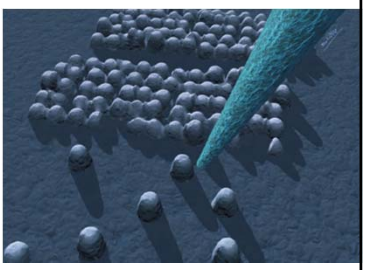
Redox Reaction

- Example: The formation of NaCl
- The Sodium atom loses one electron to achieve stability when it forms an ionic bond with Cl
- The sodium atom undergoes oxidation (- an e^-)
- The chlorine atom gains an electron from the sodium it undergoes reduction (+ an e^-)

Na + Cl → NaCl

Science is a Process

- **Our understanding of the atom was developed over time with each scientist building on the work of those who came before them.**



In this picture atoms are being moved by the single atom tip of a Atomic Force Microscope (AFM). This instrument allows scientists to view and move atoms one at the time.

Matter and Molecules Review

- 1. Define matter.
- 2. Define mass.
- 3. Explain the difference between mass & weight.
- 4. Why do biologists study chemistry?
- 5. Define element.

Matter and Molecules Review

- 6. Name the 5 really important elements that make up most of the mass of living things. Give the symbol for each of these elements.
- 7. Anything that takes up space and has mass or weight is called
- 8. What do the columns of the periodic table tell you about the valence electrons of an element.
- 9. Define atom and tell whether they can be seen.
- 10. What is the center of an atom called & what 2 subatomic particles are found there?

Matter and Molecules Review

- 11. How does the charge of a proton differ from the charge of a neutron?
- 12. Where is most of the mass of an atom concentrated?
- 13. How is the atomic number of an element determined?
- 14. What is the charge on an electron?
- 15. Explain why the overall or net charge on an atom is zero.

Matter and Molecules Review

- 16. Where are electrons found in an atom & describe their movement?
- 17. In which energy levels do the electrons have more energy?
- 18. How many electrons can these energy levels hold --- a. first? b. second?
- 19. Define compound and write a formula for water, carbon dioxide, & sodium chloride (table salt).
- 20. Do compounds have the same chemical properties as the elements that compose them?

Matter and Molecules Review

- 21. When would an atom be chemically stable (not react)?
- 22. What occurs in a chemical reaction?
- 23. What is a covalent bond?
- 24. Define molecule.
- 25. Give an example of a gas that exists as a molecule.

Matter and Molecules Review

- 26. Define ionic bond.
- 27. What is an ion?
- 28. Name a compound formed from --- a. covalent bonding? b. ionic bonding?
- 29. If electrons are shared, a(n) _____ compound forms.
- 30. If electrons are transferred, a(n) _____ compound forms.
- 31. Forming ionic or covalent bonds helps make atoms more _____.

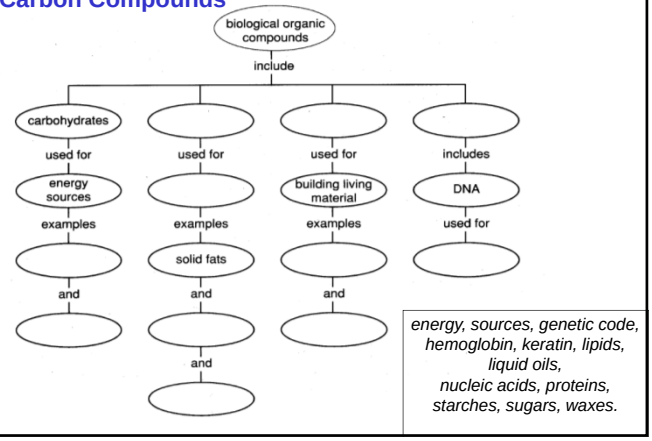
Carbon Review

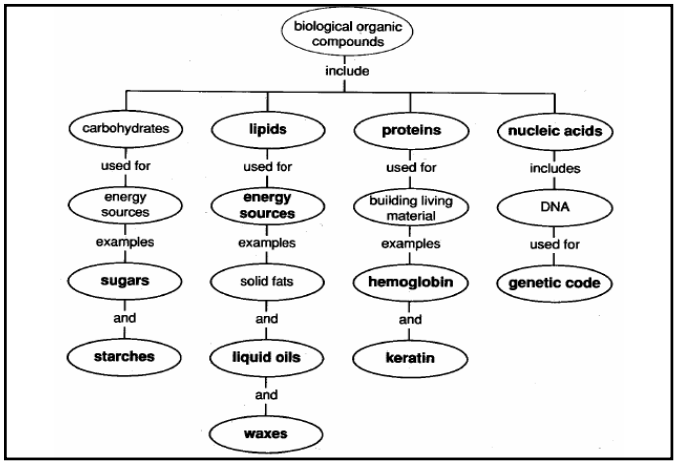
- What is an organic compound?
- Besides carbon, name 3 other elements that make up most organic compounds.
- Carbon dioxide, CO_2, is NOT an organic compound. Explain why.
- How many electrons are in the outermost energy level of carbon? How many does it need to have this energy level filled?
- How many covalent bonds can carbon form?
- How many electrons are being shared in a single covalent bond? double covalent bond? triple covalent bond? quadruple covalent bond?

Sugars

- What process creates sugars using atmospheric gas?
- What is the chemical formula of glucose
- What forms a polysaccharide?
- Name a polysaccharide?

Carbon Compounds




biological organic compounds
include
carbohydrates
lipids
proteins
nucleic acids
used for
used for
used for
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energy sources
energy sources
building living material
DNA
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examples
examples
used for
sugars
solid fats
hemoglobin
genetic code
and
and
and
starches
liquid oils
keratin
and
waxes