Environmental Health

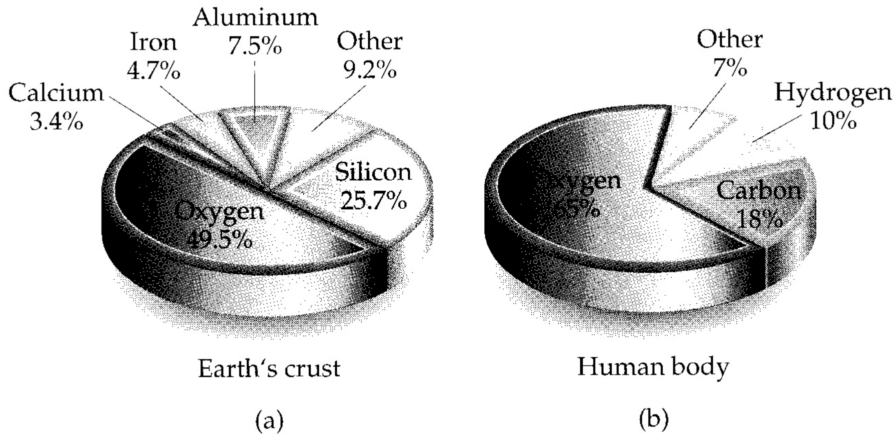
Chemistry basics

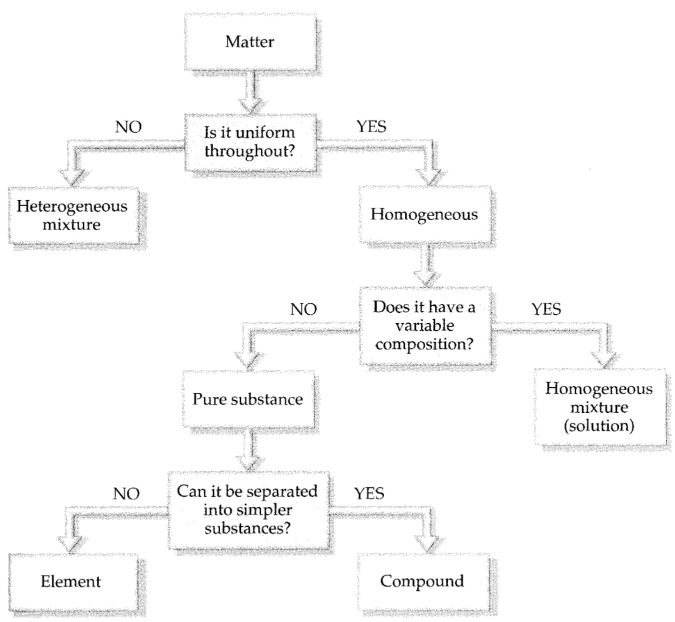
Week 2

Properties of chemicals

- Physical
  - Color, odor, density, melting point, boiling point and hardness
  - Changes in appearance, or state but not in composition
- Chemical
  - Change in structure, reaction with other (flammability)

Elemental composition of earth crust and human body





▲ **Figure 1.9** Classification scheme for matter. At the chemical level all matter is classified ultimately as either elements or compounds.

Metric Units (SI system)

TABLE 1.4 SI Base Units

Physical Quantity	Name of Unit	Abbreviation
Mass	Kilogram	kg
Length	Meter	m
Time	Second	s[a]
Temperature	Kelvin	K
Amount of substance	Mole	mol
Electric current	Ampere	A
Luminous intensity	Candela	cd

[a] The abbreviation sec is frequently used.

Production volumes for common chemicals

TABLE 1.1 The Top Ten Chemicals Produced by the Chemical Industry in 2000[a]

Rank	Chemical	Formula	2000 Production (billions of pounds)	Principal End Uses
1	Sulfuric acid	H_2SO_4	87	Fertilizers, chemical manufacturing
2	Nitrogen	N_2	81	Fertilizers
3	Oxygen	O_2	55	Steel, welding
4	Ethylene	C_2H_4	55	Plastics, antifreeze
5	Lime	CaO	44	Paper, cement, steel
6	Ammonia	NH_3	36	Fertilizers
7	Propylene	C_3H_6	32	Plastics
8	Phosphoric acid	H_3PO_4	26	Fertilizers
9	Chlorine	Cl_2	26	Bleaches, plastics, water purification
10	Sodium hydroxide	NaOH	24	Aluminum production, soap

[a] Most data from *Chemical and Engineering News*, June 25, 2001, pp. 45, 46.

Properties of H_2O, H_2 and O_2

TABLE 1.3 Comparison of Water, Hydrogen, and Oxygen

	Water	Hydrogen	Oxygen
State[a]	Liquid	Gas	Gas
Normal boiling point	100°C	−253°C	−183°C
Density[a]	1.00 g/mL	0.084 g/L	1.33 g/L
Flammable	No	Yes	No

[a] At room temperature and atmospheric pressure. (See Section 10.2.)

Metric scale

TABLE 1.5 Selected Prefixes Used in the Metric System

Prefix	Abbreviation	Meaning	Example
Giga	G	10^9	1 gigameter (Gm) $= 1 \times 10^9$ m
Mega	M	10^6	1 megameter (Mm) $= 1 \times 10^6$ m
Kilo	k	10^3	1 kilometer (km) $= 1 \times 10^3$ m
Deci	d	10^{-1}	1 decimeter (dm) = 0.1 m
Centi	c	10^{-2}	1 centimeter (cm) = 0.01 m
Milli	m	10^{-3}	1 millimeter (mm) = 0.001 m
Micro	μ[a]	10^{-6}	1 micrometer (μm) $= 1 \times 10^{-6}$ m
Nano	n	10^{-9}	1 nanometer (nm) $= 1 \times 10^{-9}$ m
Pico	p	10^{-12}	1 picometer (pm) $= 1 \times 10^{-12}$ m
Femto	f	10^{-15}	1 femtometer (fm) $= 1 \times 10^{-15}$ m

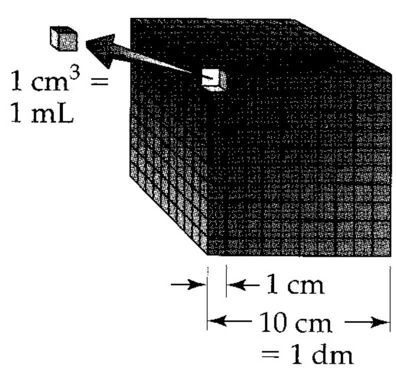
[a] This is the Greek letter mu (pronounced "mew").

Temperature conversion (°C, °F)

$$°C = \frac{5}{9}(°F - 32) \quad \text{or} \quad °F = \frac{9}{5}(°C) + 32$$

Volume units

$1\ L = 1\ dm^3 = 1000\ cm^3$



▲ **Figure 1.19** A liter is the same volume as a cubic decimeter, $1\ L = 1\ dm^3$. Each cubic decimeter contains 1000 cubic centimeters, $1\ dm^3 = 1000\ cm^3$. Each cubic centimeter equals a milliliter, $1\ cm^3 = 1\ mL$.

Density

$$\text{Density} = \frac{\text{mass}}{\text{volume}}$$

mg/L

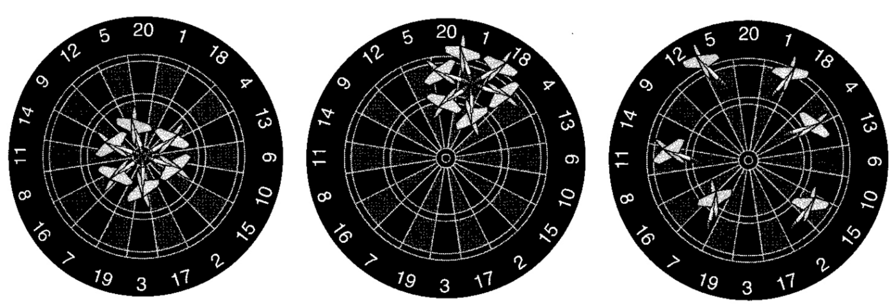
g/L

g/cm^3

TABLE 1.6 Densities of Some Selected Substances at 25°C

Substance	Density (g/cm^3)
Air	0.001
Balsa wood	0.16
Ethanol	0.79
Water	1.00
Ethylene glycol	1.09
Table sugar	1.59
Table salt	2.16
Iron	7.9
Gold	19.32

Precision *vs.* Accuracy



Good accuracy
Good precision

Poor accuracy
Good precision

Poor accuracy
Poor precision

Stoichiometry

$$CH_4 + O_2 \longrightarrow CO_2 + H_2O \qquad \text{(unbalanced)}$$ 1

$$CH_4 + O_2 \longrightarrow CO_2 + 2H_2O \qquad \text{(unbalanced)}$$ 2

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O \qquad \text{(balanced)}$$ 3

Composition and decomposition reactions

TABLE 3.1 Combination and Decomposition Reactions

Combination Reactions	
$A + B \longrightarrow C$ $C(s) + O_2(g) \longrightarrow CO_2(g)$ $N_2(g) + 3H_2(g) \longrightarrow 2NH_3(g)$ $CaO(s) + H_2O(l) \longrightarrow Ca(OH)_2(s)$	Two reactants combine to form a single product. Many elements react with one another in this fashion to form compounds.
Decomposition Reactions	
$C \longrightarrow A + B$ $2KClO_3(s) \longrightarrow 2KCl(s) + 3O_2(g)$ $PbCO_3(s) \longrightarrow PbO(s) + CO_2(g)$ $Cu(OH)_2(s) \longrightarrow CuO(s) + H_2O(l)$	A single reactant breaks apart to form two or more substances. Many compounds react this way when heated.

The mole (mol)

Avagadro's number = $6.022 * 10^{23}$
= number of atoms in 12 g of ^{12}C

$$1\ \text{mol}\ ^{12}\text{C atoms} = 6.02 \times 10^{23}\ ^{12}\text{C atoms}$$

$$1\ \text{mol}\ H_2O\ \text{molecules} = 6.02 \times 10^{23}\ H_2O\ \text{molecules}$$

$$1\ \text{mol}\ NO_3^-\ \text{ions} = 6.02 \times 10^{23}\ NO_3^-\ \text{ions}$$

Molar Mass

Atomic mass = (AW * # atoms) g

1mole = (AW * $6.022*10^{23}$) g

FW - molar mass

TABLE 3.2 Mole Relationships

Name	Formula	Formula Weight (amu)	Molar Mass (g/mol)	Number and Kind of Particles in One Mole
Atomic nitrogen	N	14.0	14.0	6.022×10^{23} N atoms
Molecular nitrogen	N_2	28.0	28.0	6.022×10^{23} N_2 molecules; $2(6.022 \times 10^{23})$ N atoms
Silver	Ag	107.9	107.9	6.022×10^{23} Ag atoms
Silver ions	Ag^+	107.9[a]	107.9	6.022×10^{23} Ag^+ ions
Barium chloride	$BaCl_2$	208.2	208.2	6.022×10^{23} $BaCl_2$ units; 6.022×10^{23} Ba^{2+} ions; $2(6.022 \times 10^{23})$ Cl^- ions

[a] Recall that the electron has negligible mass; thus, ions and atoms have essentially the same mass.

TABLE 2.3 Important Families of Organic Compounds

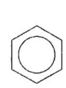
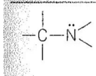
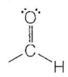
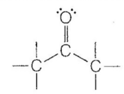
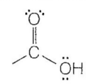
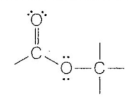
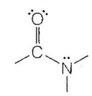
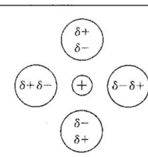
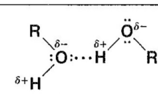
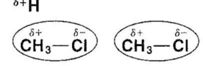
	Family						
	Alkane	Alkene	Alkyne	Aromatic	Haloalkane	Alcohol	Ether
Functional group	C—H and C—C bonds	C=C	—C≡C—	Aromatic ring	—C—X:	—C—OH	—C—O—C—
General formula	RH	RCH=CH$_2$ RCH=CHR R$_2$C=CHR R$_2$C=CR$_2$	RC≡CH RC≡CR	ArH	RX	ROH	ROR
Specific example	CH_3CH_3	$CH_2{=}CH_2$	HC≡CH		CH_3CH_2Cl	CH_3CH_2OH	CH_3OCH_3
IUPAC name	Ethane	Ethene	Ethyne	Benzene	Chloroethane	Ethanol	Methoxymethane
Common name[a]	Ethane	Ethylene	Acetylene	Benzene	Ethyl chloride	Ethyl alcohol	Dimethyl ether

TABLE 2.3 Important Families of Organic Compounds (cont.)

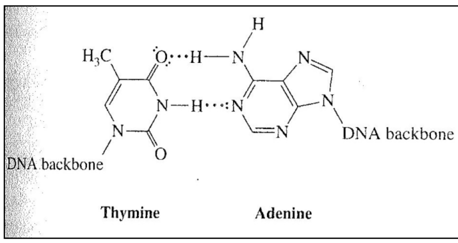
Amine	Aldehyde	Ketone	Carboxylic Acid	Ester	Amide	Nitrile
						$—C≡N:$
RNH_2 R_2NH R_3N	$R\overset{\overset{O}{\Vert}}{C}H$	$R\overset{\overset{O}{\Vert}}{C}R'$	$R\overset{\overset{O}{\Vert}}{C}OH$	$R\overset{\overset{O}{\Vert}}{C}OR'$	$R\overset{\overset{O}{\Vert}}{C}NH_2$ $R\overset{\overset{O}{\Vert}}{C}NHR'$ $R\overset{\overset{O}{\Vert}}{C}NR'R''$	RCN
CH_3NH_2	$CH_3\overset{\overset{O}{\Vert}}{C}H$	$CH_3\overset{\overset{O}{\Vert}}{C}CH_3$	$CH_3\overset{\overset{O}{\Vert}}{C}OH$	$CH_3\overset{\overset{O}{\Vert}}{C}OCH_3$	$CH_3\overset{\overset{O}{\Vert}}{C}NH_2$	$CH_3C≡N$
Methanamine	Ethanal	Propanone	Ethanoic acid	Methyl ethanoate	Ethanamide	Ethanenitrile
Methylamine	Acetaldehyde	Acetone	Acetic acid	Methyl acetate	Acetamide	Acetonitrile

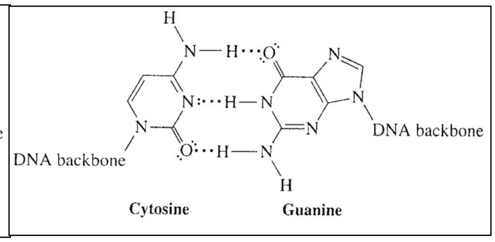
Types of Bonds

TABLE 2.6 Attractive Electric Forces

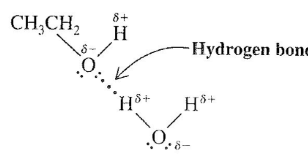
Electric Force	Relative Strength	Type	Example
Cation–anion (in a crystal)	Very strong	⊕ ⊖	Lithium fluoride crystal lattice
Covalent bonds	Strong (140–523 kJ mol^{-1})	Shared electron pairs	H—H (436 kJ mol^{-1}) $CH_3—CH_3$ (378 kJ mol^{-1}) I—I (151 kJ mol^{-1})
Ion–dipole	Moderate		Na^+ in water (see Fig. 2.9)
Dipole–dipole (including hydrogen bonds)	Moderate to weak (4–38 kJ mol^{-1})	$—\overset{\delta-}{Z}:\cdots\overset{\delta+}{H}—$	 and 
van der Waals	Variable	Transient dipole	Interactions between methane molecules

H-bonds



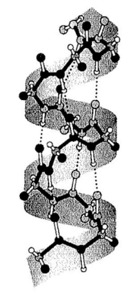


Solubility



- Intermolecular forces determine solubility
- Water (and few polar compounds) are able to dissolve ionic molecules
- Water is highly polar and forms dipole-ion forces with polar molecules
- Non-polar liquids dissolve non-polar compounds
- Long CH chains are hydrophobic (lipophilic)
- Generally: “like-dissolves-like”

Solubility guidelines



- A compound is water-soluble if >=3g dissolves in 100ml water
- If there is at least one hydrophilic group:
  - 1-3 C are water soluble
  - 4-5 C are borderline soluble
  - >6 C are insoluble
- If more than one hydrophilic group it is water soluble

Ionization

Acids Proton donors	Base Proton acceptors
$HA \rightleftharpoons H^+ + A^-$	$A + H^+ \rightleftharpoons AH^+$
$K' = \frac{[H^+][A^-]}{[HA]}$	$K' = \frac{[AH^+]}{[A][H^+]}$
pK' = -logK'	pK' = -logK'
pKa: the pH at which there is 50% of HA and 50% of A^-	pKb: the pH at which there is 50% of A and 50% of HA^+ pKa = 14 - pKb

Examples

- Acids

$HCl \rightleftarrows H^+ + Cl^-$

$CH_3COOH \rightleftarrows H^+ + CH_3COO^-$

$H_2SO_4 \rightleftarrows H^+ + HSO^-_4$

- Bases

$OH + H^+ \rightleftarrows H_2O$

$NH_3 + H^+ \rightleftarrows NH^+_4$

$RNH_2 + H^+ \rightleftarrows RNH^+_3$

Water

[redacted]

[redacted]

[redacted]

[redacted]

Degree of ionization

- Acids: [redacted]

- Bases: [redacted]

	1	7	14
pH	acidic		basic
pK':	acids		bases