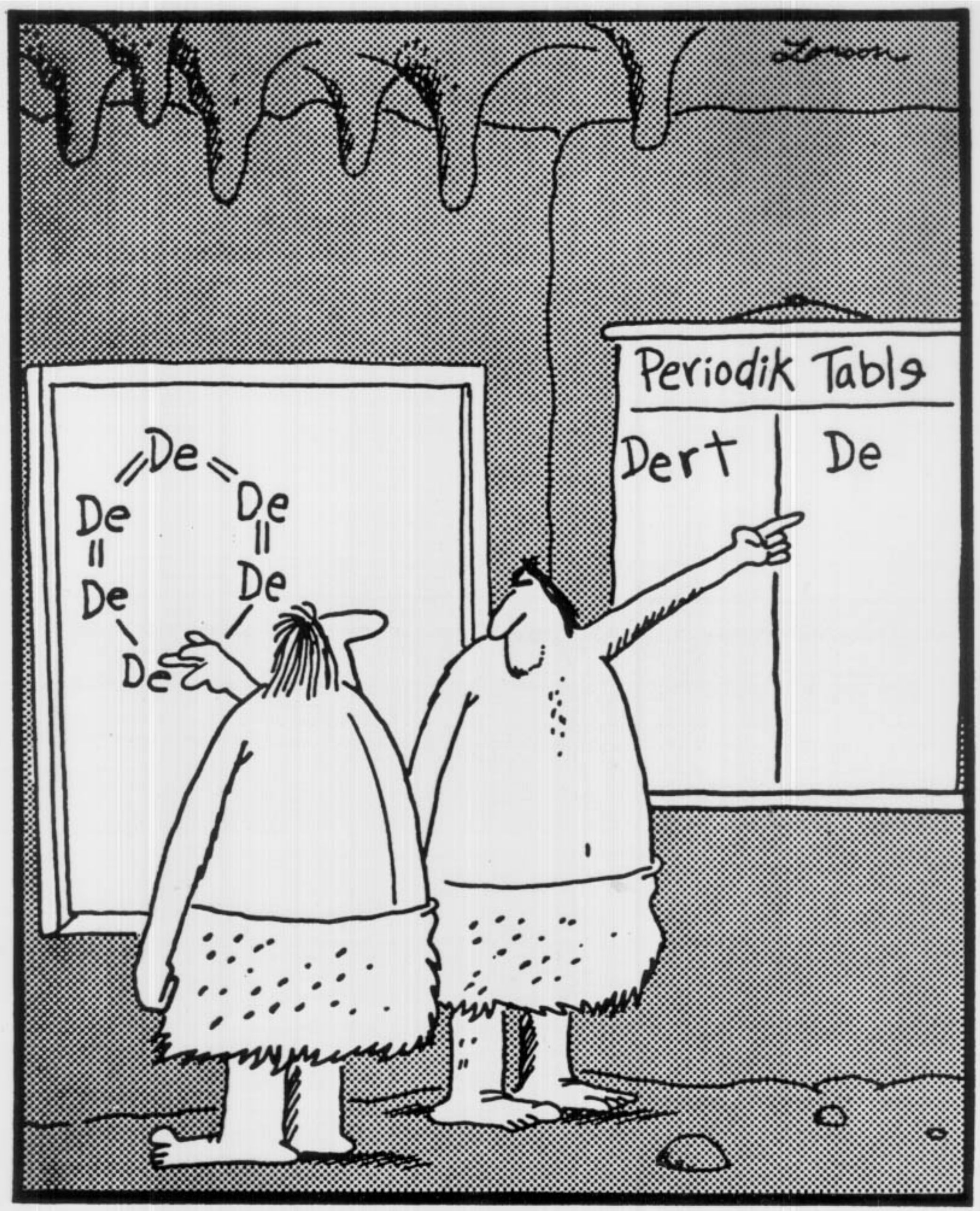
Lecture Series 2
Water as THE Biological Solvent

A. Atoms: The Constituents of Matter

- An element is made up of only one kind of atom.
- The number of protons identifies the element.
- Isotopes differ in the number of neutrons.



Early chemists describe the first dirt molecule.

Yellow elements make up 98% of all biomass!

Chemical symbol

Atomic number **= protons**

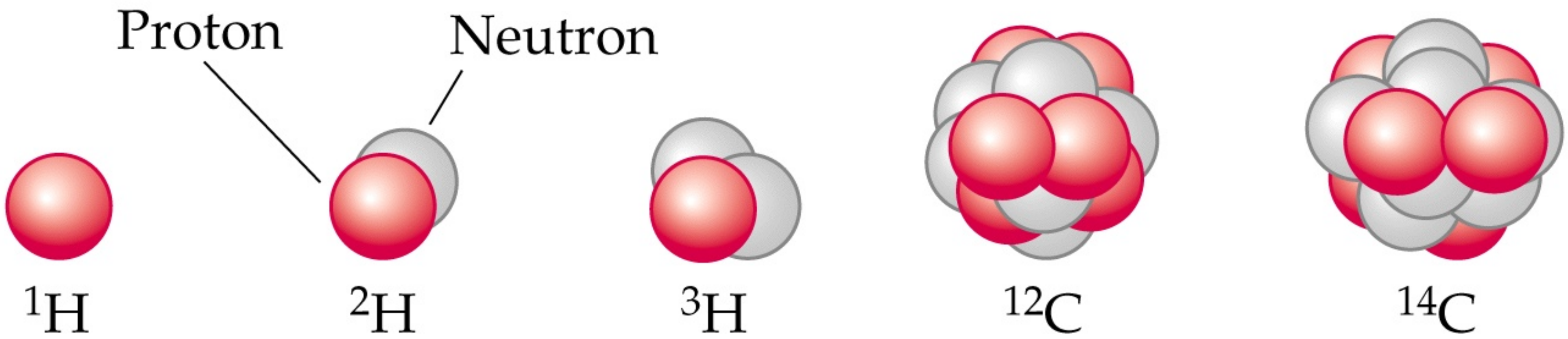
Atomic mass **= protons + neutrons**
(average of all isotopes)

1 H 1.0079																	2 He 4.003
3 Li 6.941	4 Be 9.012											5 B 10.81	6 C 12.011	7 N 14.007	8 O 15.999	9 F 18.998	10 Ne 20.179
11 Na 22.990	12 Mg 24.305											13 Al 26.982	14 Si 28.086	15 P 30.974	16 S 32.06	17 Cl 35.453	18 Ar 39.948
19 K 39.098	20 Ca 40.08	21 Sc 44.956	22 Ti 47.88	23 V 50.942	24 Cr 51.996	25 Mn 54.938	26 Fe 55.847	27 Co 58.933	28 Ni 58.69	29 Cu 63.546	30 Zn 65.38	31 Ga 69.72	32 Ge 72.59	33 As 74.922	34 Se 78.96	35 Br 79.909	36 Kr 83.80
37 Rb 85.4778	38 Sr 87.62	39 Y 88.906	40 Zr 91.22	41 Nb 92.906	42 Mo 95.94	43 Tc (99)	44 Ru 101.07	45 Rh 102.906	46 Pd 106.4	47 Ag 107.870	48 Cd 112.41	49 In 114.82	50 Sn 118.69	51 Sb 121.75	52 Te 127.60	53 I 126.904	54 Xe 131.30
55 Cs 132.905	56 Ba 137.34	71 Lu 174.97	72 Hf 178.49	73 Ta 180.948	74 W 183.85	75 Re 186.207	76 Os 190.2	77 Ir 192.2	78 Pt 195.08	79 Au 196.967	80 Hg 200.59	81 Tl 204.37	82 Pb 207.19	83 Bi 208.980	84 Po (209)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra 226.025	103 Lr (260)	104 Rf (261)	105 Db (262)	106 Sg (266)	107 Bh (264)	108 Hs (269)	109 Mt (268)	110 (269)	111 (272)	112 (277)	113	114 (285)	115 (289)	116	117	118 (293)

Orange elements make up Trace amounts of biomass.

Lanthanide series	57 La 138.906	58 Ce 140.12	59 Pr 140.9077	60 Nd 144.24	61 Pm (145)	62 Sm 150.36	63 Eu 151.96	64 Gd 157.25	65 Tb 158.924	66 Dy 162.50	67 Ho 164.930	68 Er 167.26	69 Tm 168.934	70 Yb 173.04
Actinide series	89 Ac 227.028	90 Th 232.038	91 Pa 231.0359	92 U 238.02	93 Np 237.0482	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)

Isotopes

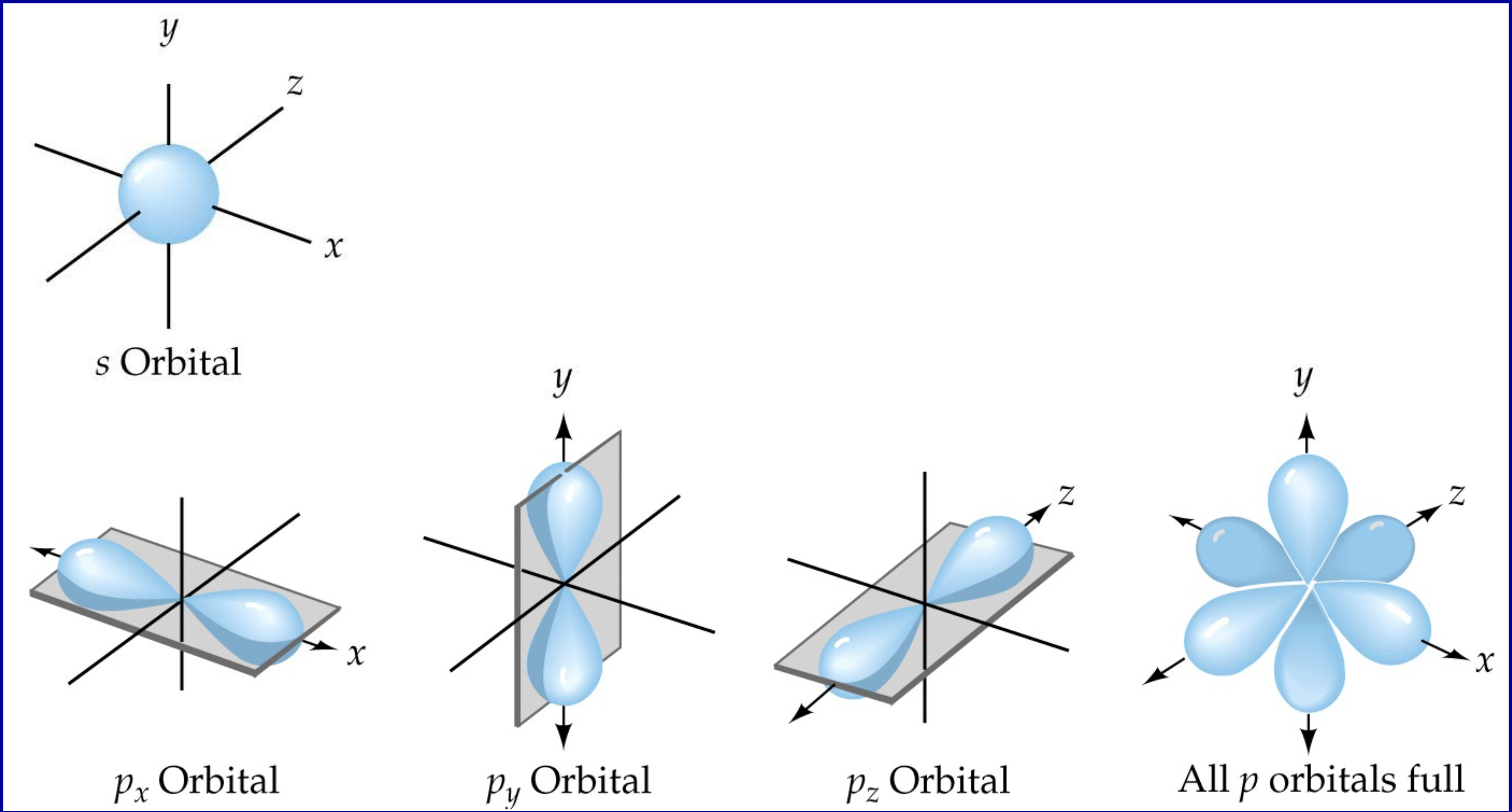


Isotopes of hydrogen			Isotopes of carbon	
Hydrogen	Deuterium	Tritium	Carbon-12	Carbon-14
1 proton	1 proton 1 neutron	1 proton 2 neutrons	6 protons 6 neutrons	6 protons 8 neutrons

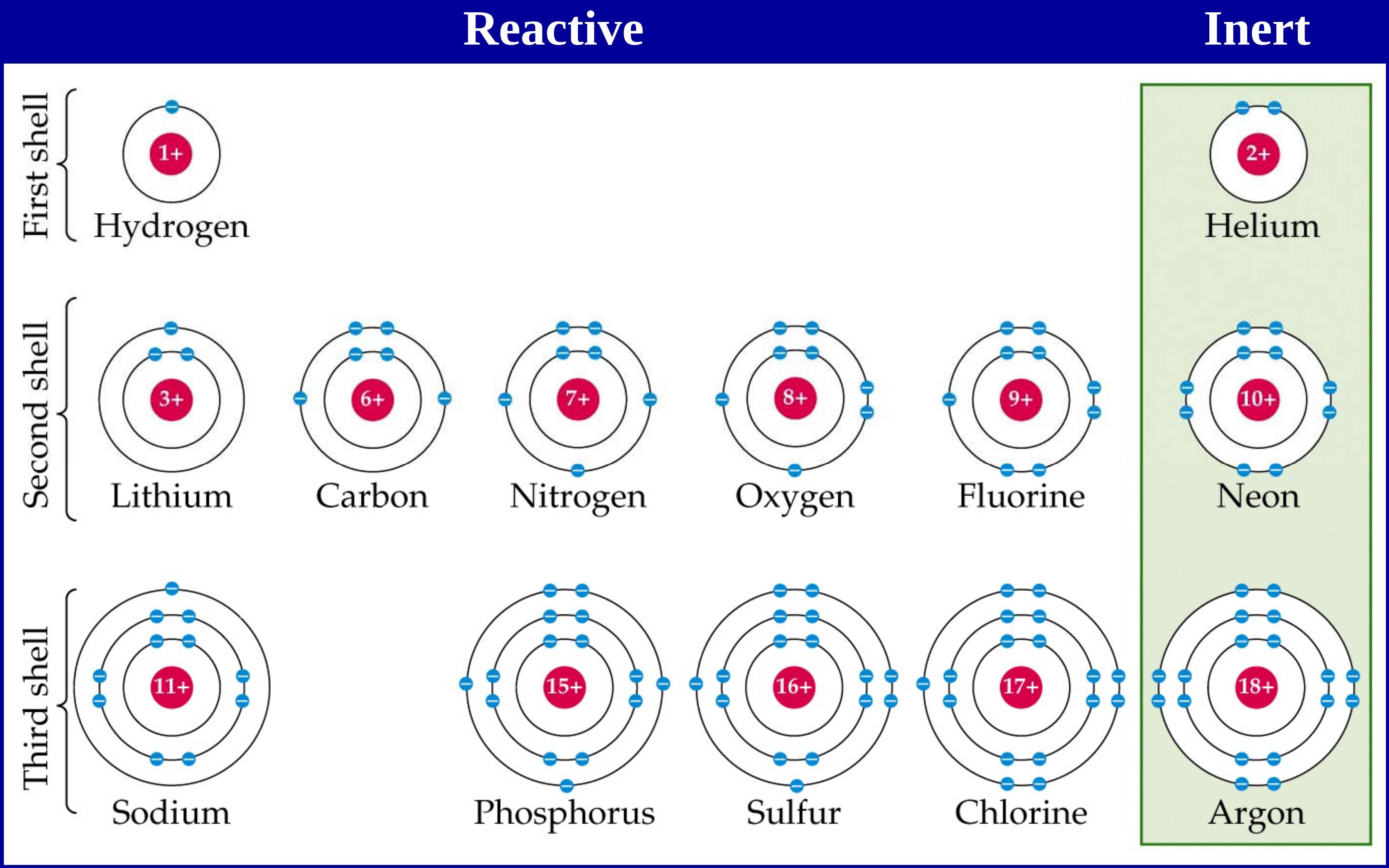
A. Atoms: The Constituents of Matter

- Electron behavior determines chemical bonding.
- Electrons are distributed in shells of "orbitals" containing a maximum of two.
  - Octet Rule: stable molecules have 8 electrons in outer shell.

Orbitals

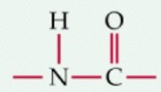
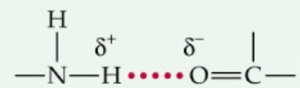
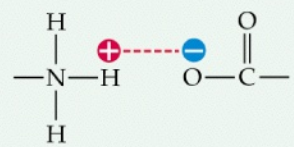
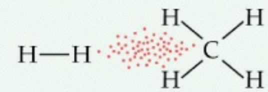
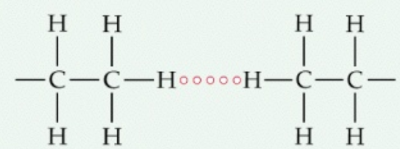

y
z
x
s Orbital
y
x
z
p_x Orbital
p_y Orbital
p_z Orbital
All p orbitals full

Electron Shells

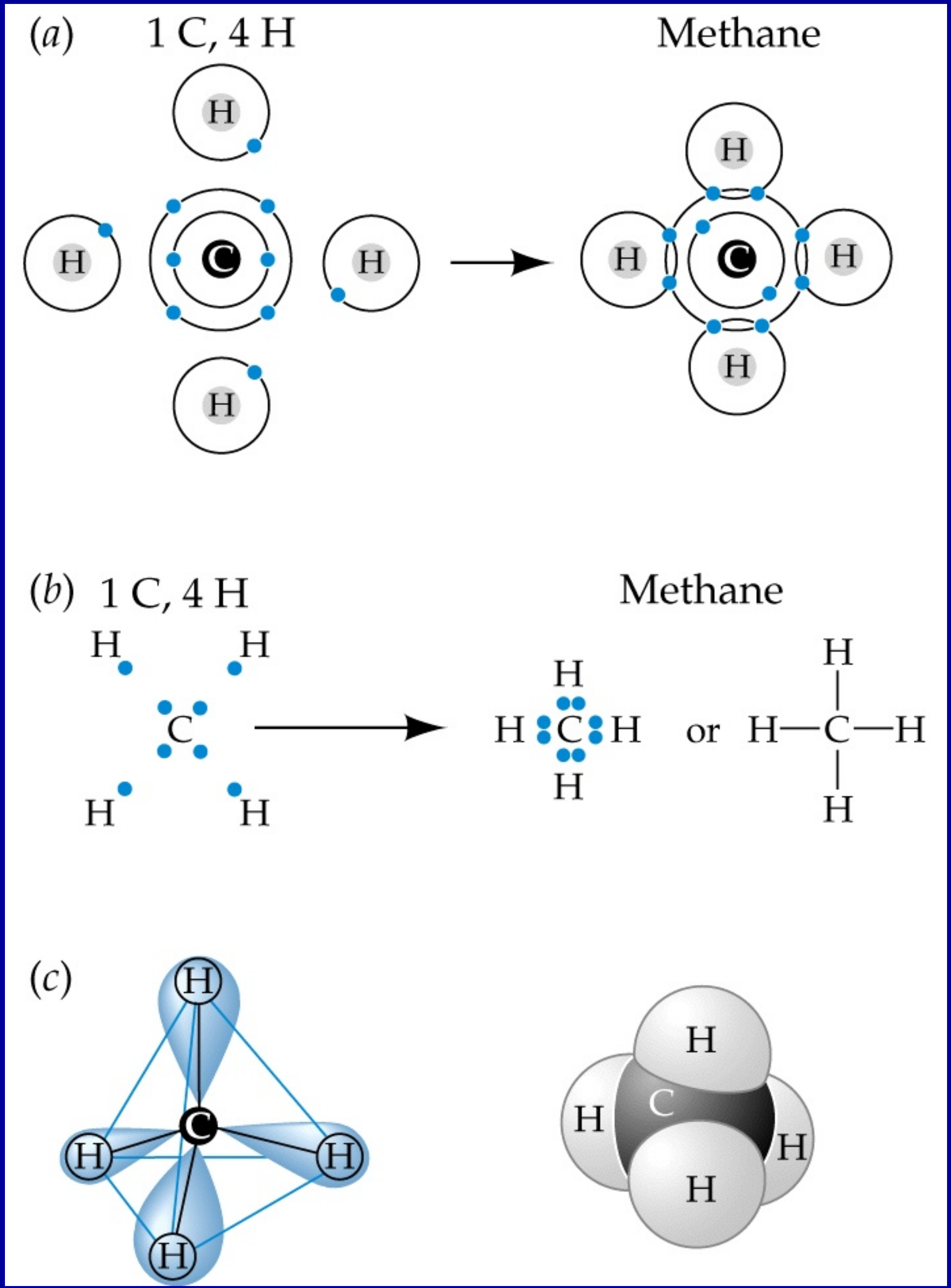


Nobel Gases

2.1 *Chemical Bonds and Interactions*

NAME	BASIS OF INTERACTION	STRUCTURE	BOND ENERGY[a] (KCAL/MOL)
Covalent bond	Sharing of electron pairs		50–110
Hydrogen bond	Sharing of H atom		3–7
Ionic interaction	Attraction of opposite charges		3–7
van der Waals interaction	Interaction of electron clouds		1
Hydrophobic interaction	Interaction of nonpolar substances		1–2

[a]*Bond energy* is the amount of energy needed to separate two bonded or interacting atoms under physiological conditions.



Covalent Bonding with Carbon

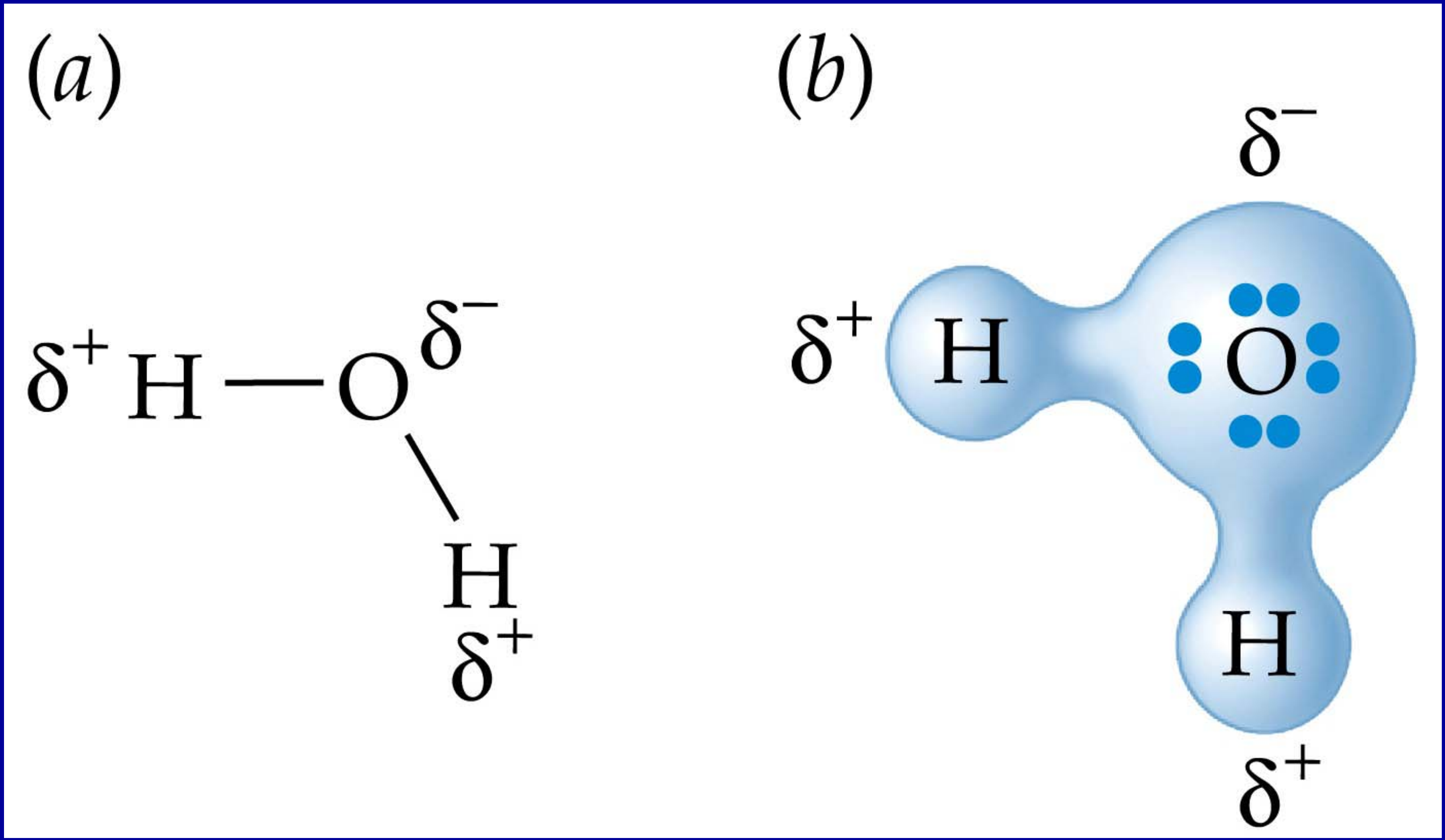
2.2 *Covalent Bonding Capabilities of Some Biologically Important Elements*

ELEMENT	NUMBER OF COVALENT BONDS
Hydrogen	1
Oxygen	2
Sulfur	2
Nitrogen	3
Carbon	4
Phosphorus	5

B. Chemical Bonds: Linking Atoms Together

- Nonpolar covalent bonds form when the electronegativities of two atoms are approximately equal. When atoms with strong electronegativity (such as oxygen) bond to atoms with weaker electronegativity (such as hydrogen), a polar covalent bond forms, in which one end is δ^+ and the other is δ^-.
- Covalent bonds involve sharing of electrons.

Water has Polar Covalent Bonds



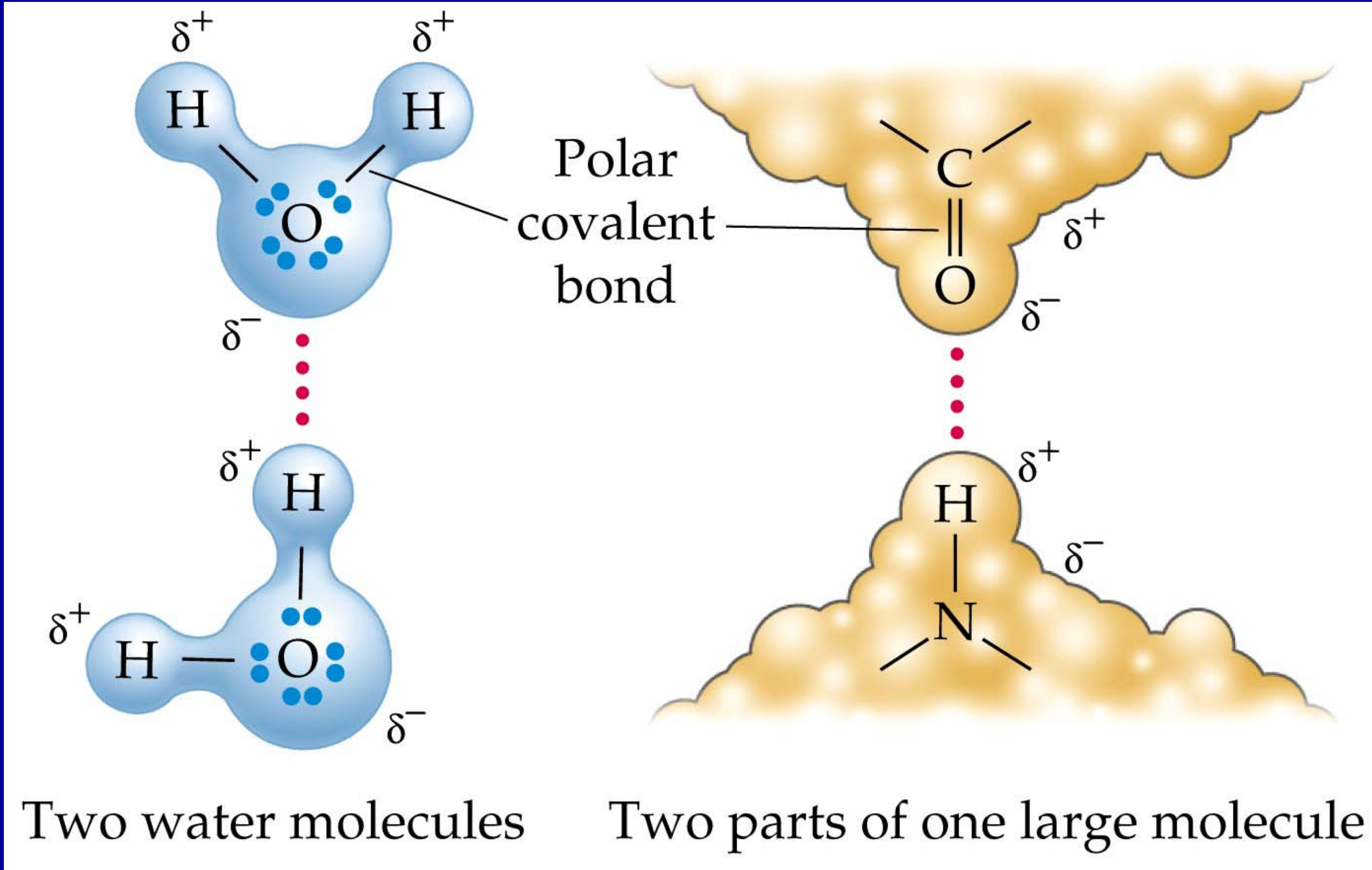
2.3 Some Electronegativities

ELEMENT	ELECTRONEGATIVITY
Oxygen	3.5
Chlorine	3.1
Nitrogen	3.0
Carbon	2.5
Phosphorus	2.1
Hydrogen	2.1
Sodium	0.9
Potassium	0.8

B. Chemical Bonds: Linking Atoms Together

- Hydrogen bonds form between a δ^+ hydrogen atom in one molecule and a δ^- nitrogen or oxygen atom in another molecule or in another part of a large molecule.
- Some sharing at work.

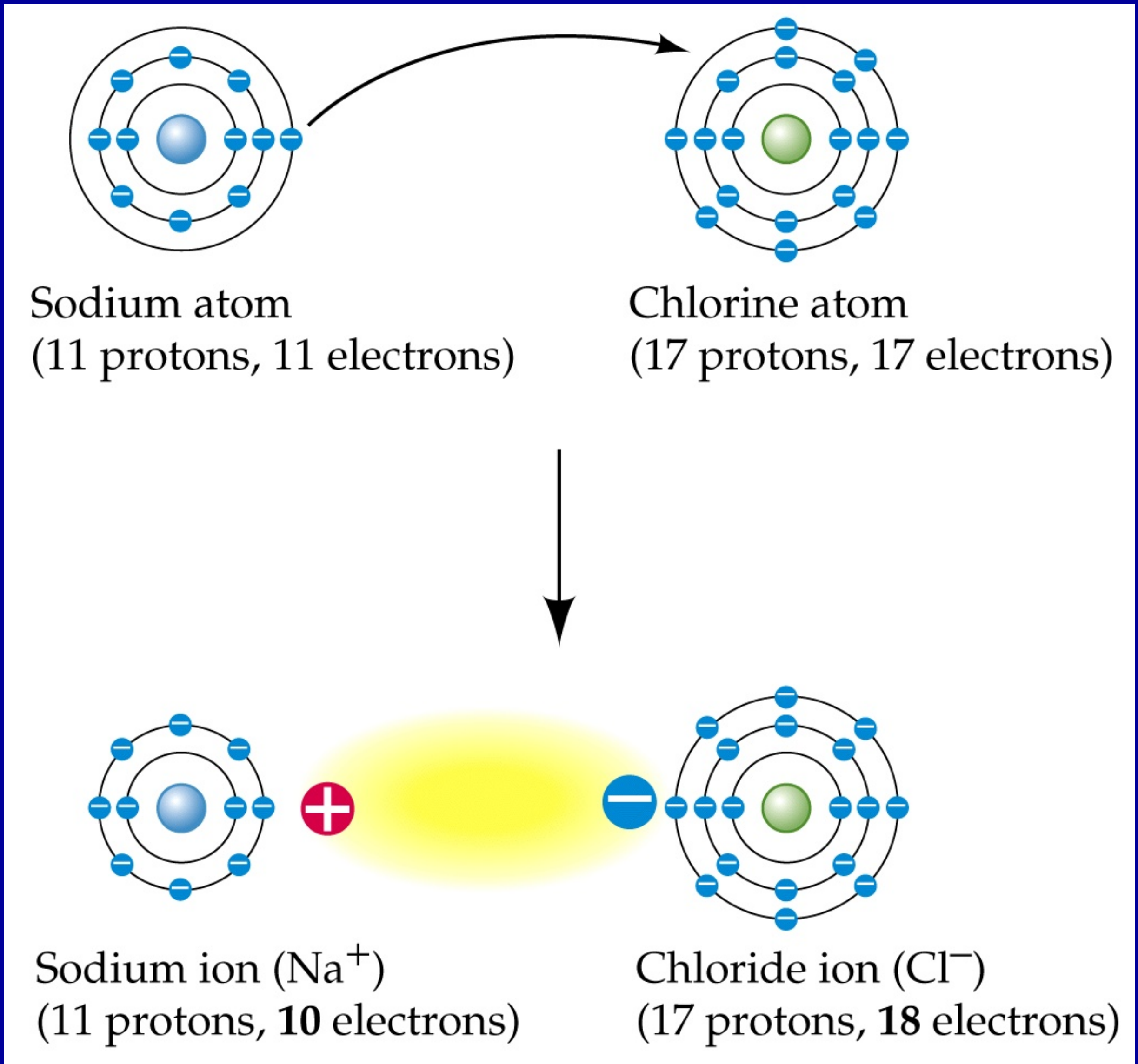
Hydrogen Bonding

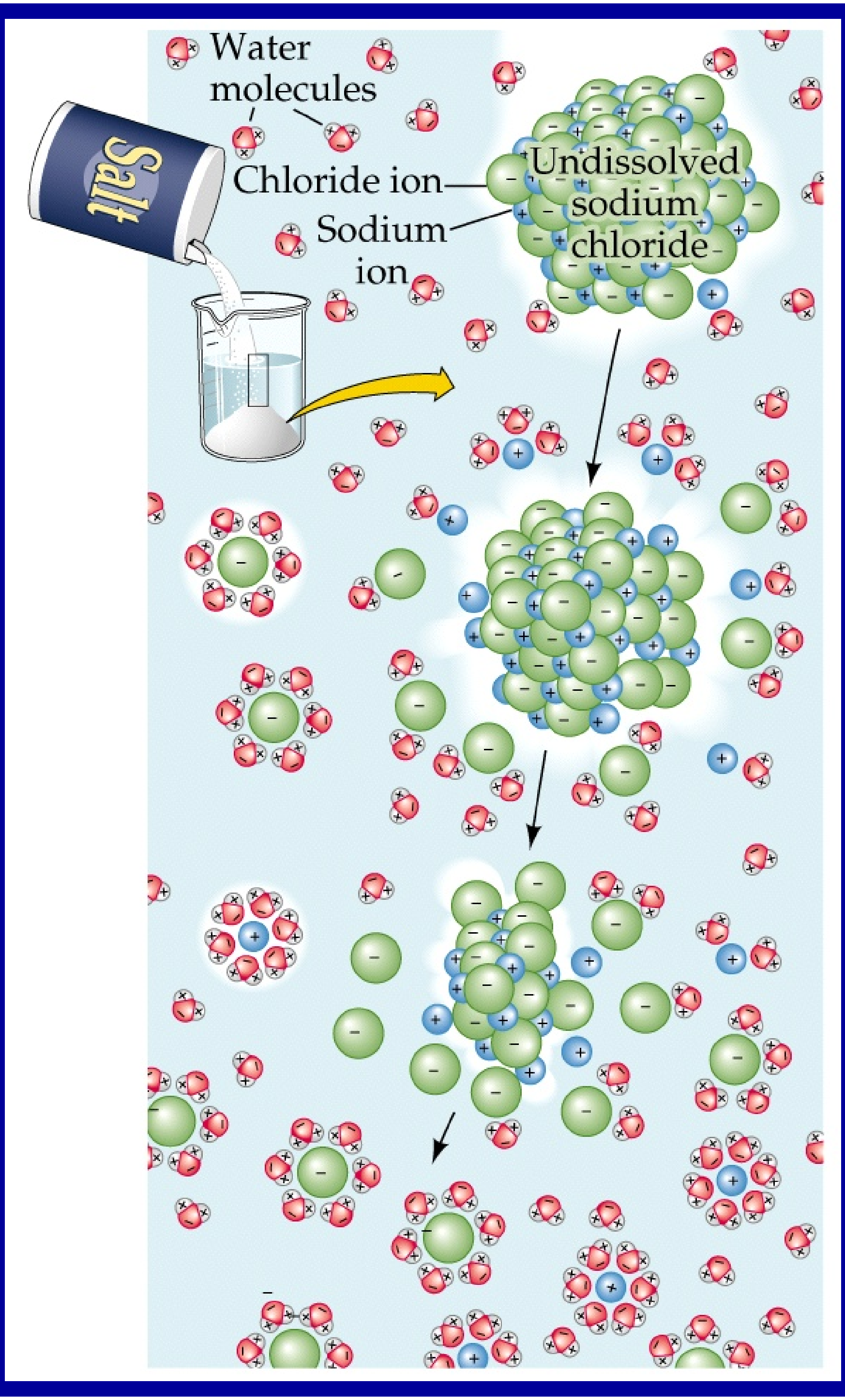


B. Chemical Bonds: Linking Atoms Together

- Ions, electrically charged bodies, form when an atom gains or loses one or more electrons. Ionic bonds are electrical attractions between oppositely charged ions.
- No sharing involved!

Ionic Bonds


Sodium atom
(11 protons, 11 electrons)
Chlorine atom
(17 protons, 17 electrons)
Sodium ion (Na^+)
(11 protons, **10** electrons)
Chloride ion (Cl^-)
(17 protons, **18** electrons)

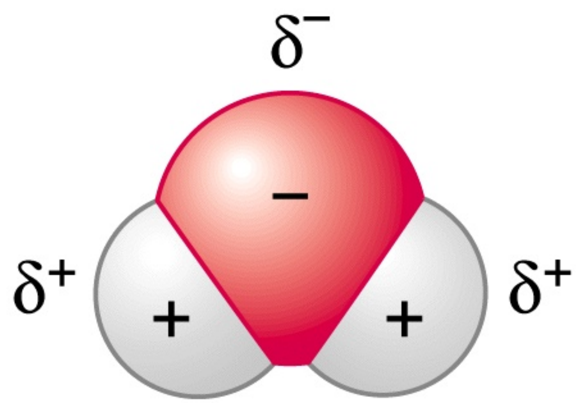


Water forms “Hydration Spheres” around ions

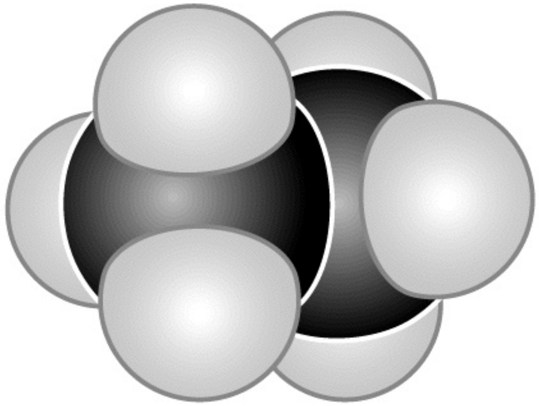
B. Chemical Bonds: Linking Atoms Together

- Nonpolar molecules have no attraction for polar substances. They are attracted to each other by very weak bonds called van der Waals forces.
- These are very important for membranes.
  - Hydrophobic vs. hydrophilic molecules.

Polar and Nonpolar Molecules



Water, a polar molecule
(H_2O)



Ethane, a nonpolar molecule
(CH_3CH_3)

C. Eggs by the Dozen: Molecules by the Mole

- Calculate the number of molecules by weighing: Avogadro's # = 6.023×10^{23}
- This is the weight in grams equal to a molecules combined atomic weight.
- Useful as in Biology, most reactions take place in solutions, which yields units of Molarity.

Moles

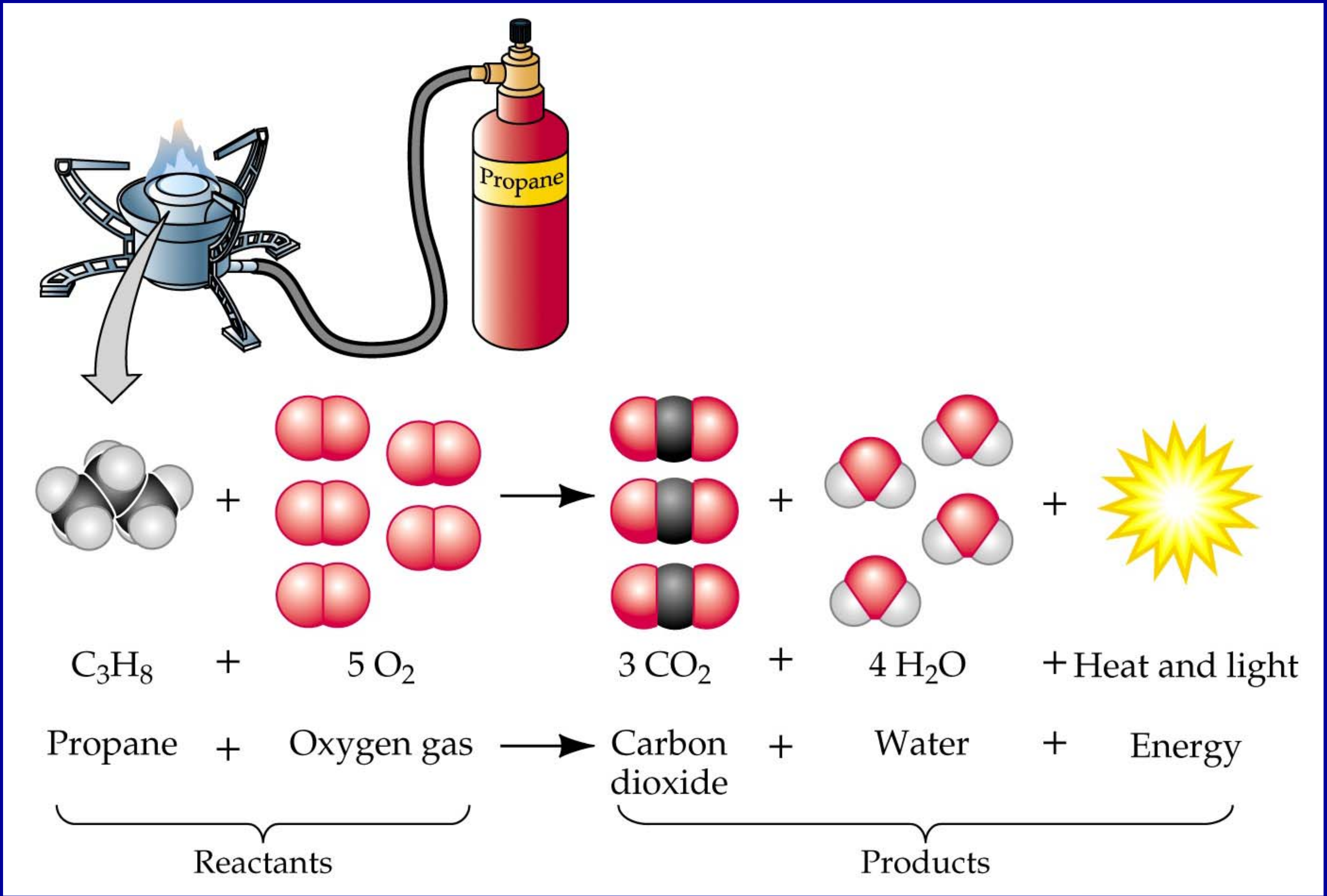
D. Chemical Reactions: Atoms Change Partners

- In chemical reactions, substances change their atomic compositions and properties. Energy is either released or added. Matter and energy are not created or destroyed, but change form.
- Conservation of Mass & Energy.

D. Chemical Reactions: Atoms Change Partners

- Combustion reactions are oxidation-reduction aka “redox” reactions.
- Fuel is converted to carbon dioxide and water, while energy is released as heat and light.
- In living cells, these reactions occur in multiple steps.

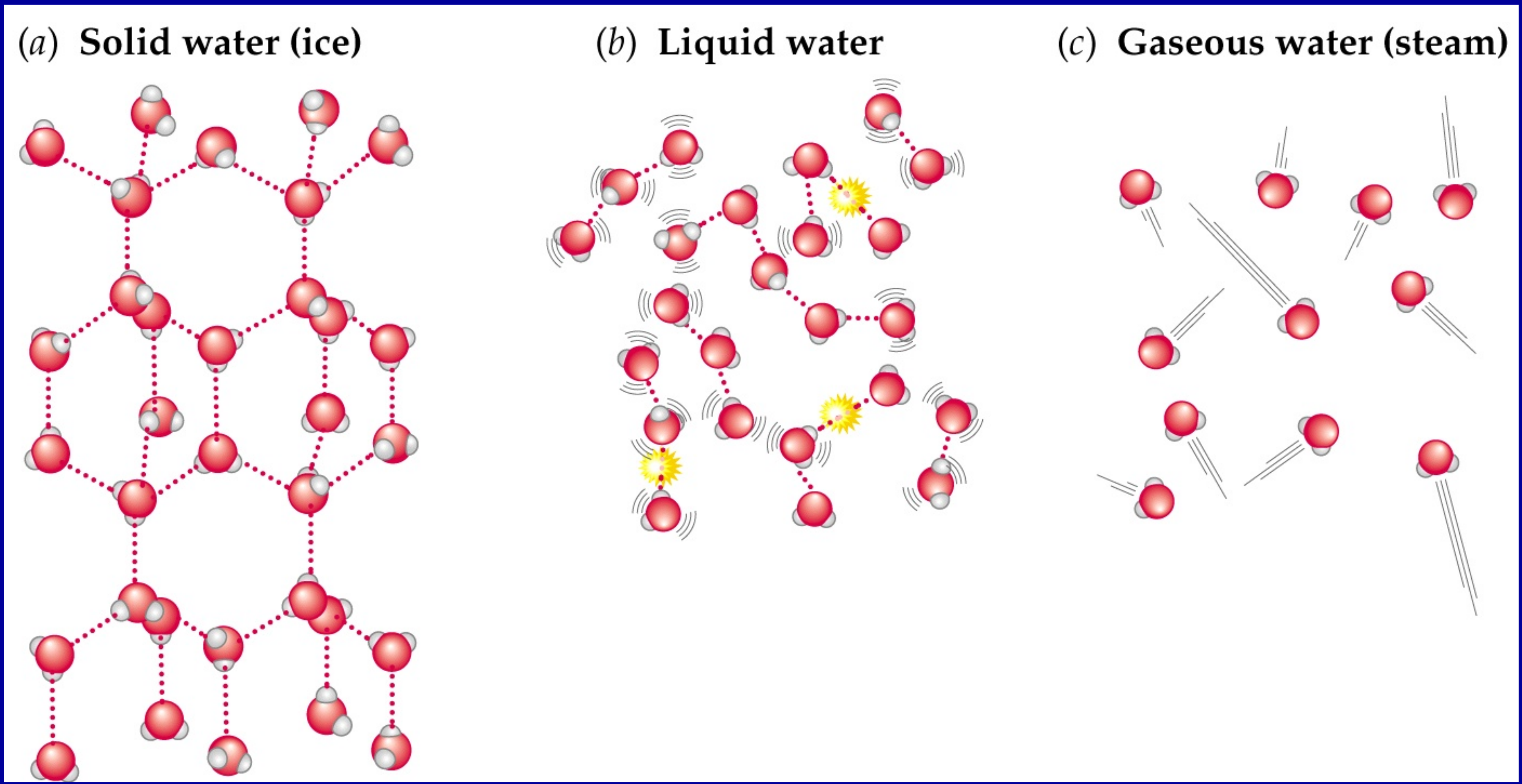
Chemical Energy Release



E. Water: Structure and Properties

- Water's molecular structure and capacity to form hydrogen bonds give it unusual and special properties significant for life.
- These include: Phase change avoidance, Specific Heat, Cohesive and Adhesive Strength, Latent Heat of Vaporization.
- Rare Ion formation (1 in 5 $x10^8$) or pH 7.0

Hydrogen Bonds Hold Water Molecules Together



Water in the environment

Ice floats and frozen benzene sinks

E. Water: Structure and Properties

- “Cohesion” of water molecules results in a high surface tension.
- Water’s high “heat of vaporization” assures cooling when it evaporates.
- Wide range of “Reynold’s Numbers” encountered by organisms.


Benjamin
Cummings


Benjamin
Cummings

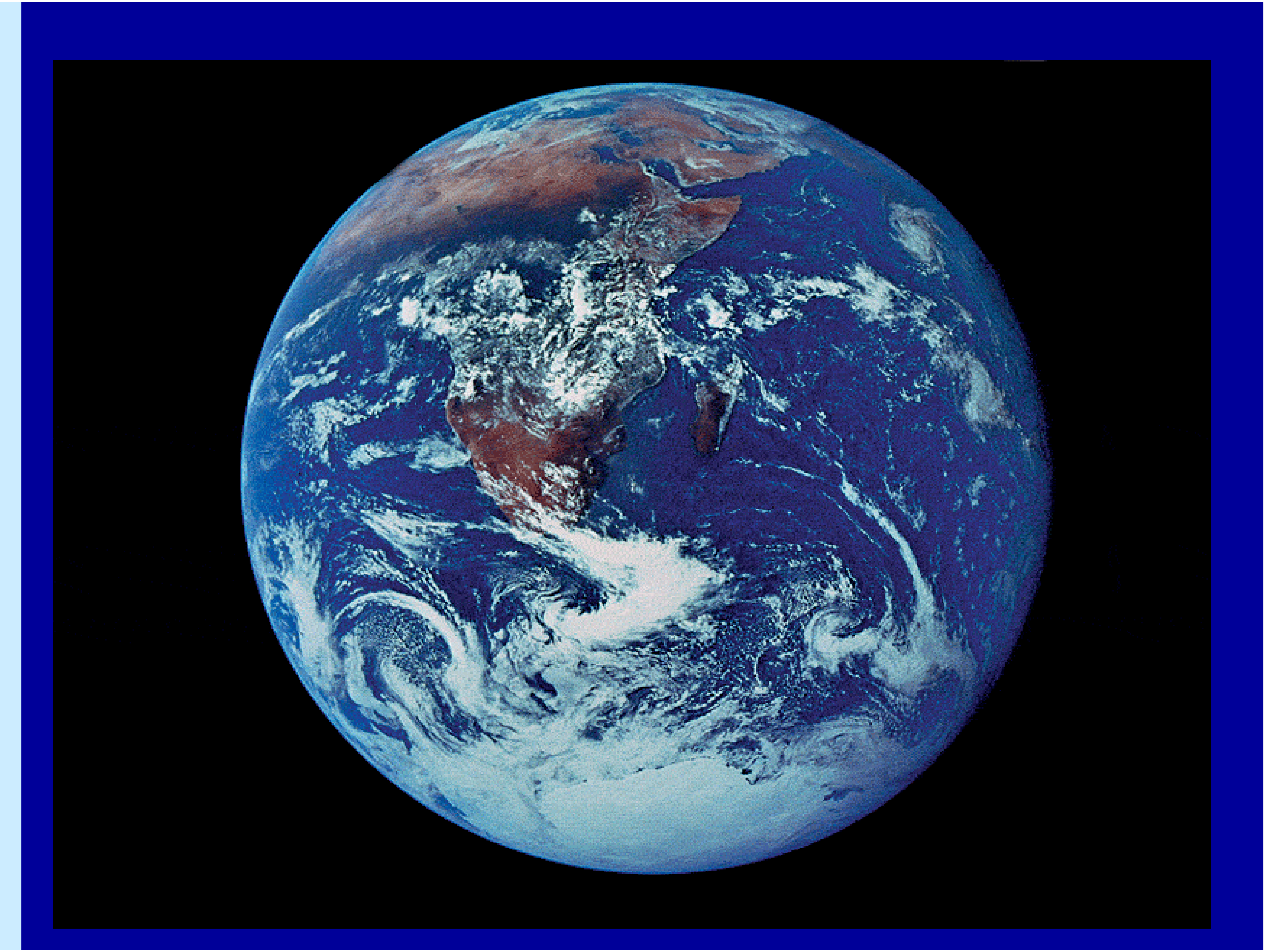


TABLE 6.2. REYNOLDS NUMBERS—EXAMPLES

Bacterium swimming	0.000001
Pollen grain falling, or sperm swimming	0.01
Fruit fly (fuselage) in flight	100
Small bird flying	100,000
Squid fast jetting	1,000,000
Large whale swimming	200,000,000

Re = Reynold's Number

$$Re = \frac{\text{Inertial Forces}}{\text{Viscous Forces}}$$

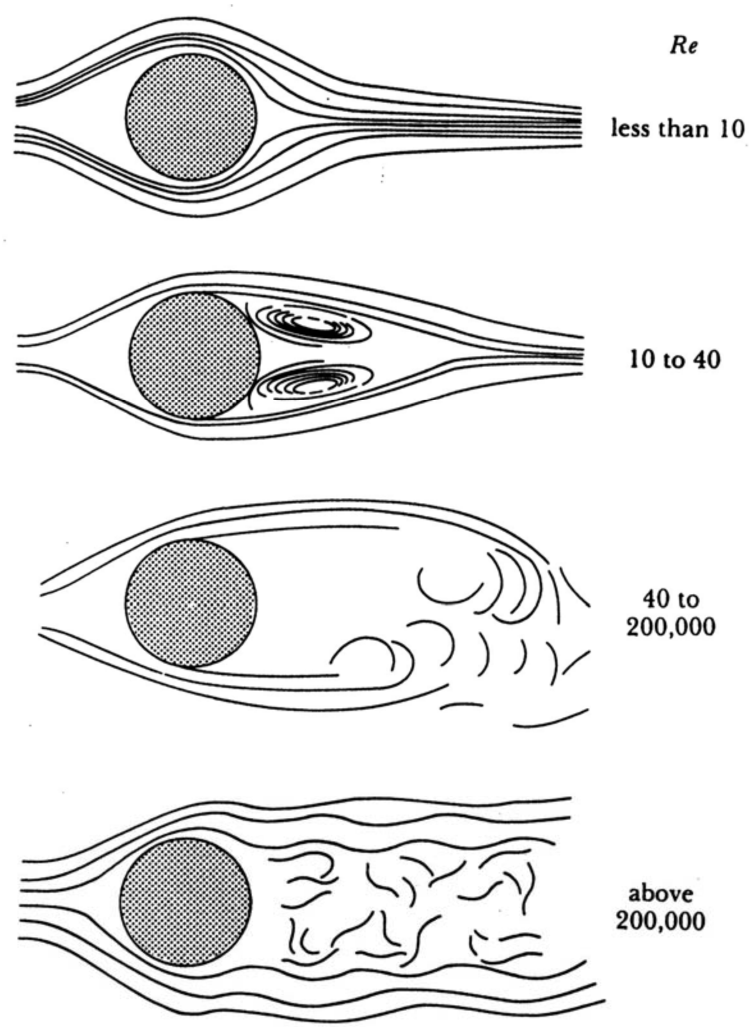
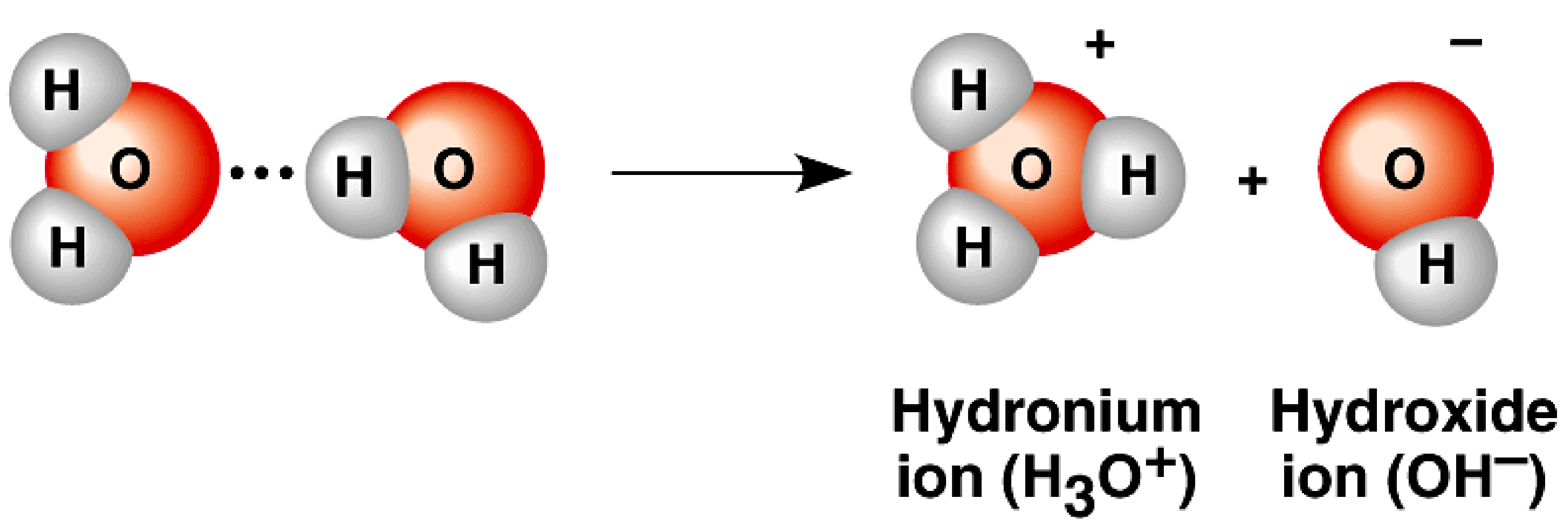


FIGURE 6.8. The character of flow around a circular cylinder (shown in cross section) depends very strongly on the Reynolds number, from orderly flows at low values through several transition regimes—attached vortices and periodically shed vortices—to thoroughly disorderly flows at high values.

F. Acids, Bases, & pH Scale

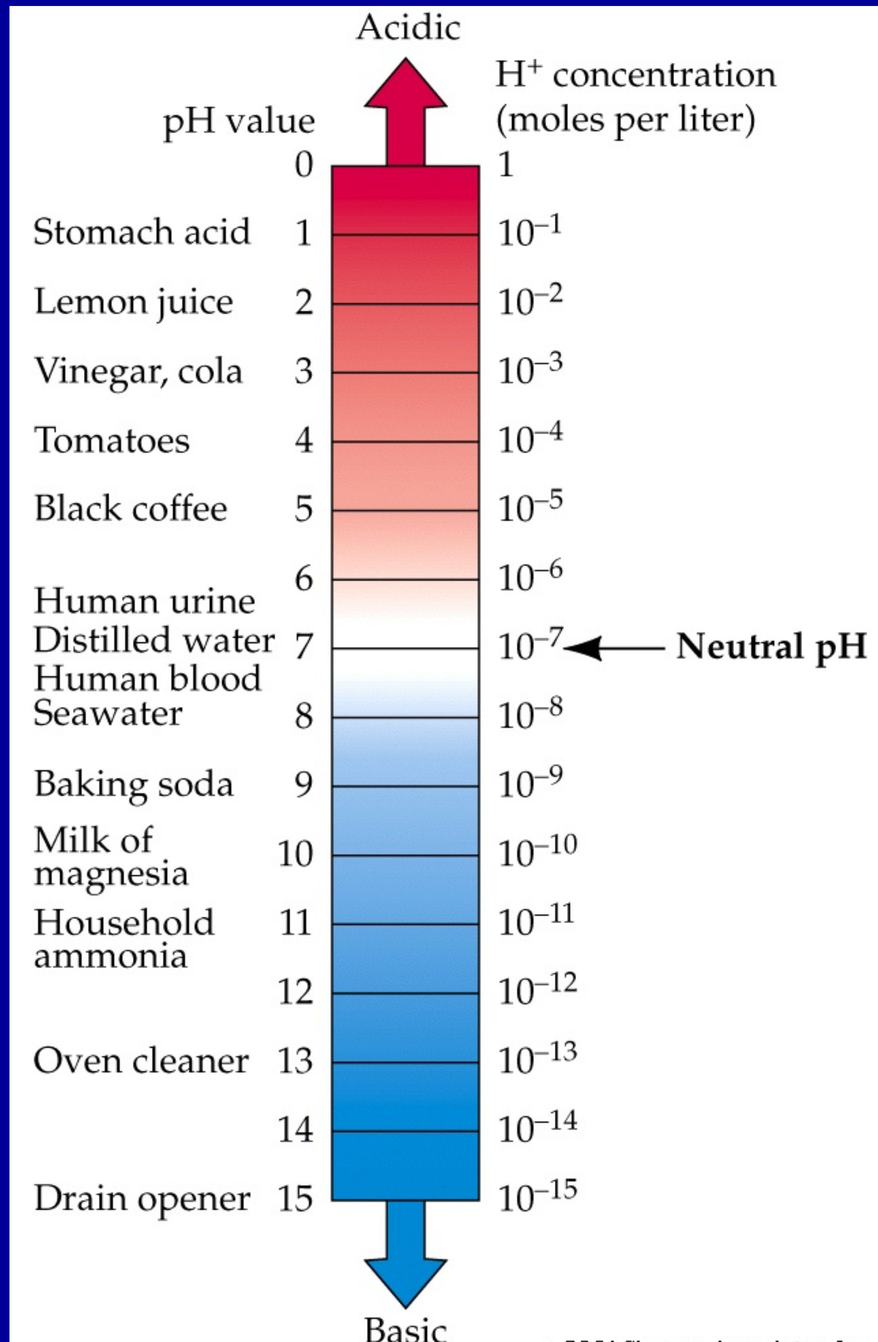
- Acids are substances that donate hydrogen ions. Bases are those that accept hydrogen ions.

Chemical reaction: hydrogen bond shift



F. Acids, Bases, & pH Scale

- The pH of a solution is the negative logarithm of the hydrogen ion concentration. $pH = -\log[H^+]$
- pH scales range from 0 to 14 as $[H^+][OH^-] = 1 \times 10^{-14}$
- Most biological solutions are between the pH range of 6 to 8.

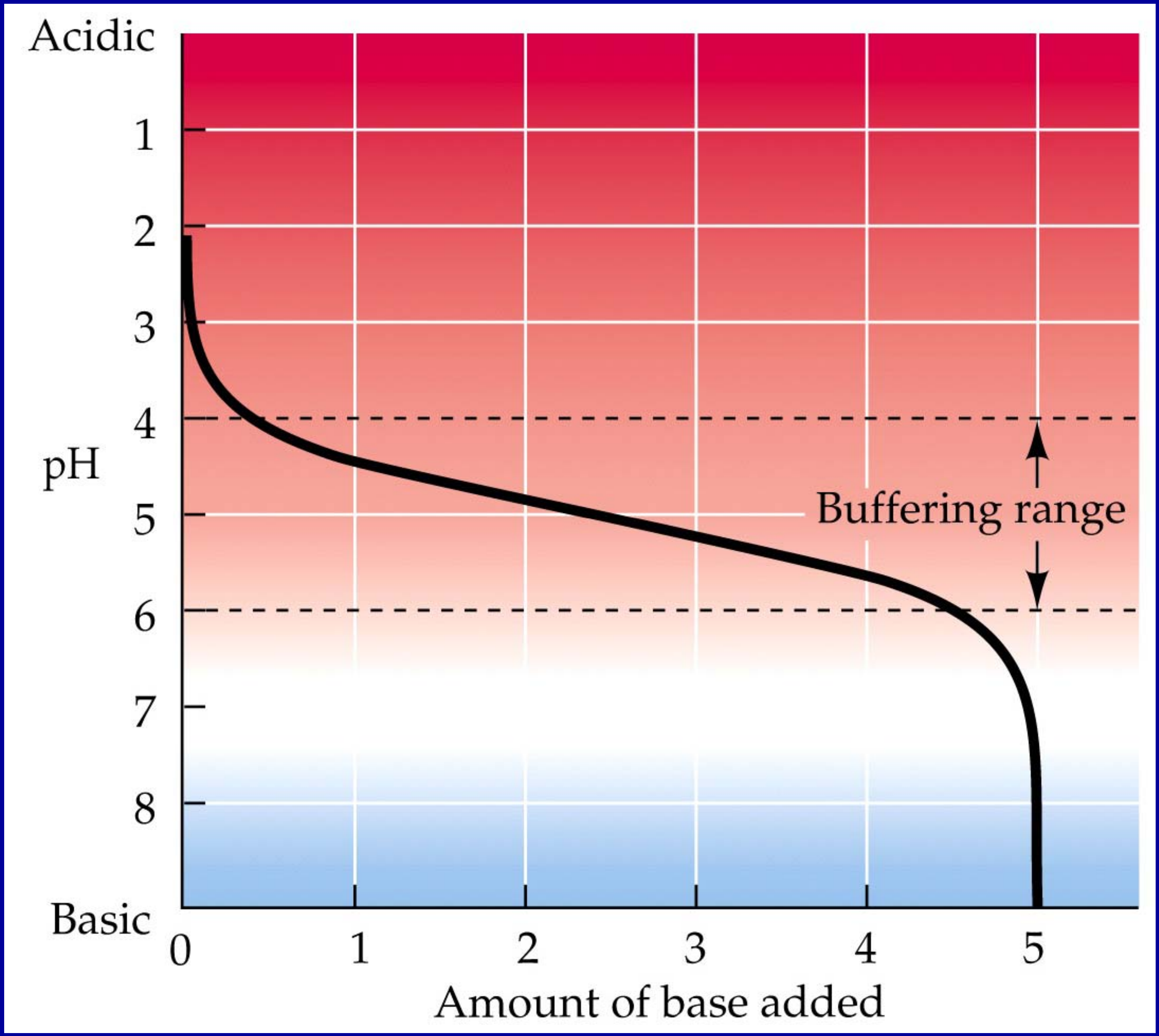

Acidic
H+ concentration (moles per liter)
pH value
0 1
Stomach acid 1 10–1
Lemon juice 2 10–2
Vinegar, cola 3 10–3
Tomatoes 4 10–4
Black coffee 5 10–5
6 10–6
Human urine
Distilled water 7 10–7
Neutral pH
Human blood
Seawater 8 10–8
Baking soda 9 10–9
Milk of magnesia 10 10–10
Household ammonia 11 10–11
12 10–12
Oven cleaner 13 10–13
14 10–14
Drain opener 15 10–15
Basic
© 2001 Sinauer Associates, Inc.

pH Scale

F. Acids, Bases, & pH Scale

- Buffers are systems of weak acids and bases that limit the sudden change in pH when hydrogen ions are added or removed.
- Examples are Bicarbonate or Phosphate Buffers.

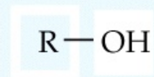
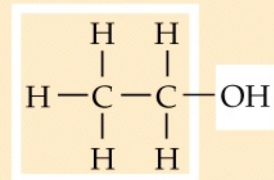
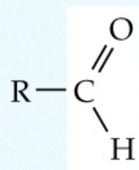
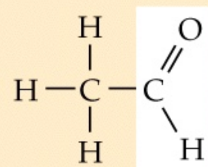
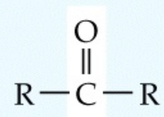
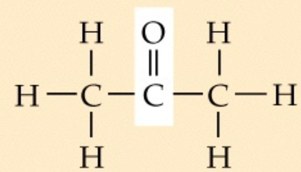
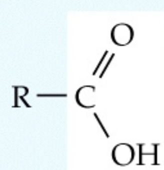
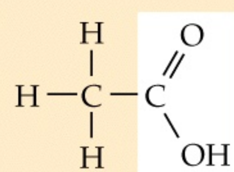
Buffers


Acidic
1
2
3
4
pH
5
6
7
8
Basic
Buffering range
0
1
2
3
4
5
Amount of base added

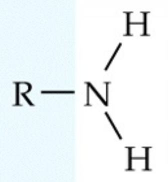
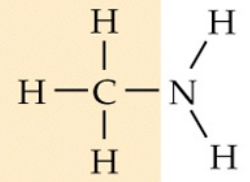
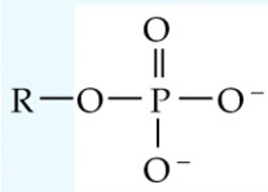
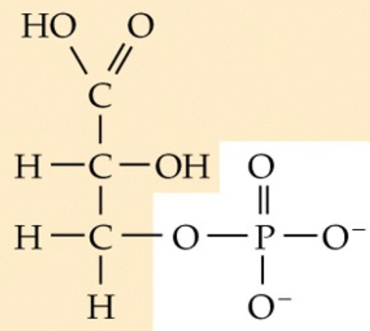
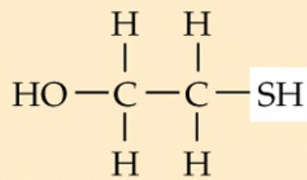
G. Properties of Molecules

- Molecules vary in size, shape, reactivity, solubility, and other chemical properties.
- Functional groups make up part of a larger molecule and provide specific chemical properties.

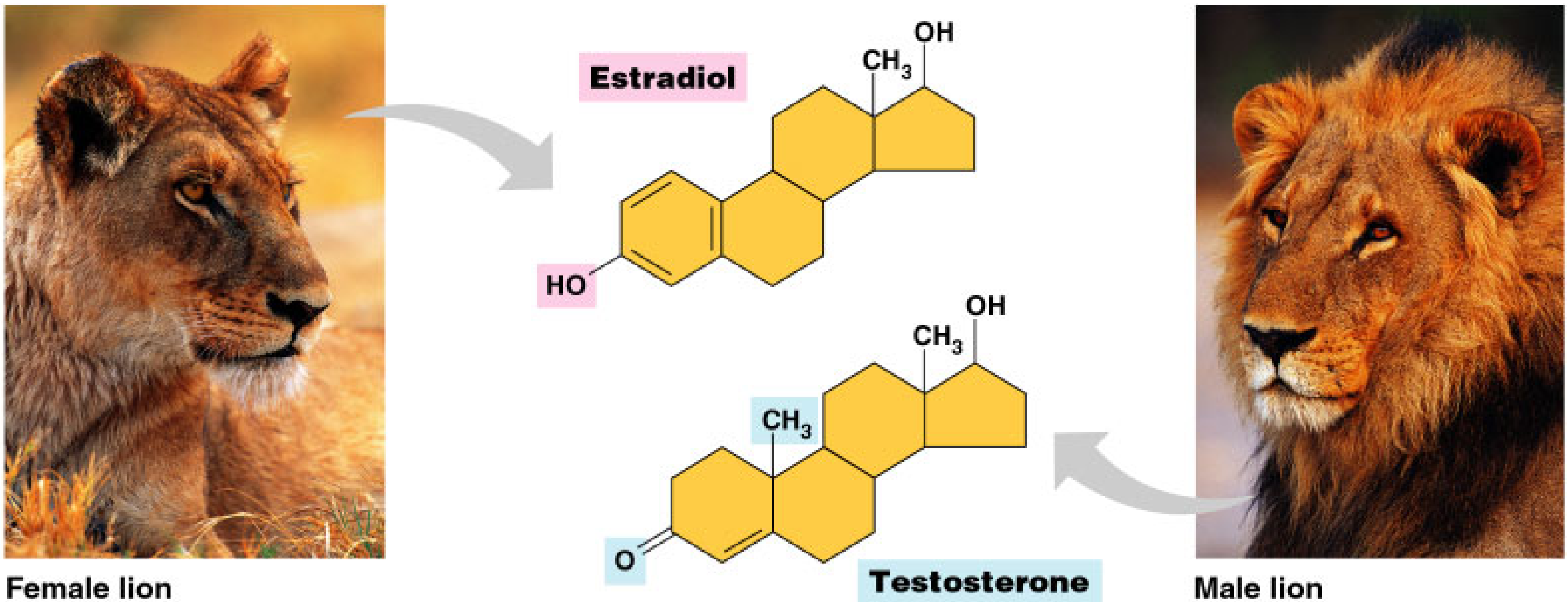
Functional Groups

Functional group	Class of compounds	Structural formula	Example
Hydroxyl —OH	Alcohols		 Ethanol
Aldehyde —CHO	Aldehydes		 Acetaldehyde
Keto >CO	Ketones		 Acetone
Carboxyl —COOH	Carboxylic acids		 Acetic acid

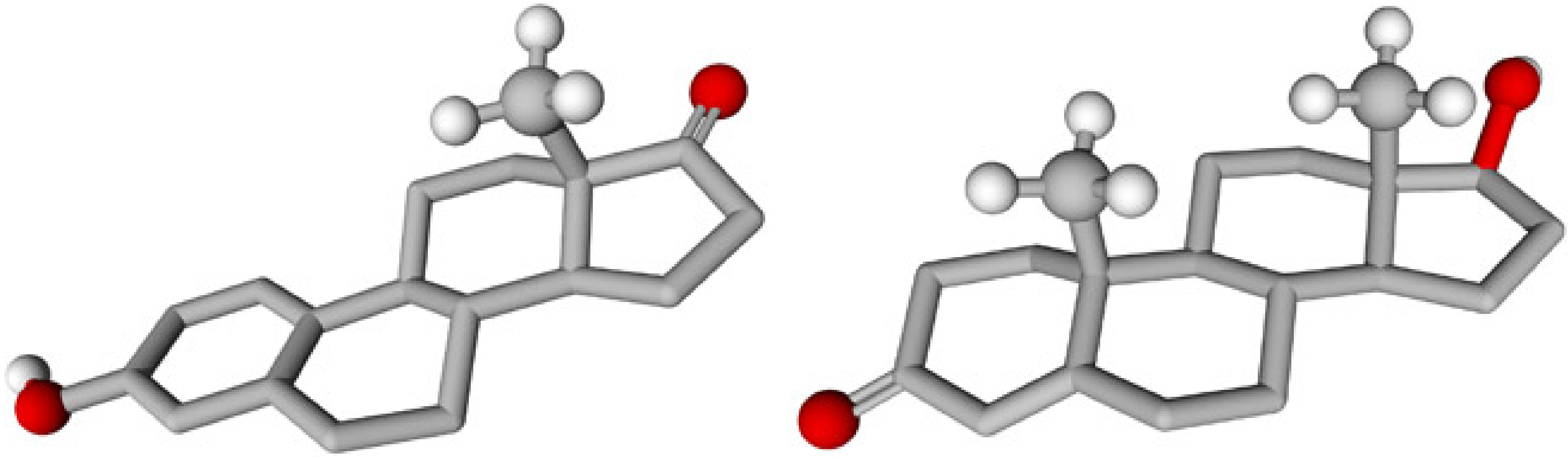
Functional Groups

Functional group	Class of compounds	Structural formula	Example
Amino $-NH_2$	Amines		 Methylamine
Phosphate $-OPO_3^{2-}$	Organic phosphates		 3-Phosphoglyceric acid
Sulfhydryl $-SH$	Thiols	R—SH	 Mercaptoethanol

A comparison of functional groups of female (estradiol) and male (testosterone) sex hormones



Estradiol and Testosterone



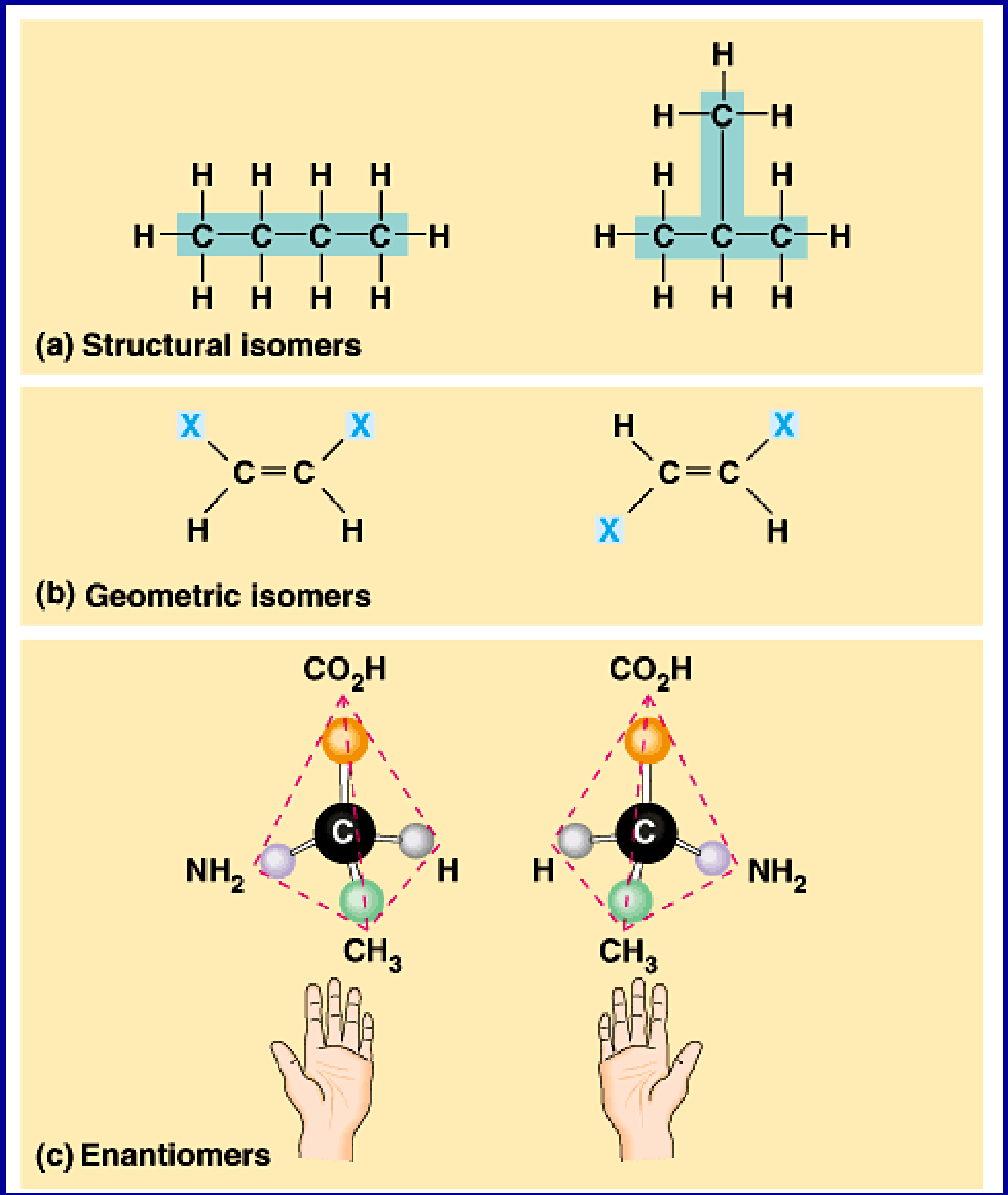
G. Properties of Molecules

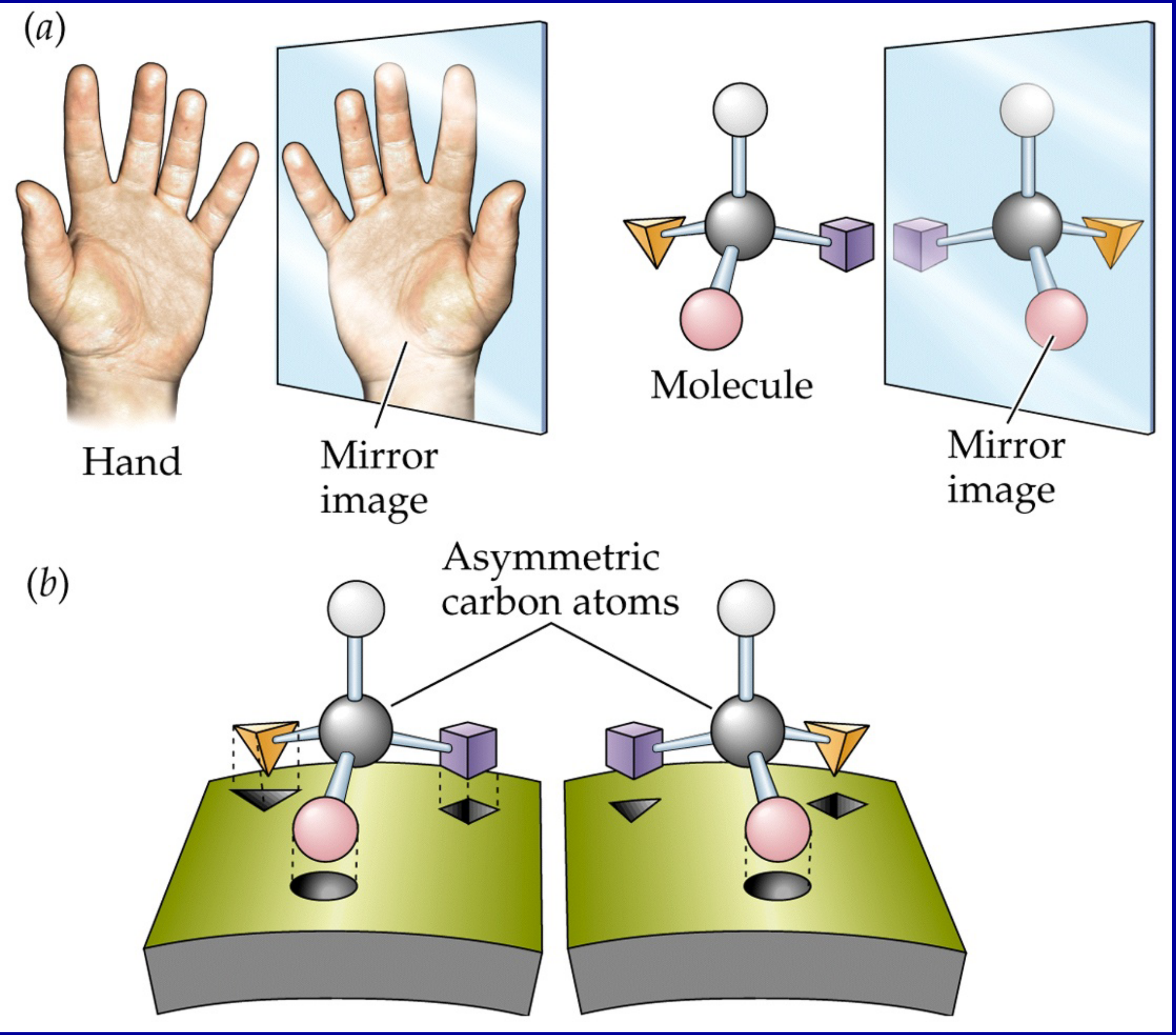
- Structural, geometric and optical isomers have the same kinds and numbers of atoms, but differ in their structures and properties.

G. Properties of Molecules

- Structural isomers: variation in covalent bond arrangement such as butane and isobutane.
- Geometric isomers: variation in the arrangement about a double bond such as with cis or trans configurations.
- Optical isomers: variation in the spatial arrangement around an asymmetric carbon, resulting molecules that are mirror images.

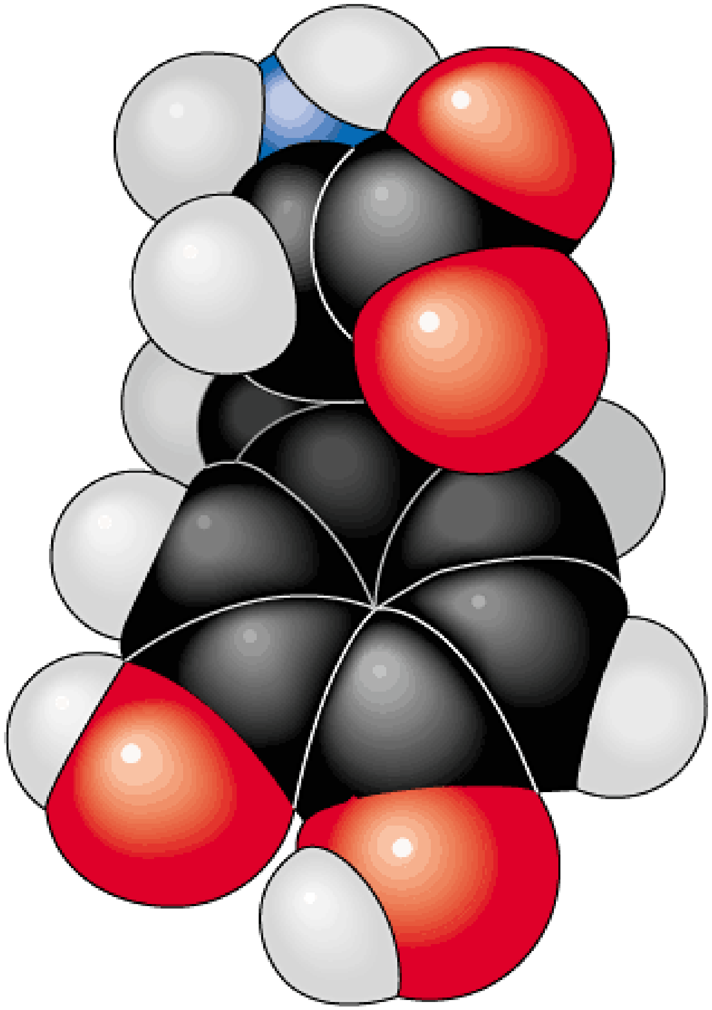
Three types of isomers



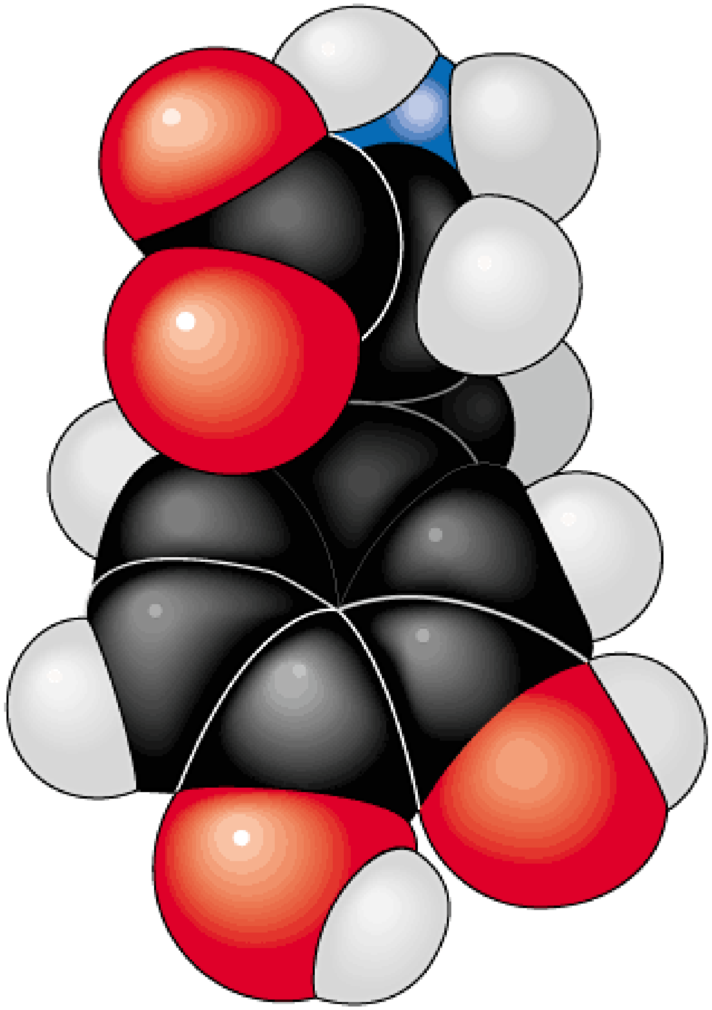


Optical Isomers aka Enantiomers

The pharmacological importance of enantiomers



L-Dopa
(effective against Parkinson's disease)



D-Dopa
(biologically inactive)