Everything in life and elsewhere are made up of atoms.

• We are made up mostly of elements oxygen, carbon, hydrogen, and nitrogen (96%).
• Compounds are combinations of elements: water $H_2O$, salt $NaCl$, methane (gas) $CH_4$.
• Atom is an unit of matter of a single element.
• Question: The human body, which has $7 \times 10^{27}$ atoms, is composed mostly of which element?
Atoms are made up of neutrons, protons (+), and electrons (-).

- Atomic mass = # protons + # neutrons.
- Atomic number = # protons = # electrons.
- Isotopes have the same atomic number but different atomic mass (carbon 13).
- Radioactive isotopes used for dating.
- Electrons occupy different levels of energy.
Chemistry is determined by number of protons and distribution of electrons.

The Octet rule governs reactivity of most chemical elements.
Things to ponder while lining up to get ramen (aka review).

• Question: titanium has atomic number 22, an isotope of titanium with mass of 48 has how many neutrons?

• Question: how many electrons does chlorine (atomic number 17) have in its outermost (valence) shell?

Chemical reactivity is dependent on the number of valence shell electrons.

• **Covalent bonds** are made up of atoms sharing valence shell electrons in a molecule (H-H single bond, O=O double bond).

• Water: oxygen - two single bonds - hydrogen.
Chemical reactivity is dependent on the number of valence shell electrons.

- Ionic bonds are formed from atoms with such differing electronegativity that one pulls electron away from the other and both become charged.

Other chemical interactions hold biological molecules together.
The 3D shape of molecules determines their biological reactivity.

Chemical reactions preserve the number of atoms of each element.

- **Acid-Base:**
  \[ \text{HCl} + \text{KOH} \rightarrow \text{KCl} + \text{H}_2\text{O} \]
- **Combustion:**
  \[ \text{C}_3\text{H}_8 + 5\text{O}_2 \rightarrow 4\text{H}_2\text{O} + 3\text{CO}_2 + \text{energy} \]
- **Photosynthesis:**
  \[ \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O} + \text{energy} \]
- **Question:** X and Y are? \[ 2\text{H}_2 + \text{XO}_2 \rightarrow \text{YH}_2\text{O} \]
The polarity of the water molecule gives rise to hydrogen bonds.

Properties of water sustain life on Earth.

- Adhesion to water allows transport up thin vesicles; surface tension allows floatation.
- Water can absorb heat when it’s hot and release heat when it’s cold; high specific heat.
- Water that evaporates as steam leaves behind a cooler reservoir of liquid to prevent overheating; high heat of vaporization 580 cal.
Ability of solid ice to float on liquid ice means lakes/seas won’t freeze solid.

Global warming causes polar ice caps to form later and melt earlier.

- Combustion:
  \[ \text{C}_3\text{H}_8 + 5\text{O}_2 \rightarrow 4\text{H}_2\text{O} + 3\text{CO}_2 + \text{energy} \]

- Impact:
  Sea level rise 1.8mm/yr, increased rain in wet areas, reduced rain in dry areas, heat waves, droughts, ocean acidification, conversion of tropical forests to savannahs, species extinct.
Water can dissolve almost anything due to its weak hydrogen bonding.

Calculating amount of materials using molar definition of mass.

• A mole of a compound has its molecular mass expressed in grams (for 6.02x10^{23} molecules).
  – One mole of water weighs 18 grams:
    – 2 hydrogens (2 x 1.0079g) + 1 oxygen (15.9994g)
• Concentration is moles per liter of solution.
• Question: How many grams of salt (sodium chloride) should you add to one liter of water to get one molar concentration salt solution?
NaCl is one Na (22.99 g/mol) and one Cl (35.453 g/mol).

So one mol of NaCl is 22.99+35.45 = 58.44 gram, put that in one liter of water to give you 1M NaCl in H₂O.
Acidic and basic solutions affect living conditions.

- At 25°C, $[\text{H}^+] = 10^{-7}\text{M}$, $[\text{OH}^-] = 10^{-7}\text{M}$.
- pH = - log $[\text{H}^+]$, inversely related to hydrogen concentration.
- Neutral solution has pH 7.
- Acidic solution has pH < 7, basic has pH > 7.
- Biological buffers reduce the effect of pH changes:

<table>
<thead>
<tr>
<th>$\text{H}_2\text{CO}_3$ (acid)</th>
<th>$\text{H}^+$ donor</th>
<th>Response to a rise in pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{HCO}_3^-$ (base)</td>
<td>$\text{H}^+$ acceptor</td>
<td>Response to a drop in pH</td>
</tr>
<tr>
<td>$\text{H}^+$</td>
<td>Hydrogen ion</td>
<td></td>
</tr>
</tbody>
</table>

The study of carbon based “life” compounds is organic chemistry.

- **Miller and Urey** (12-11).
- 4 valence electrons of C:
  - Single bonds (ethane $\text{C}_2\text{H}_6$)
    - $109.5^\circ$
  - Double bonds (carbon dioxide $\text{CO}_2$)
    - $180^\circ$
  - Triple bonds (acetylene $\text{C}_2\text{H}_2$)
    - $H\equiv C\equiv C\equiv H$
Isomers have the same number of atoms of each element.

(a) Structural isomers

\[
\begin{align*}
\text{Pentane} & : \\
\text{H} & - C - C - C - C - H \\
\text{H} & - H - H - H - H
\end{align*}
\]

\[
\begin{align*}
\text{2-methyl butane} & : \\
\text{H} & - C - C - C - H \\
\text{H} & - H - H - H
\end{align*}
\]

(b) Cis-trans isomers

\[
\begin{align*}
\text{cis isomer: The two Xs are on the same side.} & : \\
\text{H} & - C - C - H \\
\text{H} & - H - H
\end{align*}
\]

\[
\begin{align*}
\text{trans isomer: The two Xs are on opposite sides.} & : \\
\text{H} & - C - C - X \\
\text{X} & - H - H
\end{align*}
\]

(c) Enantiomers

\[
\begin{align*}
\text{L isomer} & : \\
\text{H} & - C & - \text{NH}_2 \\
\text{CH}_3 & & \text{CO}_2\text{H}
\end{align*}
\]

\[
\begin{align*}
\text{D isomer} & : \\
\text{H} & - C & - \text{NH}_2 \\
\text{CH}_3 & & \text{CO}_2\text{H}
\end{align*}
\]
Isomers have the same number of atoms of each element.

- Question: what kind of isomers are propanal and acetone?

![Chemical structures of propanal and acetone]

Functional groups give “personalities” to biological molecules.

<table>
<thead>
<tr>
<th>Hydroxyl group (—OH)</th>
<th>Ethanol, the alcohol present in alcoholic beverages</th>
</tr>
</thead>
<tbody>
<tr>
<td>(may be written HO—)</td>
<td>Polar due to electronegative oxygen. Forms hydrogen bonds with water.</td>
</tr>
<tr>
<td><strong>Compound name:</strong> Alcohol</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Carboxyl group (—COOH)</th>
<th>Acetic acid, which gives vinegar its sour taste</th>
<th>Ionized form of —COOH (carboxylate ion), found in cells</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Compound name:</strong> Carboxylic acid, or organic acid</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

10/9/2015
Functional groups give “personalities” to biological molecules.

**Functional groups**

- **Amino group** (—NH$_2$)
  - Glycine, an amino acid (note its carboxyl group)
  - Ionized form of —NH$_2$, found in cells
  - Acts as a base.
  - Compound name: Amine

- **Sulphydryl group** (—SH)
  - Cysteine, a sulfur-containing amino acid
  - Two —SH groups can react, forming a ‘cross-link’ that helps stabilize protein structure.
  - Compound name: Thiol

**Examples of functional groups**

- **Phosphate group** (—PO$_4^{3-}$)
  - Glycerol phosphate, which takes part in many important chemical reactions in cells
  - Contributes negative charge. When attached, confers on a molecule the ability to react with water, releasing energy.
  - Compound name: Organic phosphate

- **Methyl group** (—CH$_3$)
  - 5-Methyl cytosine, a component of DNA that has been modified by addition of a methyl group
  - Affects the expression of genes. Affects the shape and function of sex hormones.
  - Compound name: Methylated compound
ATP is the energy “currency” of the cell.

Life has three main classes of macromolecules.

- Carbohydrates store energy (starch, glycogen) and form structures (cellulose, chitin) and make up the backbones of DNA (ribose).
- Proteins catalyze reactions and bind important substrates like oxygen.
- Nucleic acids carry genetic information and information about making proteins (DNA, RNA).
Monomers are built into polymers in dehydration reactions.

(a) Dehydration reaction: synthesizing a polymer

(b) Hydrolysis: breaking down a polymer

Carbohydrates are chains of sugars with carbonyl and hydroxyl groups.
Carbohydrates monomers are joined together by glycosidic bonds.

- In solution, each monosaccharide form rings of (usually) 5 or 6 carbons.

Starch (α glucose) and cellulose (β glucose) link monomers differently.
Fats are made up of glycerol and three fatty acids joined together.

Phospholipids form the (bilayer) membranes of cells.
Proteins are required for diverse functions of cells.

**Enzymatic proteins**
- Function: Selective acceleration of chemical reactions
- Example: Digestive enzymes catalyze the hydrolysis of bonds in food molecules.

**Defensive proteins**
- Function: Protection against disease
- Example: Antibodies inactivate and help destroy viruses and bacteria.

**Storage proteins**
- Function: Storage of amino acids
- Examples: Casein, the protein of milk, is the major source of amino acids for baby mammals. Plants have storage proteins in their seeds. Ovalbumin is the protein of egg white, used as an amino acid source for the developing embryo.

**Transport proteins**
- Function: Transport of substances
- Examples: Hemoglobin, the iron-containing protein of vertebrate blood, transports oxygen from the lungs to other parts of the body. Other proteins transport molecules across membranes, as shown here.

Proteins are required for diverse functions of cells.

**Hormonal proteins**
- Function: Coordination of an organism’s activities
- Example: Insulin, a hormone secreted by the pancreas, causes other tissues to take up glucose, thus regulating blood sugar concentration.

**Receptor proteins**
- Function: Response of cell to chemical stimuli
- Example: Receptors built into the membrane of a nerve cell detect signaling molecules released by other nerve cells.

**Contractile and motor proteins**
- Function: Movement
- Examples: Motor proteins are responsible for the undulations of cilia and flagella. Actin and myosin proteins are responsible for the contraction of muscles.

**Structural proteins**
- Function: Support
- Examples: Keratin is the protein of hair, horns, feathers, and other skin appendages. Insects and spiders use silk fibers to make their cocoons and webs, respectively. Collagen and elastic proteins provide a fibrillar framework in animal connective tissues.
Proteins are made up of amino acids characterized by different side chains.

Individual amino acids are joined together by peptide bonds.
Team work.

Which of the following chemicals do you NOT expect to be readily dissolved in water?

• A. Uric acid
• B. Hexane
• C. Glycerol
• D. Ethanol
• E. Potassium chloride

ATP is the main energy currency in cells, and it can especially be used to drive condensation reactions that produce macromolecular polymers. How does ATP normally catalyze the condensation reaction, which by itself is energetically unfavorable?

• A. It transfers its terminal phosphate to an enzyme and is released as ADP.
• B. It transfers its two terminal phosphates to an enzyme, and is released as AMP.
• C. It covalently attaches to both of the substrates.
• D. It transfers either one or two terminal phosphate(s) to one of the substrates and is released as either ADP or AMP.
• E. It covalently attaches to the enzyme, forming an enzyme–AMP adduct.