Life-Friendly Chemistry

Key Principles

A Small Subset of Elements combined in the right position and proportion are used to create diverse chemical structures. Abundant elements, primarily H, C, N, and O, create life-friendly compounds and materials that can be disassembled and reused. Hierarchies allow small things to scale up from nano to macro.

Self-Assembly is the spontaneous organization or transformation of forms or structures. In nature self-assembly generally happens at ambient temperatures (~300K and ~1 atm) and is facilitated by chemical attachments that attract or repel each other.

3D Shape governs functionality: lock-and-key mechanisms trigger a cascade of reactions that enable the signalling, transportation, and synthesis of molecules. Weak bonds facilitate self-assembly into 3D shapes and the joining of individual molecules into supra-molecular complexes. Vibration helps things fit together.

Water-Based Chemistry where water acts as a solvent facilitates self-assembly, the making and breaking of bonds, and the flow of ions including H+ (protons). Water is polar which makes it a good solvent for other polar substances, including some organic molecules. In biomaterials, hydration levels are proportional to the degree of plasticity. Water and hydration are essential to all forms of life.

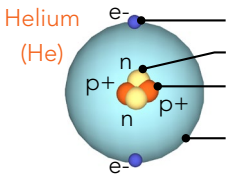
Disassembly and Reuse is facilitated by enzymes and made easier by the widespread presence of weak bonds that allow compounds and materials to be broken down into their constituent building blocks.

The Chemistry Lens

This perspective helps you understand how things work at the micro & nano scale. Ask questions about chemical composition, reactions, and linkages and try to find patterns across many organisms.

Definitions

Atom: the defining structure of elements. Atoms contain cloud-like electron shells surrounding a nucleus made up of protons and neutrons. The number of protons in the nucleus defines the element and its position in the periodic table of elements.



Electron 1e- (0.1 amu)
Neutron 1n (1 amu)
Proton 1p+ (1 amu)

Electron Cloud
all of the possible places an electron could be at one time.

Element: a substance whose atoms all have the same number of protons, these are the simplest chemical substances and they make up the periodic table of elements (below). Elements cannot be broken down with chemical reactions.

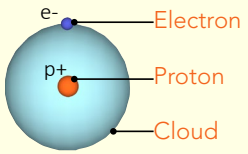
Particle: A portion of matter, always in a constant state of motion. Particles can be atoms, molecules, or ions.

Molecule: a substance consisting of 2 or more atoms of the same element joined with a molecular bond. O2 and H2 are examples of molecules that share atoms.

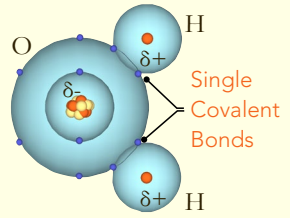
Compound: when two or more atoms of different elements are chemically joined together ie: H20, CO2. Despite the technical difference, in practice compounds are sometimes referred to as molecules.

Special Properties of Hydrogen

Hydrogen (H): the chemical element with atomic number 1.

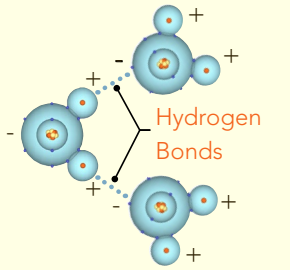


Hydrogen (H)



Water (H20)

Water (H20): a chemical compound consisting of two H atoms and an O atom joined by two single covalent bonds. Hydrogen bonds in water continually form, break apart, and reform, and are the reason for water's high surface tension.



Hydrogen Bonds

Hydrogen Bond: a special type of electrostatic attraction where an H atom attached to a highly electronegative element, especially O or N, is attracted to another electronegative atom (again, usually N or O) on another chemical entity.

Nature's Subset of Elements

Make more chemicals with fewer elements

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba		Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra		Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Nh	Fl	Mc	Lv	Ts	Og
			La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
			Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

- Most abundant in all organisms
- Less abundant in all organisms
- Small amounts in all organisms
- Trace amounts in some organisms
- Not used by organisms

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Life-Friendly Chemistry

Roles of Chemistry in Nature

Energy Management
convert, control,
& store energy

Chemicals Management
acquire, process, synthesize, &
recycle chemical compounds

Materials Management
assemble, provide function,
protect, repair, & decompose

Communication
send & receive
chemical signals

Defence & Predation
detect, confuse, irritate, nauseate,
kill, or attract helpers to do so

Disassembly and Reuse

Enzymes: proteins that catalyze reactions. Nature uses enzymes to facilitate chemical transformations, including assembly and break-down of building blocks.

Biopolymers: large molecules found in living organisms that are made up of small repeating molecular building blocks.

Biopolymer	Building Blocks	Example
carbohydrates, polysaccharides	sugars, monosaccharides	cellulose chitin
fats, lipids oils, waxes	fatty acids glycerol	steroids cell membranes
polyphenols	phenol structural units	lignin tanin
polynucleotides nucleic acids	nucleotides	RNA DNA
protein	amino acids	collagen keratin

Materials and Gradients

Chemical diversity at the micro scale and geometric arrangements at the meso scale give materials their diverse functionality.

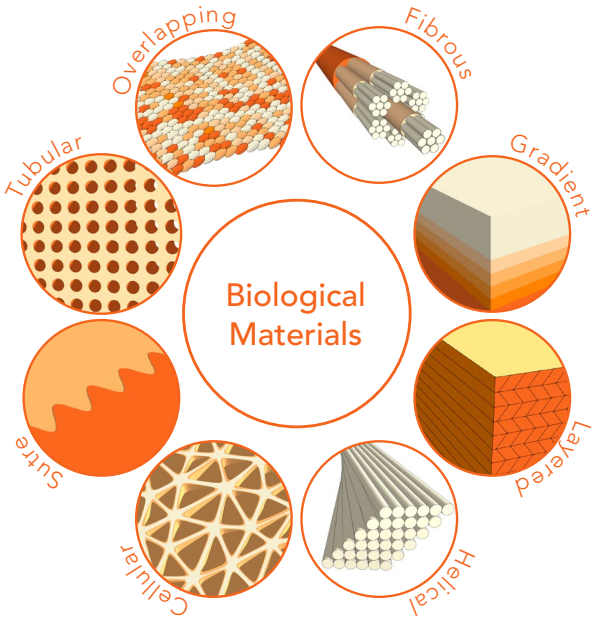

Diagram modified from: Liu, Z, Meyers, M A, Zhang, Z, & Ritchie, R O (2017). Functional gradients and heterogeneities in biological materials. Progress in Materials Science, 88, 467-498.

Definitions

Electronegativity: tendency of an atom to attract a bonding pair of electrons.

Ions: The charge state of an atom, molecule or compound resulting from the transfer of electrons.

- Anions (-): A chemical entity that has gained electrons. Negatively charged.
- Cations (+): A chemical entity that has lost electrons. Positively charged.

Polar: Has a slight positive charge on one side, and a slight negative charge on the other. Water is polar, and polar molecules are water soluble.

Non-polar: a molecule with no separation of charge, they are fat soluble (ie: hexane, a major component of gasoline: C6H14).

States of Matter

Matter changes states when thermal energy is applied

Solid: particles are closely packed together and cannot move freely.

Liquid: a fluid that can't be compressed, its shape conforms to its container.

Gas: a compressible fluid, it's molecules have lots of kinetic energy.

Plasma: a compressible fluid that is electrically conductive.

...a thermometer is a molecular speedometer!

Bonds between Molecules/Compounds

Bond Type	Strength (kJ/mol)
Dipole-Dipole	2-8
Hydrogen	10 - 40
London Dispersion	<4 - 60

Dipole-Dipole Bond: attraction between the positive and negative ends of two molecules.

Hydrogen Bond: a special type of electrostatic attraction involving H atoms. Full definiton on reverse.

London Dispersion (van der Waals Forces): especially weak forces that temporarily induce a dipole effect. Oily things rely on these forces.

Bonds within Molecules/Compounds

Bond Type	Strength (kJ/mol)
Covalent Single	200 - 500
Covalent Double	500 - 700
Covalent Triple	800 - 1000
Ionic	700 - 4000

Covalent Bonds: shared electron pairs between atoms.
Single: one pair of electrons shared
Double: two pairs of electrons shared
Triple: three pairs of electrons shared

Ionic Bonds: complete transfer of valence electrons between atoms.

Nature is Life-Friendly

generally only making toxins when toxicity is the intended function.