Chemical introduction

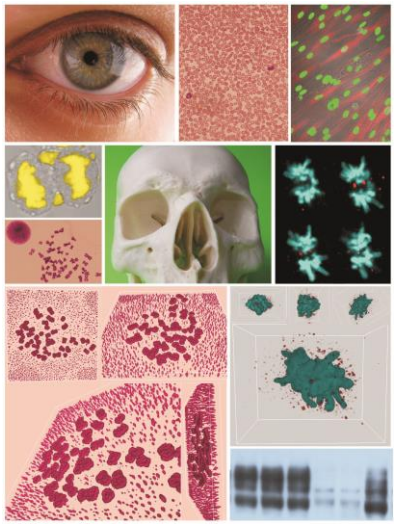
Katalin Kiss

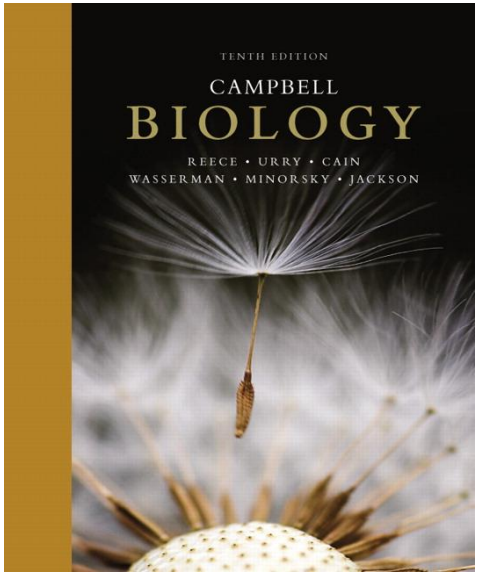
Topic list

1. Chemical basis of life 1 (atoms, biological elements)
2. Chemical basis of life 2 (functional groups, bonds, water, pH)
3. Lipids and Carbohydrates
4. Amino acids, Proteins, Biochemical reactions, Enzymes
5. Nucleosides, nucleotides, nucleic acids
6. Discovering the genetic material; DNA replication
7. Synthesis of RNAs: Transcription
8. Flow of genetic information: Genetic code
9. Synthesis of Proteins: Translation
10. Mid-term test (multiple choice type)
11. Structure of cells I: pro-and eukaryotic cells, viruses,fungi, plant cells
12. Structure of cells II: nucleus, nucleolus, cell wall, cell membrane, transport
13. Structure of the cells III: ERs, Golgi, vesicles, lysosomes, cytoplasm, cytoskeleton
14. Mitochondria, the production of ATP
15. Organization of the genetic material, chromosomes, chromatids
16. Cell division: Mitosis and meiosis
17. Mendelian genetics
18. Tissues and cell types
19. Final test (multiple choice type)
20. Basics of immunology

Recommended books

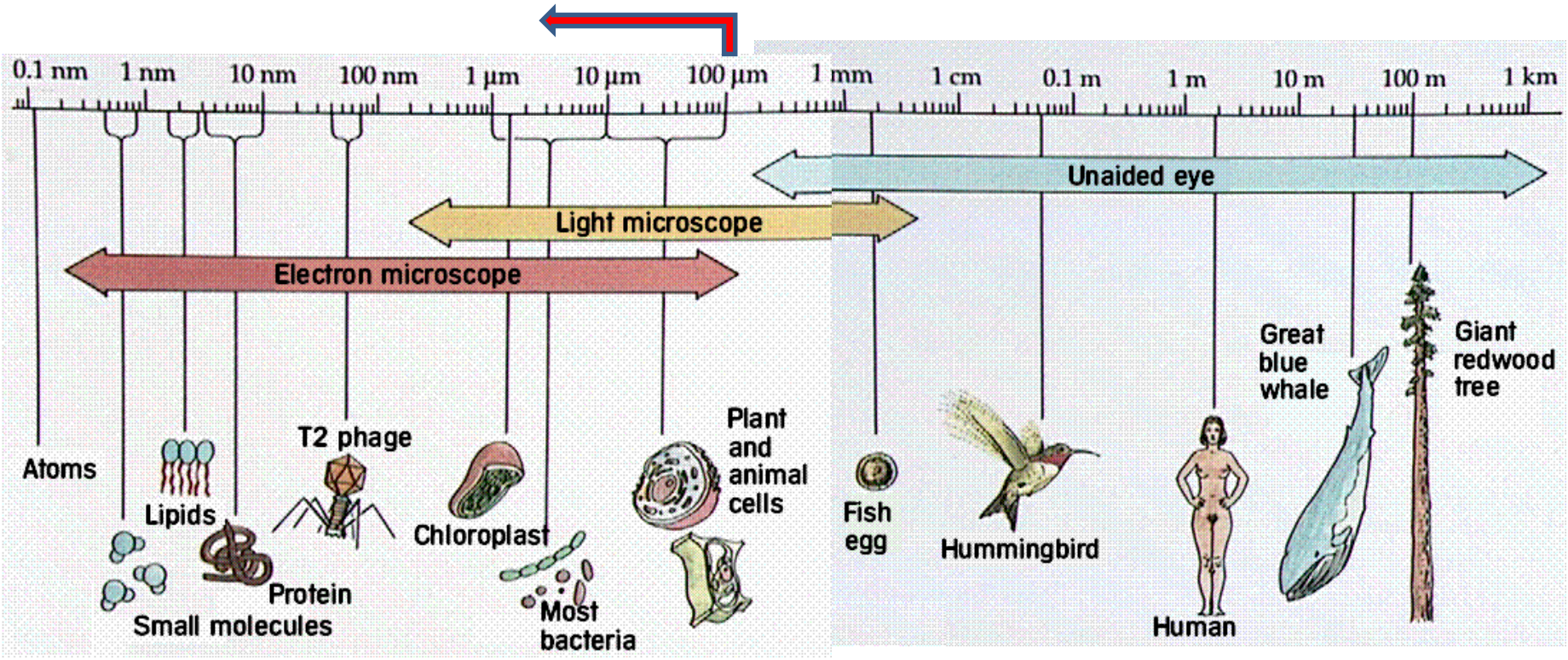
- BIOLOGY A TEXTBOOK FOR PRE-MEDICAL COURSE STUDENTS (by University of Pécs Medical School)
- Campbell: BIOLOGY





SIZE-SCALE

Metric = in meter/in metre



Millimeter= mm 1 mm=10^{-3}m

Mikrometer=µm 1 µm=10^{-6}m

Nanometer=nm 1 nm=10^{-9}m

Centimeter=cm 1 cm=10^{-2}m

Kilometer=km 1 km=10^{3}m

Microscopes

Magnification

- Light microscope: 1000x
- Electron microscope: 500 000x

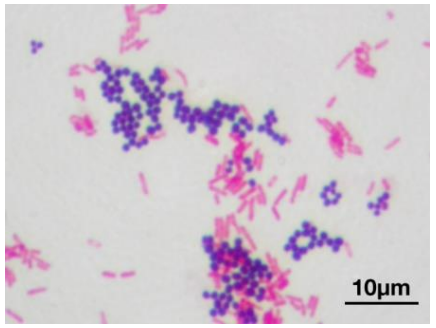
Resolution

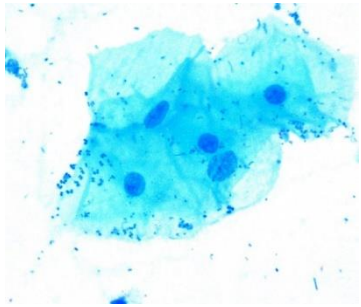
limits of resolution:

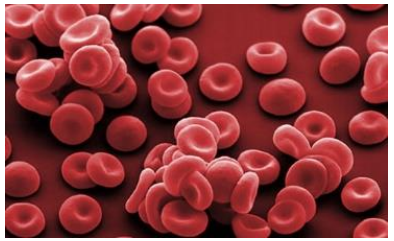
- Human eye: 1 mm
- Light microscope: 1 μm
- Electron microscope: 1 nm
- High resolution microscope

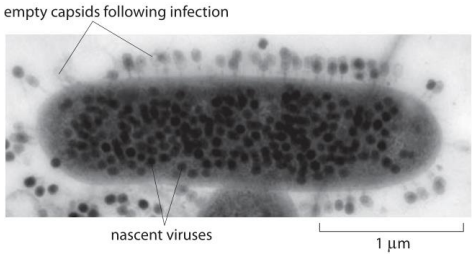
Contrasting

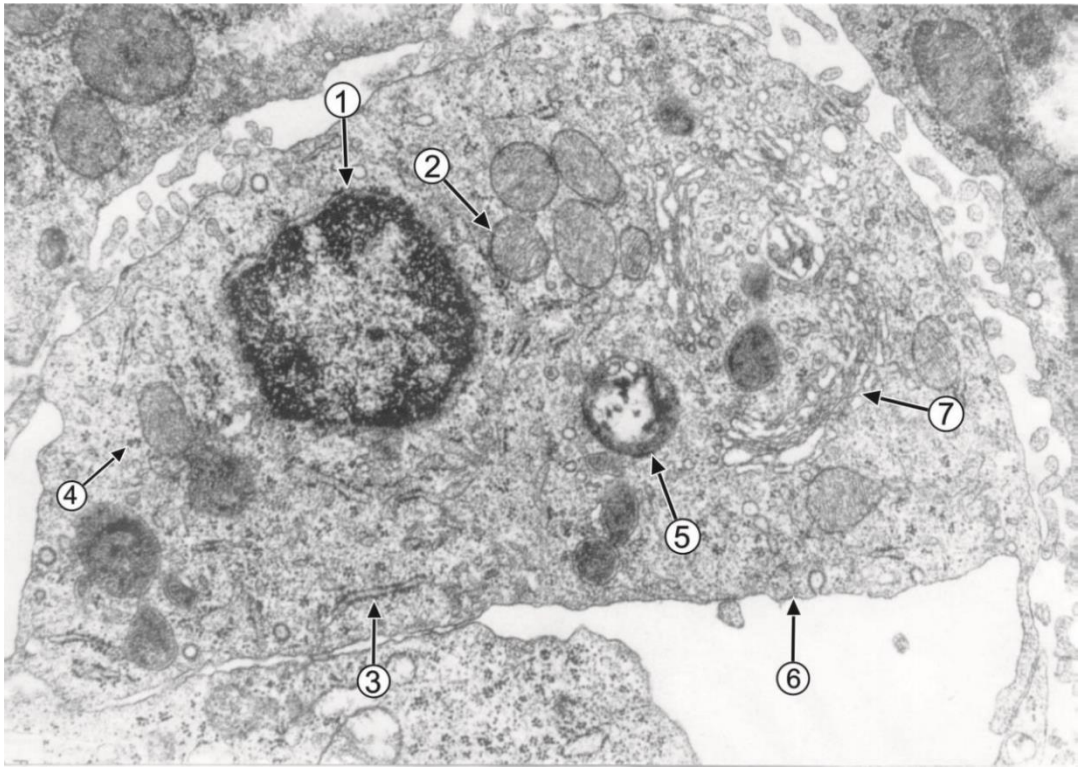
- Light microscope: dyes
- Electron microscope: metal particles







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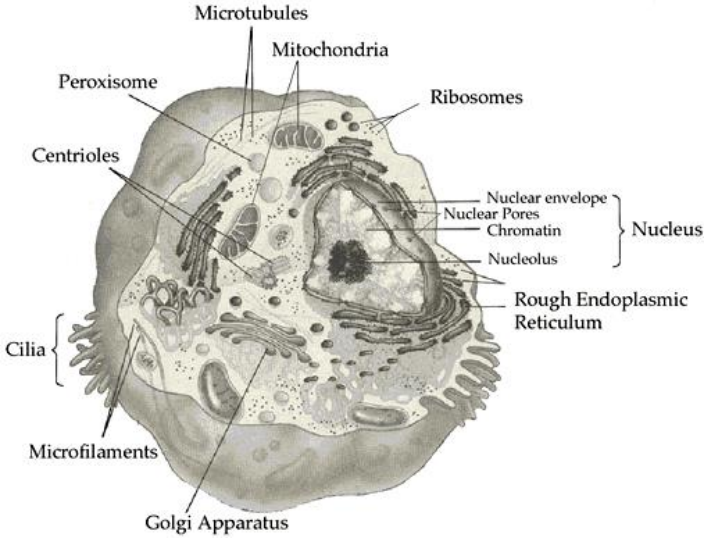

Microtubules
Mitochondria
Peroxisome
Ribosomes
Centrioles
Nuclear envelope
Nuclear Pores
Chromatin
Nucleolus
Nucleus
Rough Endoplasmic Reticulum
Cilia
Microfilaments
Golgi Apparatus

Levels of organization in human body

- Biogenic elements
- Molecules, macromolecules
- Cells (viruses), cellular organelles
- Tissues
- Organs
- Organic systems

atom, ion, isotope, element, molecule

1. A substance composed of atoms with the same atomic number; it cannot be broken down in ordinary chemical reactions.

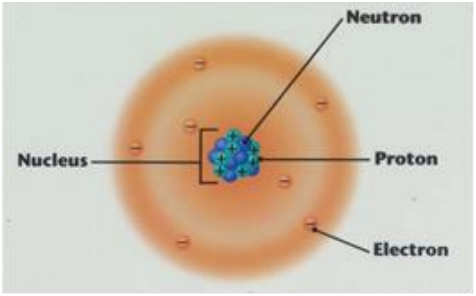
2.The smallest indivisible particle of matter that can have an independent existence.

3.Two or more atoms which are chemically combined to form a single species.

4. An atom that has lost or gained electrons from its outer shell and therefore has a positive or negative charge, respectively; symbolized by a superscript plus or minus sign and sometimes a number, e.g., H^+, Na^+, O^{2-} Cl^-.

5. Atoms with the same atomic number but different numbers of neutrons; indicated by adding the mass number to the element's name, e.g., carbon 12 or ^{12}C.

Atom, subatomic particles



www.csmate.colostate.edu

- **2 parts of an atom: nucleus** and electron **cloud** („1cm/100m")
- Electron **orbital**: space of one electron
- Electron **shell**s
  composed of orbitals
  determine the size of the atom
  4 major shells (K: 2 electrons, L: 8 electrons, M: 18 electrons, N: 32 electrons)
- Number of protons=number of electrons
- Atom is neutral=uncharged
- **Atomic number**: number of protons
- **Atomic mass/weight = mass number**: number of protons + number of neutrons

Subatomic particles

Name	Charge	Location	Mass	Atomic mass
Proton	+1	atomic nucleus	1.6726 X 10^{-27} kg	1Dalton
Neutron	0	atomic nucleus	1.6750 X 10^{-27} kg	1Dalton
Electron	-1	electron orbital	9.1095 X 10^{-31} kg	negligible (1/1800Da)

Dalton = Da = unit of mass/weight (NOT METRIC!)
1 Dalton = mass/weight of 1 Hydrogen ion (H^+)
1 Dalton = mass/weight of 1/12 Carbon atom

Mass/weight of proteins, eg. 60 000Da=60kDa

Kilodalton (kDa)= 10^3 Dalton

Ions

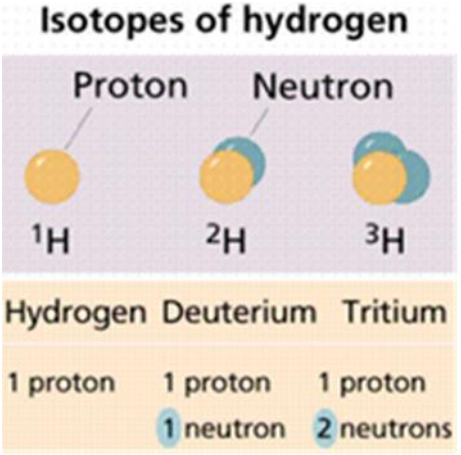
- **more or less electrons than protons**
- charged
- types:

  cation (+ charge) :1st and 2nd groups tend to lose 1 or 2 electrons
  eg. Na^{+}, Mg^{2+}

  anion (- charge) : 6th and 7th groups tend to gain 2 or 1 electrons
  eg. Cl^{-}, O^{2-}

- ionic bond formation (between a cation and an anion)

Isotopes



www.csmate.colostate.edu

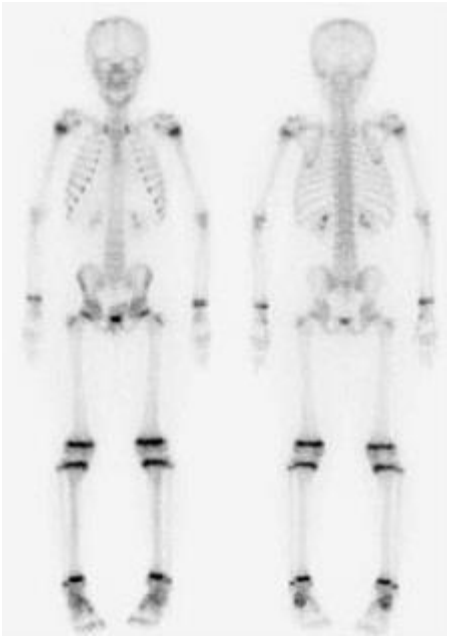
- Same number of protons but different number of neutrons = **Same atomic number** but **different mass number**

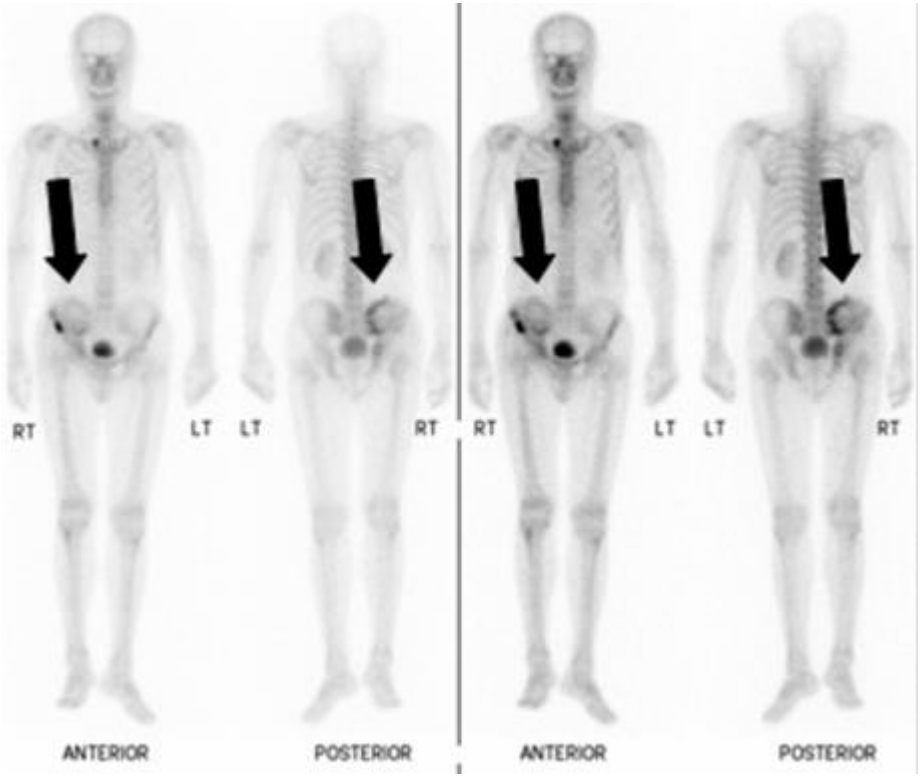
- Types: **stable** and **unstable =radioactive** (nuclear splitting)

- Role in research and medicine: change of molecular density or energy emittion

    1. to trace molecules, biochemical processes in cells (eg. Hershey –Chase experiment; Meselson-Stahl experiment)

    2. nuclear medicine: scaning the structure and function of organs with radioisotope
       eg.Technetium-99m labeled organ specific molecules
        - skeletal scintigraphy/bone scan (bone metastasis!, inflammation)
        - thyroid gland (hormone production) Tc 99 or iodine 131
        - heart (blood supply, muscle activity)
        - secretion by kidney

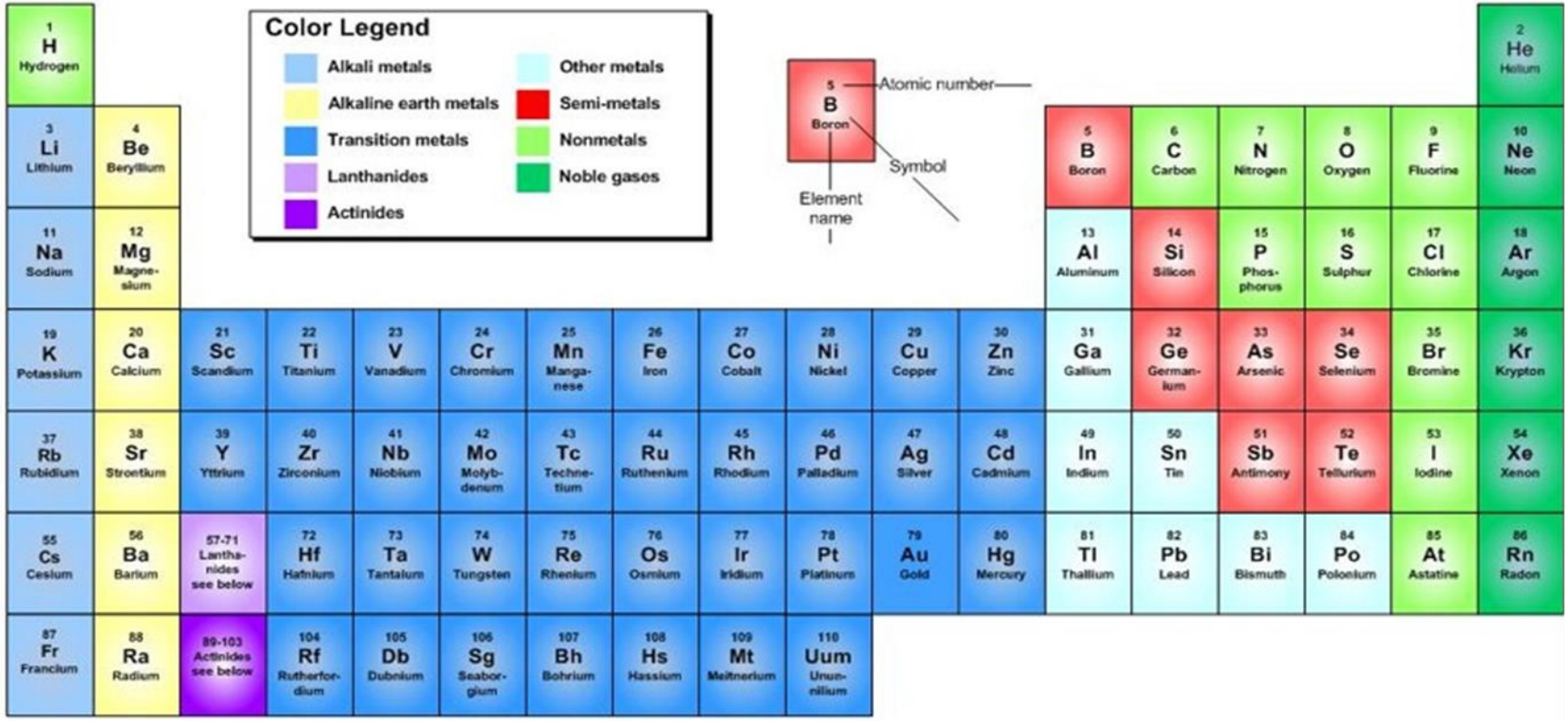




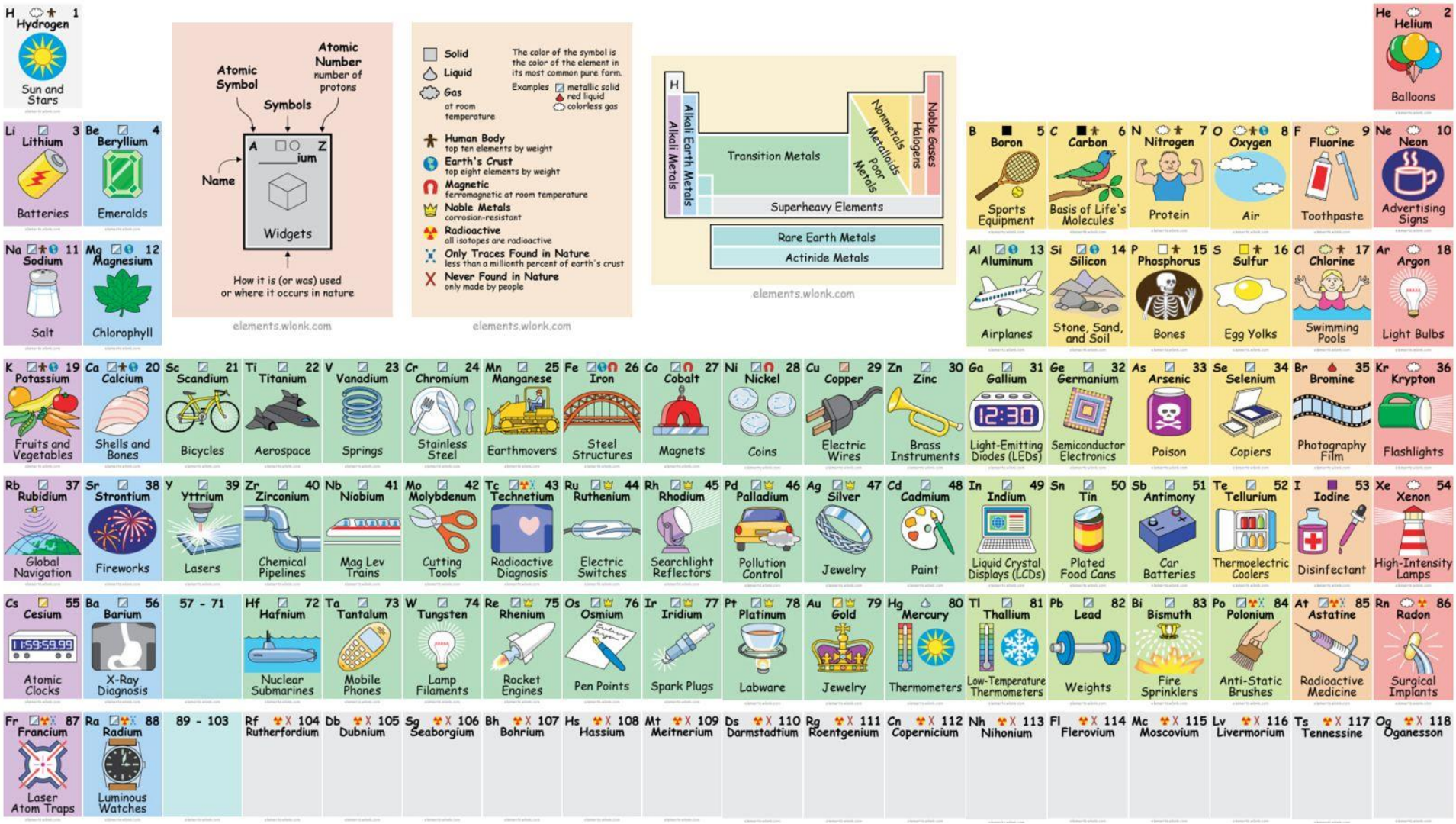
https://humanhealth.iaea.org/HHW/NuclearMedicine/PaediatricsandNephrourology/IAEA_Publications/Atlas/

https://commons.wikimedia.org/wiki/File:Scintigraphy_pelvis_with_bone_metastasis_01.jpg

Periodic Table of the Elements



http://www.ptable.com/?lang=en



http://elements.wlonk.com/ElementsTable.htm

Periodic table

- **D. I. Mendeleev**
- **symbols of elements** (element: a substance composed of atoms with the same atomic number) carbon:C; nitrogen: N; calcium: Ca etc.
- rows=**periods:** elements with the same major quantum number/same major electron shell (K, L, M, N)
- coloumns=**groups:** elements with the same versatile/unpaired electrons
- **size of elements** increases from top to bottom and from right to left.
- **electron affinity=**the amount of energy *released* or *spent* when an electron is added to a neutral atom or molecule in the gaseous state to form a negative ion.
  Electron affinity of elements increases from bottom to top, and from left to right.
  The highest electron affinities are possessed by fluorine (F) and chlorine (Cl).
- **relative atomic mass = molar mass** : gram/mole , mole:$6*10^{23}$

Molecules

- 2 or more **atoms bound to each other** through covalent bond(s)
- **central atom**
- **stabile** compound
- **shape** determined by electronpairs and the electron attraction by atomic nuclei
  eg. Linear (H-H, O-C-O), V-saped (H-O-H)
- **polarity** determined by the electronegativity of atomic nuclei
  apolar (eg. H-H) or polar (eg. H-Cl) molecules

Chemical bonds in organic chemistry

1. Primary/Covalent bonds:

- Electrons are shared by the bound atoms (bonding electrons)
- Strong
- Inside molecules=intramolecular
- Types:
  - Single (H-H, C-C, H-O-H), Double (C=O, C=C), Triple (C=C, N=N)
  - Non polarized, polarized

2. Disulfide-bond/Disulfide-bridge: -S-S- (inside molecules, between molecules)

3. Ionic bond: between ions (eg. between Na^+ and Cl^-)

4. Secondary/Non-covalent bonds:

- Electrons are not shared by the bound atoms
- Weaker than covalent bonds
- Between molecules =intermolecular
- Types:
  - Van der Waals=London forces (between apolar molecules)
  - Dipole-dipole bonds (between polar molecules)
  - Hydrogen bond

Hydrogen bond

- is a secondary bond
- **between a H atom covalently attached to an electronegative atom** (atom with a high affinity for electrons) eg O, N, **and an electronegative atom of another molecule or another part of the same molecule**

- weaker than covalent bonds

- between water molecules, inside protein molecules, nucleic acids

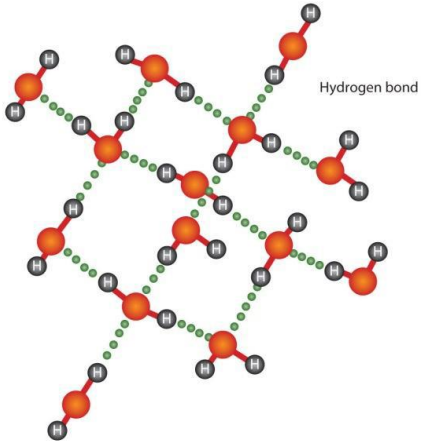


Figure 2-3. The hydrogen bond in water. http://www.flatworldknowledge.com/

Water

chemistry

1) H-O-H („V" shape)

2) Polar (slightly negative and positive sites because of different affinities for electrons)

3) H-bond formation (1water/4 neighbouring water or with other molecules)

4) Solvent of ions and polar substances (hydrohilic substances) eg. Glucose, NaCl, alcohols,… (hydrophilic functional groups)

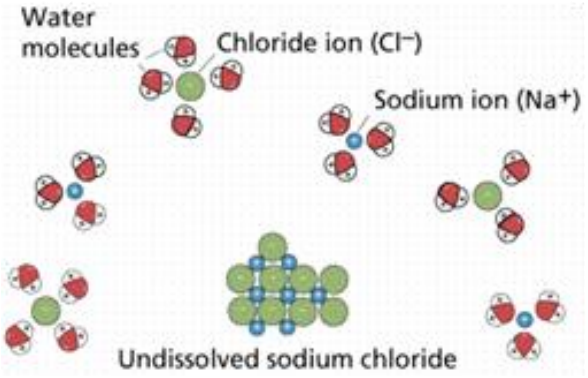
5) Tendency to dissociate into H^+ and OH^- in liquid state

6) Existence in all three states of matter (gas, liquid, solid)

7) Expansion upon freezing due to crystal formation (stabilized by H-bonds)

   – leading to lower density

Water as solvent

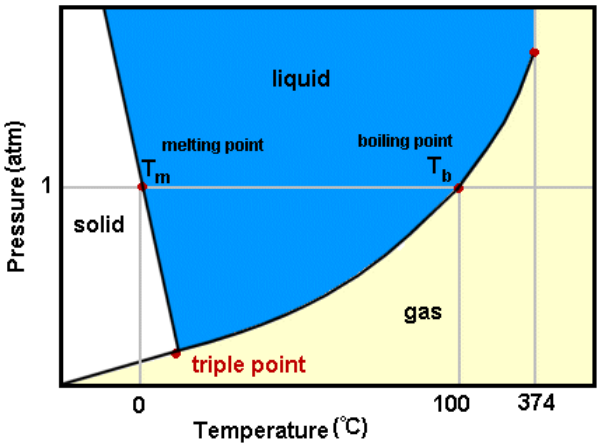


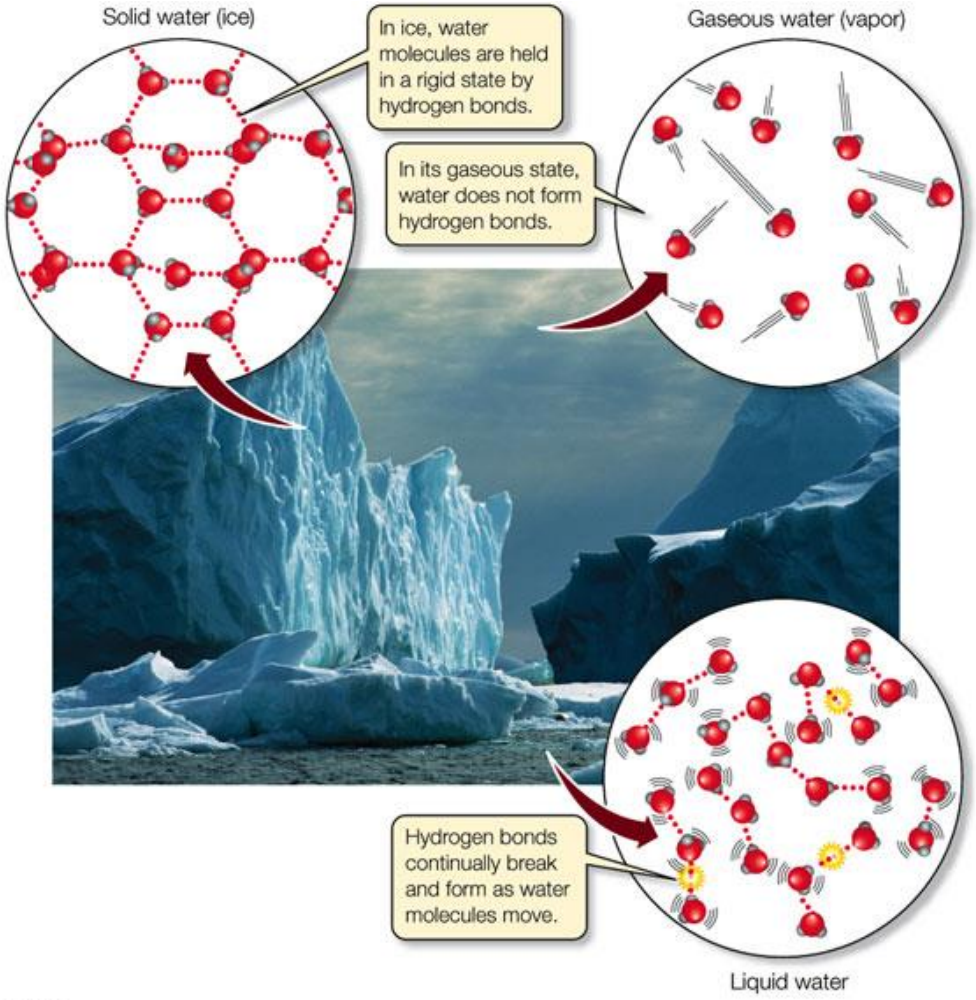
Solution: a homogeneous mixture of two or more substances. A solution may exist in any phase.

Solute is the substance that is dissolved in a solution (eg. NaCl).

Solvent is the substance in which the solute is dissolved (eg. water). The solvent is present in greater amount than the solute.

States of matter of water





LIFE 8e, Figure 2.14

Water

role in biology

1) enviroment for life
    a. cohesive behavior (H-bonds!)
    b. stabilisation of temperature
    c. expansion upon freezing
    d. dissolving capability
    e. weak viscosity (medium for transport, reactions)
    f. transparency
2) partner in biochemical reactions as either substrate or endproduct
    a. condensation (dehydration)
    b. hydrolysis (hydration)
3) role in photosynthesis (photolysis of water)
4) free movement through biological membranes without energy requirement (osmosis)
5) pH

pH, pH scale

pH = negative logarithm (to the base 10) of H^+ concentration in a water based solution

pH value can be any between 0 and 14 because of the concentration of H^+ ranging between 10^0 and 10^{-14} mole/liter

$[H^+]x\ [OH^-]= 10^{-14}$ mole/liter=CONSTANT

pH=7 concentration of H^+ equals to concentration of hydroxide ions (**neutral** solution)

pH<7 concentration of H^+ is more than concentration of hydroxide ions (**acidic** solution)

pH>7 concentration of H^+ is less than concentration of hydroxide ions (**basic** solution)

Concentration of Hydrogen ions compared to distilled water				Examples of solutions and their respective pH
	1/10,000,000	14	Liquid drain cleaner, Caustic soda	
	1/1,000,000	13	bleaches, oven cleaner	
	1/100,000	12	Soapy water	
	1/10,000	11	Household Ammonia (11.9)	
	1/1,000	10	Milk of magnesium (10.5)	
	1/100	9	Toothpaste (9.9)	
	1/10	8	Baking soda (8.4), Seawater, Eggs	
	0	7	"Pure" water (7)	
	10	6	Urine (6) Milk (6.6)	
	100	5	Acid rain (5.6) Black coffee (5)	
	1,000	4	Tomato juice (4.1)	
	10,000	3	Grapefruit & Orange juice, Soft drink	
	100,000	2	Lemon juice (2.3) Vinegar (2.9)	
	1,000,000	1	Hydrochloric acid secreted from the stomach lining (1)	
	10,000,000	0	Battery Acid	

Acid, Base, Buffer

Acid: lowers pH

- substance that **increases the H^+ concentration** of an aquous solution
- by **dissociating into H^+**
- eg. HCl , H_2CO_3

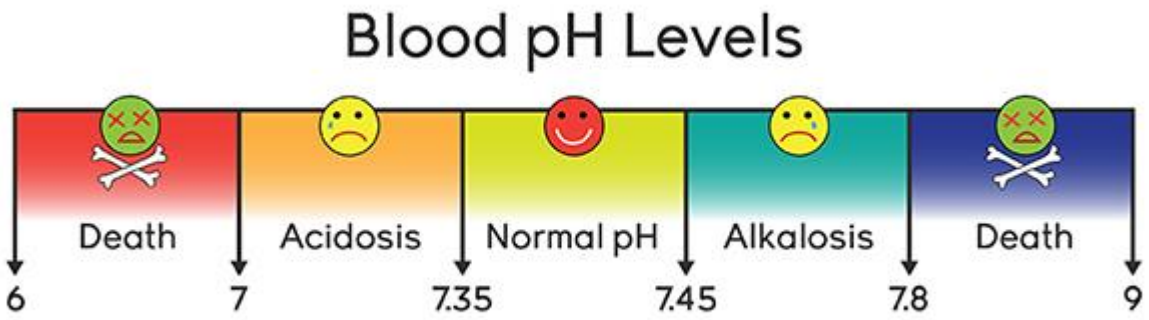
Base: increases pH

- substance that **decreases the H^+ concentration** of an aquous solution
- by **accepting H^+ or by dissociating into OH^-**
- eg. NaOH, NH_3

Buffer: minimizes changes of pH („pH regulator")

- substance easily shifting between its H^+ dissociated and H^+ accepted forms
- weak acid and its corresponding base
- eg. H_2CO_3 and HCO_3^+

Blood pH



Maintenance of blood pH mainly by H_2CO_3/HCO_3^- buffer system:

- chemical shifting between H_2CO_3 and HCO_3^-
  $H_2CO_3=HCO_3^- + H^+$
- elimination or retain of CO_2 by lungs
- elimination of H^+ or retain of HCO_3^- by kidneys

Functional groups / chemical groups
in organic chemistry

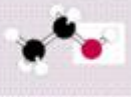
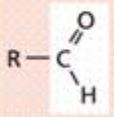
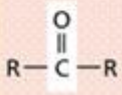
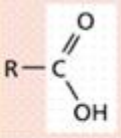
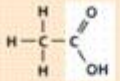
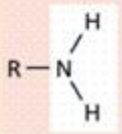
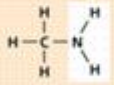
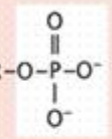
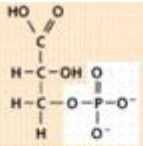
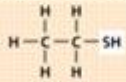
A **complex** of covalently joined atoms (minimum 2 atoms are coupled to each other).

The group is **covalently linked to** the carbon backbone (skeleton) of a **molecule**.

The group is responsible for

- the **chemical properties** of the molecule (eg. solubility, polarity, charge, acidic/basic feature…)
- the **chemical interactions** (bond forming capability) of the molecule.

Functional groups in organic chemistry

Functional group	Class of compounds	Structural formula	Example	Ball-and-stick model	Water solubility	Acid/Base	Charge	Molecules	Bonds
Hydroxyl –OH	Alcohols	R—OH	Ethanol		yes	no	no	Carbohydrates	ester
Carbonyl –CHO	Aldehydes		Acetaldehyde		yes	no	no	Carbohydrates eg. glucose	
Carbonyl >CO	Ketones		Acetone		yes	no	no	Carbohydrates eg. fructose	
Carboxyl –COOH	Carboxylic acids		Acetic acid		yes	weak acids (protein buffers)	negative	Organic acids, eg. citric acid; Aminoacids, proteins	ester, peptide
Amino –NH_2	Amines		Methylamine		yes	bases	positive	Aminoacids, proteins	peptide
Phosphate –OPO_3^{2-}	Organic phosphates		3-Phospho-glyceric acid		yes	weak acids (phosphate buffers)	negative	Nucleotides Nucleic acids Phospholipids	ester, phospho-anhydride (macroerg)
Sulfhydryl –SH	Thiols	R—SH	Mercapto-ethanol		yes	no	no	Aminoacids eg. cysteine	disulfide

Biogenic elements

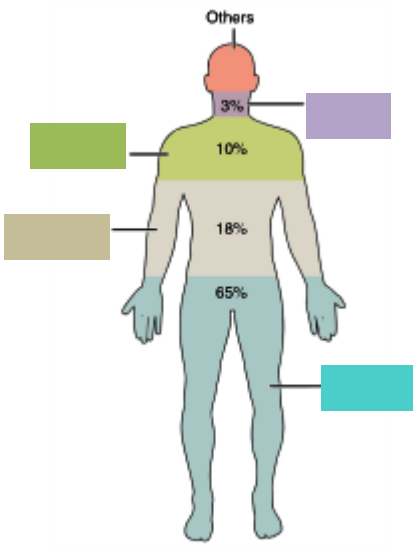
- elements present in living systems
- 25
- types:

  primary

  secondary

  tertiary =trace

4 elements compose 96% of human body



Elements of human body
primary, secondary, tertiary (trace)

1. Oxygen (65%)
2. Carbon (18%)
3. Hydrogen (10%)
4. Nitrogen (3%)
5. Calcium (1.5%)
6. Phosphorus (1.0%)
7. Kalium/Potassium (0.35%)
8. Sulfur (0.25%)
9. Natrium/Sodium (0.15%)
10. Magnesium (0.05%)
11. Copper, Zinc, Selenium, Molybdenum, Fluorine, Chlorine, Iodine, Manganese, Cobalt, Iron (0.70%)
12. Lithium, Strontium, Aluminum, Silicon, Lead, Vanadium, Arsenic, Bromine (≤0,5%)

Elements of human body

oxygen: 2 valences, electronnegative

- in water
- in CO_2
- in all organic molecules, in many functional groups
- in H-bond formation
- oxygenates H into water during ATP (energy) synthesis
  = oxidant

carbon: 4 valences

- formation of carbon backbone=skeleton of organic molecules (central atom)
  formation of complex and diverse molecules
  formation of single, double, triple bonds
  formation of linear, and ring-like backbones
- in many functional groups
- in CO_2
- is oxidized during breakdown processes (eg. glucose breakdown)

hydrogen: 1 valence

- in water
- in all organic molecules, in many functional groups
- in H-bond formation
- is reduced into water during ATP (energy) synthesis

Elements of human body

nitrogen: 3 valences, electronnegative

- in aminoacids and proteins
- in nucleotides and nucleic acids (purine, pyrimidine bases)
- (in a few lipids, carbohydrates)
- in amino group
- in H-bond formation

calcium:

- bones, teeth (rigidity)
- blood coagulation
- muscle contraction

phosphorous:

- bones, teeth (rigidity)
- in nucleotide, nucleic acids
- in phosphate functional group

Elements of human body

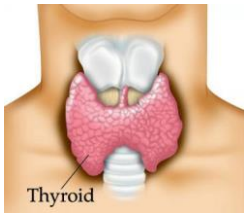
natrium=sodium and kalium=potassium:
- membrane potential, action potential

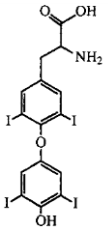
sulfur:
- in thiol functional group
- in a few aminoacids, proteins

magnesium:
- in enzyme function
- in muscle cell and nervous system function

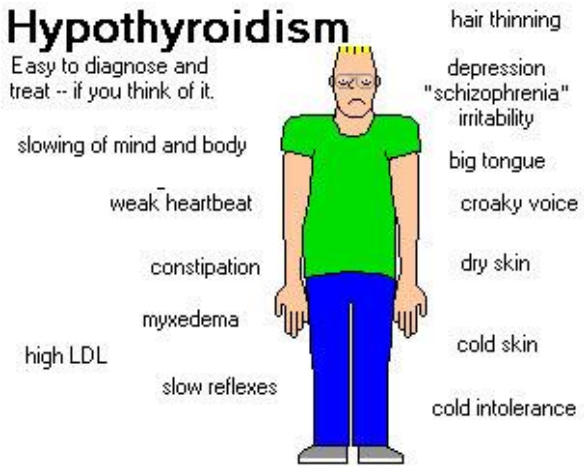
iodine:
- in thyroid gland hormone (thyroxine)

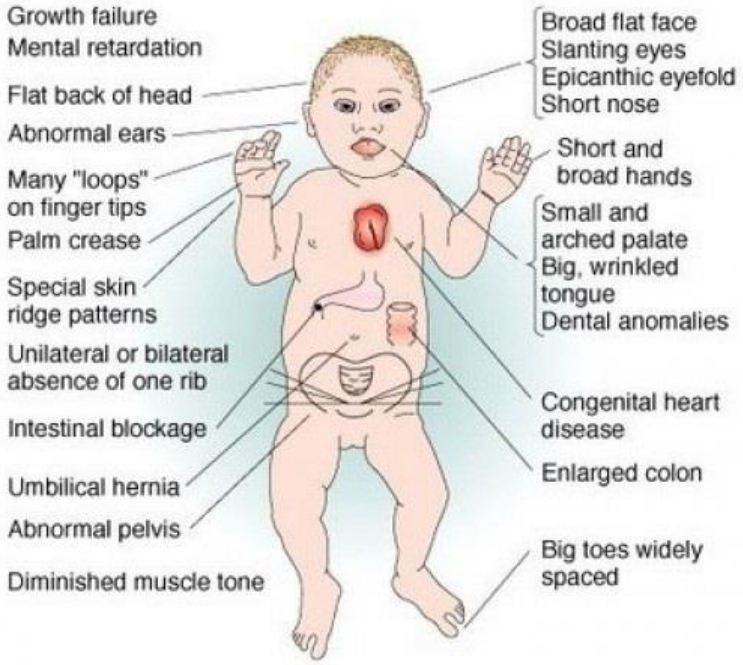
iron:
- in haemoglobin (O_2 gas transport in blood)





FORMULA 1 L- AND D- THYROXINE





TOP 10 MAGNESIUM FOODS

1	Spinach		157 MG (40% DV) 1 CUP
2	Chard		154 MG (38% DV) 1 CUP
3	Pumpkin Seeds		92 MG (23% DV) 1/8 CUP
4	Yogurt or Kefir		50 MG (13% DV) 1 CUP
5	Almonds		80 MG (20% DV) 1 CUP
6	Black Beans		60 MG (15% DV) 1/2 CUP
7	Avocado		58 MG (15% DV) 1 MED
8	Figs		50 MG (13% DV) 1/2 CUP
9	Dark Chocolate		95 MG (24% DV) 1 SQU.
10	Banana		32 MG (8% DV) 1 MED

TOP 10 POTASSIUM FOODS

1	Avocado		1068 mg (30% DV) 1 WHOLE
2	Sweet Potato		952 mg (27% DV) 1 MEDIUM
3	Acorn Squash		899 mg (26% DV) 1 CUP
4	Spinach		839 mg (24% DV) 1 CUP
5	Dried Apricots		755 mg (22% DV) 1/2 CUP
6	Coconut Water		600 mg (17% DV) 1 CUP
7	Kefir or Yogurt		579 mg (15% DV) 1 CUP
8	White Beans		502 mg (15% DV) 1/2 CUP
9	Mushrooms		428 mg (12% DV) 1 CUP
10	Banana		422 mg (12% DV) 1 LARGE

TOP 10 IRON FOODS

1	Beef Liver		5.6 mg (31% DV) 3 OZ
2	Spinach		3.2 mg (18% DV) 1/2 CUP
3	Navy Beans		2.3 mg (13% DV) 1/2 CUP
4	Swiss Chard		2.0 mg (11% DV) 1/2 CUP
5	Artichokes		2.0 mg (11% DV) 1 CUP
6	Black Beans		1.8 mg (10% DV) 1/2 CUP
7	Beef Steak		1.8 mg (10% DV) 3 OZ
8	Prunes		1.6 mg (8% DV) 1 CUP
9	Egg Yolk		0.46 mg (3% DV) 1 LARGE
10	Collard Greens		0.17 mg (1% DV) 1 CUP

TOP 10 CALCIUM FOODS

1	Raw Milk		300 mg (30% DV) 1 CUP
2	Yogurt or Kefir		300 mg (30% DV) 6 OZ
3	Kale (cooked)		245 mg (24% DV) 1 CUP
4	Cheese		224 mg (22% DV) 1 OZ
5	Sardines (with bones)		217 mg (21% DV) 2 OZ
6	Broccoli (cooked)		93 mg (9% DV) 1 ½ CUPS
7	Okra		82 mg (8% DV) 1 CUP
8	Almonds		76 mg (8% DV) 1 OZ
9	Bok Choy		74 mg (7% DV) 1 CUP
10	Watercress		41mg (4% DV) 1 CUP

TOP 10 PHOSPHORUS FOODS

1	Kefir or Yogurt		356 mg (36% DV) 6 OZ
2	Salmon		280 mg (28% DV) 3 OZ
3	Raw Milk		247 mg (24% DV) 1 CUP
4	Grass-fed Steak		209 mg (21% DV) 3 OZ
5	Brazil Nuts		203 mg (20% DV) 1 OZ
6	Hard Cheese (Romano, Parmesan)		197 mg (20% DV) 1 OZ
7	Sunflower Seeds		186 mg (18% DV) 2 TBSP
8	Lentils		178 mg (18% DV) 1/2 CUP
9	Navy Beans		131 mg (13% DV) 1/2 CUP
10	Pumpkin Seeds		59 mg (6% DV) 1 CUP

TOP 10 SODIUM FOODS

1	Table Salt		2300 mg (96% DV) 1 TSP
2	Bouillon Cubes		1200 mg (20% DV) 1 CUBE
3	Soy Sauce		1005 mg (42% DV) 1 TBSP
4	Beef Jerky		590 mg (24% DV) 1 OZ
5	Olives		420 mg (17% DV) 10 OLIVES (GREEN)
6	Parmesan Cheese		390 mg (16% DV) 1 OZ
7	Ham		320 mg (13% DV) 1 SLICE
8	Salami		226 mg (9% DV) 1 SLICE
9	Bacon		194 mg (8% DV) 1 SLICE
10	Pickles		160 mg (6% DV) 1 LARGE