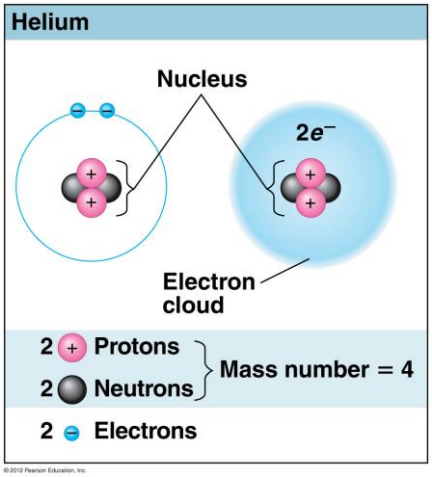
The Chemical Basis of Life

- Levels of organization in life
  organism --> system --> organ --> tissue
  --> cell --> organelle --> molecule
  --> atom, element (matter, space and mass)

1

1). Structure of atoms
proton p+ 質子, neutron nº 中子 => nucleus 原子核
electron e- 電子


Helium
Nucleus
2e⁻
Electron cloud
2 Protons
2 Neutrons
Mass number = 4
2 Electrons

2

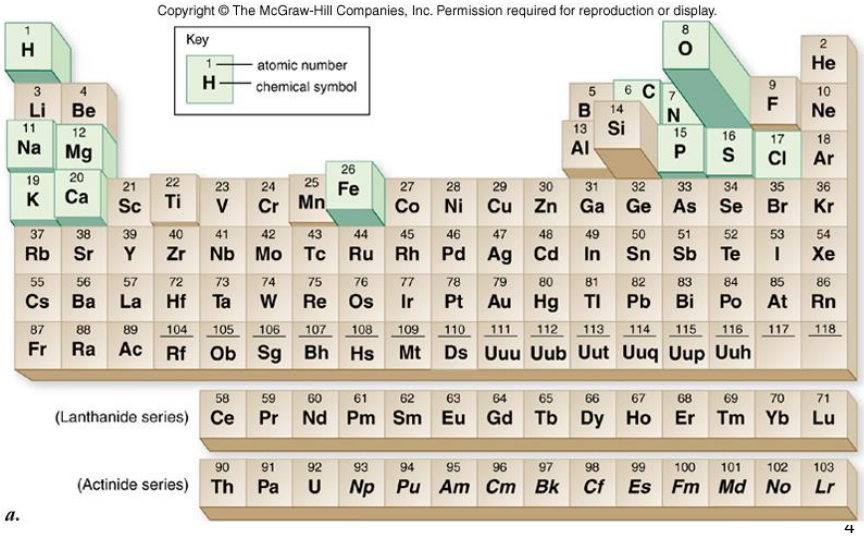
- different elements have different number of protons

atomic number: number of protons
原子序 -> define an element
mass number: number of protons plus neutrons
質量數 ≒ atomic mass 原子量

(one proton or neutron ~ 1.7×10^{-24} g ;
≒ 1 dalton, atomic mass unit, amu)

3

I. Elements (92, so far?) or atoms,
- can not be broken by ordinary chemical means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Key
atomic number
chemical symbol
(Lanthanide series)
(Actinide series)
a.

4

- isotopes: same atomic number (protons)
  同位素 different atomic mass (neutrons)
  identical in chemical reaction

TABLE 2.3 ISOTOPES OF CARBON

	Carbon-12	Carbon-13	Carbon-14
Protons	6	6	6
Neutrons	6	7	8
Electrons	6	6	6
	Mass number 12	Mass number 13	Mass number 14

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^{12}C ^{13}C ^{14}C

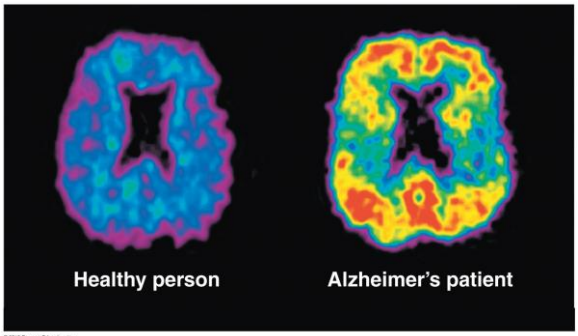
5

- radioactive isotopes
  -> spontaneously decay,
  giving off energy and particles
  -> damage molecules in cells, especially DNA

- easily detected
  -> tracer in basic research and medicine

6

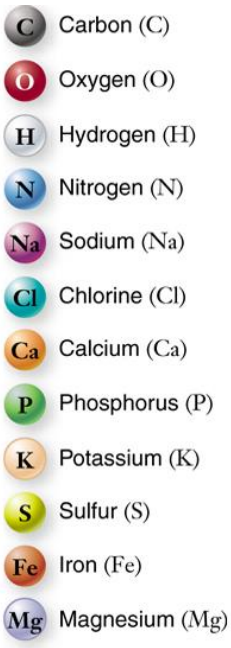
- radioactive isotopes -> easily detected
  -> tracer in basic research and medicine


Healthy person
Alzheimer's patient

PET, positon-emission tomography正子造影

radioactive PIB (**Pittsburgh compound B**, red and yellow) binds to β–amyloid accumulated in Alzheimer patient's brain

7

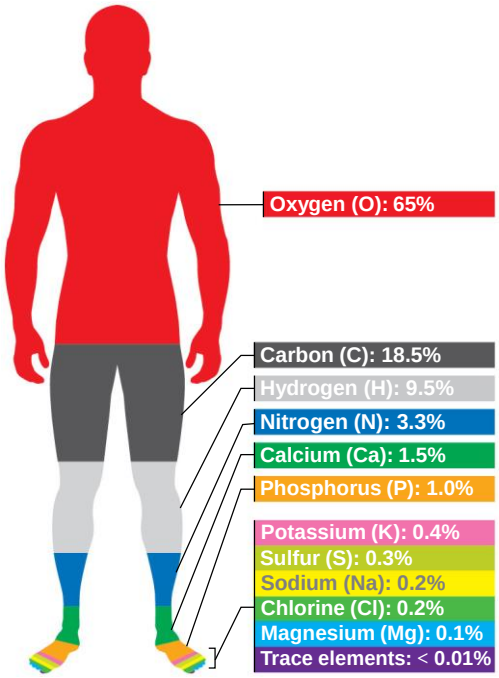

C Carbon (C)
O Oxygen (O)
H Hydrogen (H)
N Nitrogen (N)
Na Sodium (Na)
Cl Chlorine (Cl)
Ca Calcium (Ca)
P Phosphorus (P)
K Potassium (K)
S Sulfur (S)
Fe Iron (Fe)
Mg Magnesium (Mg)

2). 25 of 92 natural elements are essential to life:

O, C, H, N ---> 96.3%
氧, 碳, 氫, 氮
(human body weight)
Ca, P, K, S, Na, Cl, Mg ---> 3.7%
鈣, 磷, 鉀, 硫, 鈉, 氯, 鎂

Trace elements, e.g., Fe, Zn, I, etc.

8


Oxygen (O): 65%
Carbon (C): 18.5%
Hydrogen (H): 9.5%
Nitrogen (N): 3.3%
Calcium (Ca): 1.5%
Phosphorus (P): 1.0%
Potassium (K): 0.4%
Sulfur (S): 0.3%
Sodium (Na): 0.2%
Chlorine (Cl): 0.2%
Magnesium (Mg): 0.1%
Trace elements: < 0.01%

9

2). 25 of 92 natural elements are essential to life:
Trace elements, e.g., Fe, Zn, I, etc.

Trace elements are essential to human health, may be added to food or water

iodine (I) deficiency -> goiter
甲狀腺腫大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2). 25 of 92 natural elements are essential to life:
Trace elements, e.g., Fe, Zn, I, etc.

fluorine (F), in the form of fluoride
-> reduce tooth decay

added in drinking water

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100% CALCIUM
Total
100%
Nutrition
WHOLE GRAIN

Nutrition Facts

Serving Size ¾ cup (30g)
Servings Per Container about 17

Amount Per Serving	Whole Grain Total	with ½ cup skim milk
Calories	100	140
Calories from Fat	5	10
		% Daily Value**
Total Fat 0.5g*	**1%**	**1%**
Saturated Fat 0g	**0%**	**0%**
Trans Fat 0g		
Polyunsaturated Fat 0g		
Monounsaturated Fat 0g		
Cholesterol 0mg	**0%**	**1%**
Sodium 190mg	**8%**	**11%**
Potassium 90mg	**3%**	**8%**
Total Carbohydrate 23g	**8%**	**10%**
Dietary Fiber 3g	**10%**	**10%**
Sugars 5g		
Other Carbohydrate 15g		
Protein 2g		
Vitamin A	10%	15%
Vitamin C	100%	100%
Calcium	100%	110%
Iron	100%	100%
Vitamin D	10%	25%
Vitamin E	100%	100%
Thiamin	100%	100%
Riboflavin	100%	110%
Niacin	100%	100%
Vitamin B_6	100%	100%
Folic Acid	100%	100%
Vitamin B_{12}	100%	110%
Pantothenic Acid	100%	100%
Phosphorus	8%	20%
Magnesium	6%	10%
Zinc	100%	100%
Copper	4%	4%

* Amount in cereal. A serving of cereal plus skim milk provides 1g total fat, less than 5mg cholesterol, 260mg sodium, 290mg potassium, 29g total carbohydrate (11g sugars) and 7g protein.

** Percent Daily Values are based on a 2,000 calorie diet. Your daily values may be higher or lower depending on your calorie needs:

	Calories	2,000	2,500
Total Fat	Less than	65g	80g
Sat Fat	Less than	20g	25g
Cholesterol	Less than	300mg	300mg
Sodium	Less than	2,400mg	2,400mg
Potassium		3,500mg	3,500mg
Total Carbohydrate		300g	375g
Dietary Fiber		25g	30g

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12

Nutrition Facts

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Servings Per Container about 17

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Dietary Fiber 3g	**10%**	**10%**
Sugars 5g		
Other Carbohydrate 15g		
Protein 2g		

Vitamin A	10%	15%
Vitamin C	100%	100%
Calcium	100%	110%
Iron	100%	100%
Vitamin D	10%	25%
Vitamin E	100%	100%
Thiamin	100%	100%
Riboflavin	100%	110%
Niacin	100%	100%
Vitamin B_6	100%	100%
Folic Acid	100%	100%
Vitamin B_{12}	100%	110%
Pantothenic Acid	100%	100%
Phosphorus	8%	20%
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Zinc	100%	100%
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Sodium	Less than	2,400mg	2,400mg
Potassium		3,500mg	3,500mg
Total Carbohydrate		300g	375g
Dietary Fiber		25g	30g

13

II. Compounds & Molecules

two or more elements (atoms) combine to form compounds (molecules)

Sodium | Chlorine | Sodium chloride

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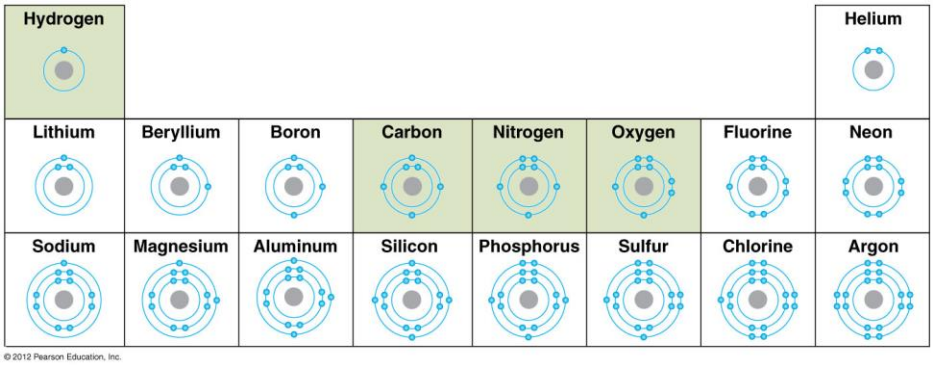
- the chemical behavior of an atom (element) is determined by the number and configuration of electrons


Hydrogen
Helium
Lithium
Beryllium
Boron
Carbon
Nitrogen
Oxygen
Fluorine
Neon
Sodium
Magnesium
Aluminum
Silicon
Phosphorus
Sulfur
Chlorine
Argon
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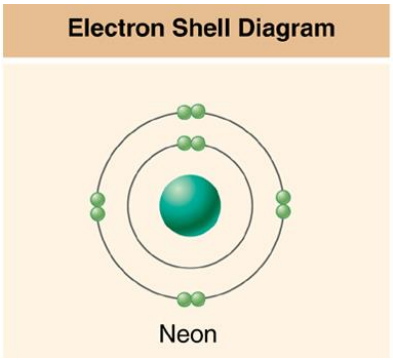
1). Chemical bonds

Electron arrangement in atoms -> shells & orbitals

electron shells --> maxium # of electrons

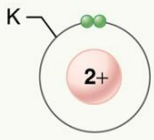
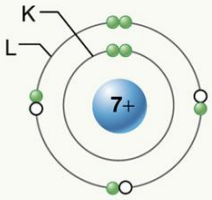
first shell 2 electrons

second shell 8 electrons etc.


Electron Shell Diagram
Neon

16

if not exact number of electrons in the outmost shall
-> tend to interact with other atoms
-> share, donate, or receive electron(s)
-> chemical bonds

Nonreactive	Reactive
2 protons 2 neutrons 2 electrons	7 protons 7 neutrons 7 electrons
 K 2+	 K L 7+
Helium	Nitrogen

17

a. ionic bond 離子鍵 - donate and receive
-> opposite attraction
positive ion Na^+ negative ion Cl^-

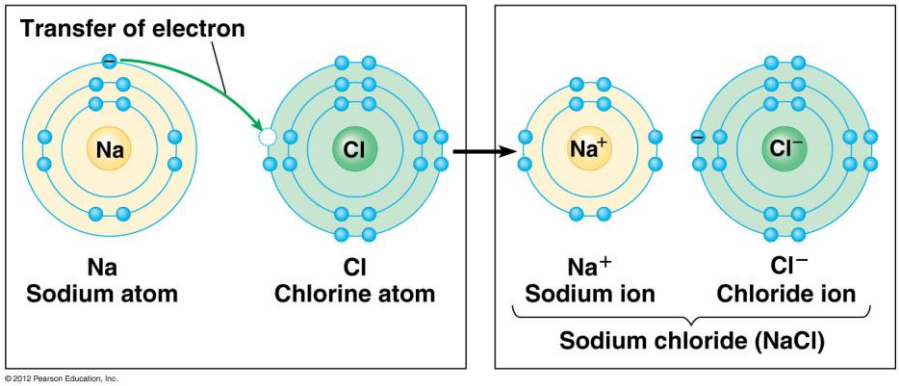

Transfer of electron
Na
Cl
Na
Sodium atom
Cl
Chlorine atom
Na+
Cl−
Na+
Sodium ion
Cl−
Chloride ion
Sodium chloride (NaCl)
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Fig. 2.7

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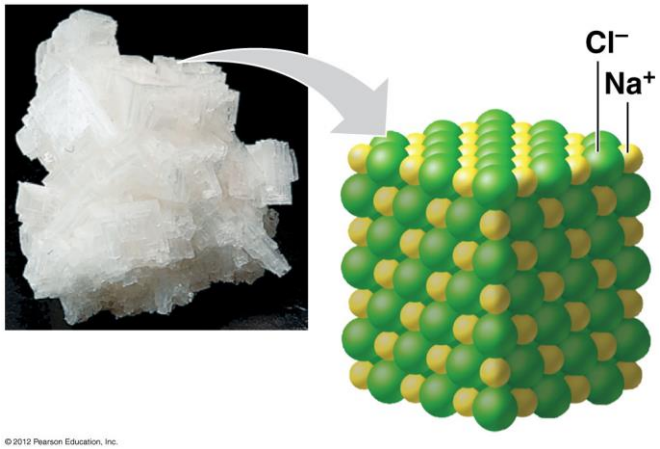
crystal of NaCl


Cl⁻
Na⁺

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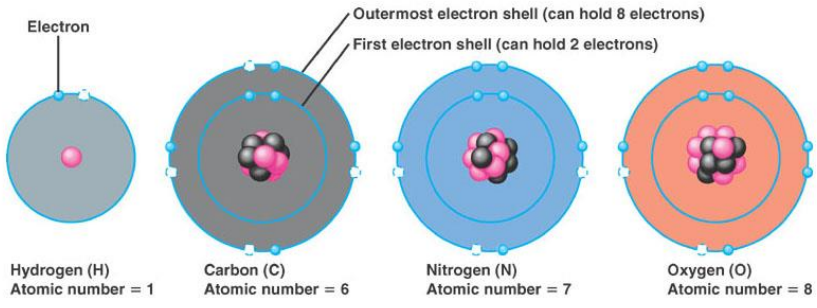
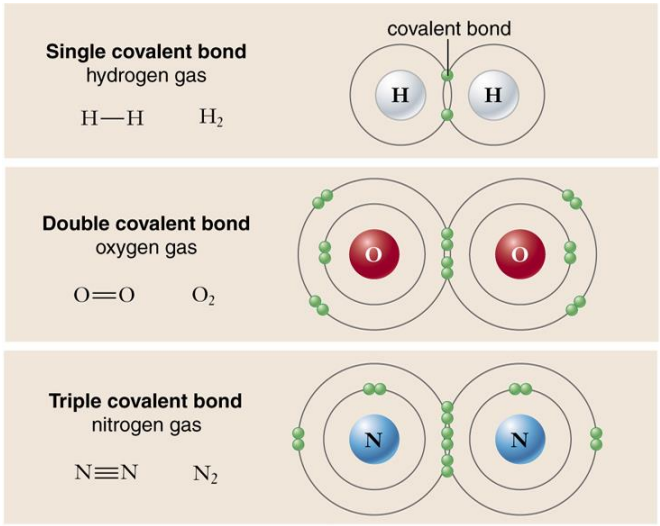
b. covalent bond 共價鍵- sharing electron
single bond, double bond;
polar, non-polar


Electron
Outermost electron shell (can hold 8 electrons)
First electron shell (can hold 2 electrons)
Hydrogen (H)
Atomic number = 1
Carbon (C)
Atomic number = 6
Nitrogen (N)
Atomic number = 7
Oxygen (O)
Atomic number = 8

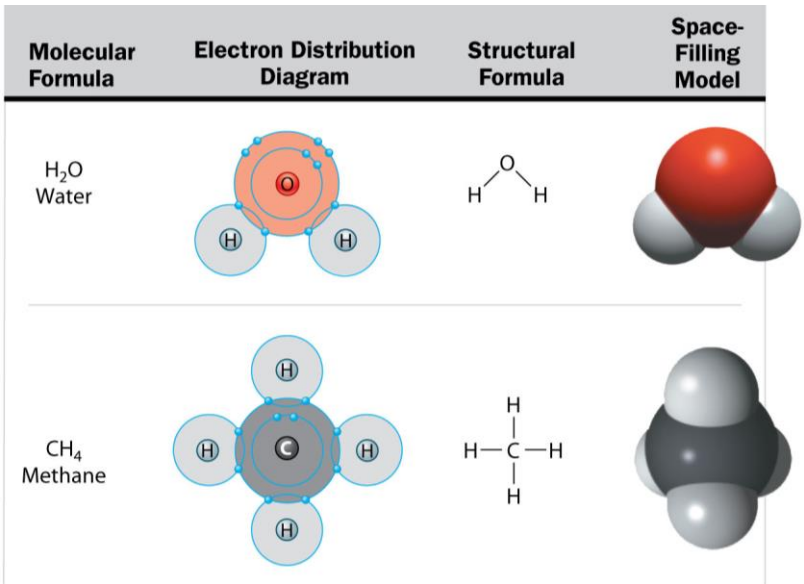
20

b. covalent bond - sharing electron
single bond, double bond; polar, non-polar


Single covalent bond
hydrogen gas
H—H H2
covalent bond
H
H
Double covalent bond
oxygen gas
O=O O2
O
O
Triple covalent bond
nitrogen gas
N≡N N2
N
N

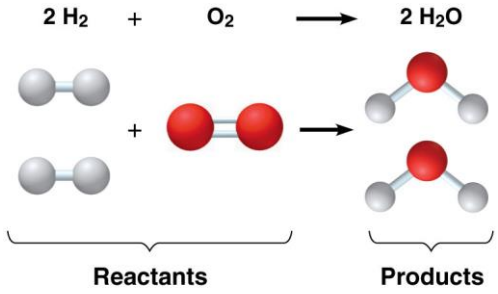
21

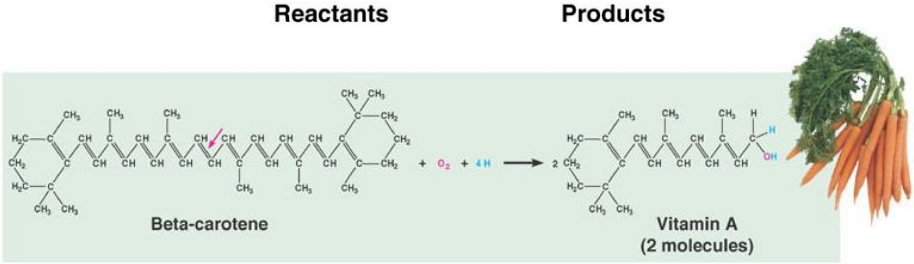
b. covalent bond - sharing electron
single bond, double bond; polar, non-polar


Molecular Formula
Electron Distribution Diagram
Structural Formula
Space-Filling Model
H2O
Water
O
H
H
O
H
H
CH4
Methane
H
H
C
H
H
H
H
C
H
H
H

22

c. chemical reactions rearrange matter,
by making and breaking chemical bonds


2 H2
+
O2
2 H2O
Reactants
Products


Beta-carotene
Vitamin A
(2 molecules)

different electronegativity電負度(affinity for electrons)
-> unequal electron sharing -> polar molecules

TABLE 2.2	Relative Electronegativities of Some Important Atoms
Atom	Electronegativity
O	3.5
N	3.0
C	2.5
H	2.1

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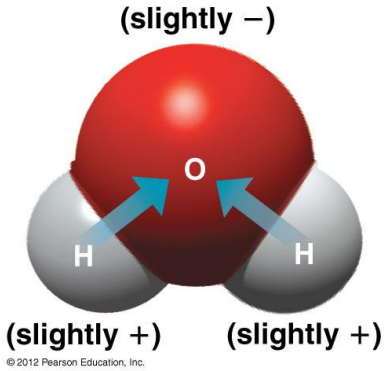
unequal electron sharing -> polar molecules
e.g., H_2O


(slightly −)
O
H
H
(slightly +)
(slightly +)
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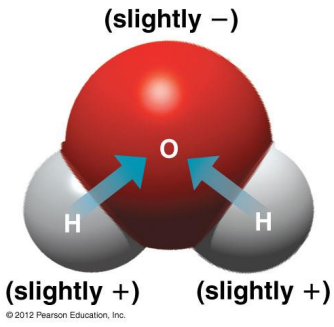
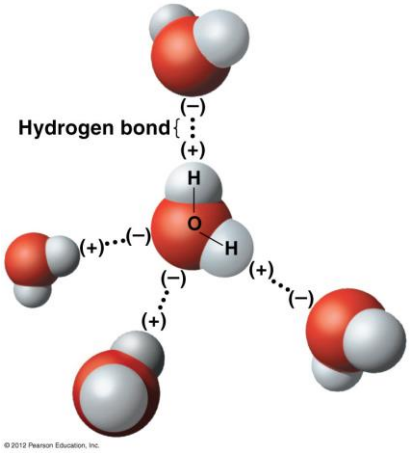
2). hydrogen bond 氫鍵
oppositely charged attraction between neighboring molecules or regions in a macromolecule, hydrogen (H) is involved


(slightly −)
O
H
H
(slightly +)
(slightly +)
© 2012 Pearson Education, Inc.


Hydrogen bond
(−)
(+)
H
O
H
(+)
(−)
(+)
(−)
(+)
(−)
(+)
(−)
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III. Water

1). H_2O, polar molecule, H-bond

2). Important to life,
living organisms contain 60 ~ 90% water

a. Solid

b. Liquid

c. Gas

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III. Water

a. moderate temperature changes

- high specific heat

-> organisms maintain a relatively constant internal temperature

- great heat of vaporization

-> cooling

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III. Water

b. low density of ice -> ice floats

-> prevent lake, even ocean from frozen

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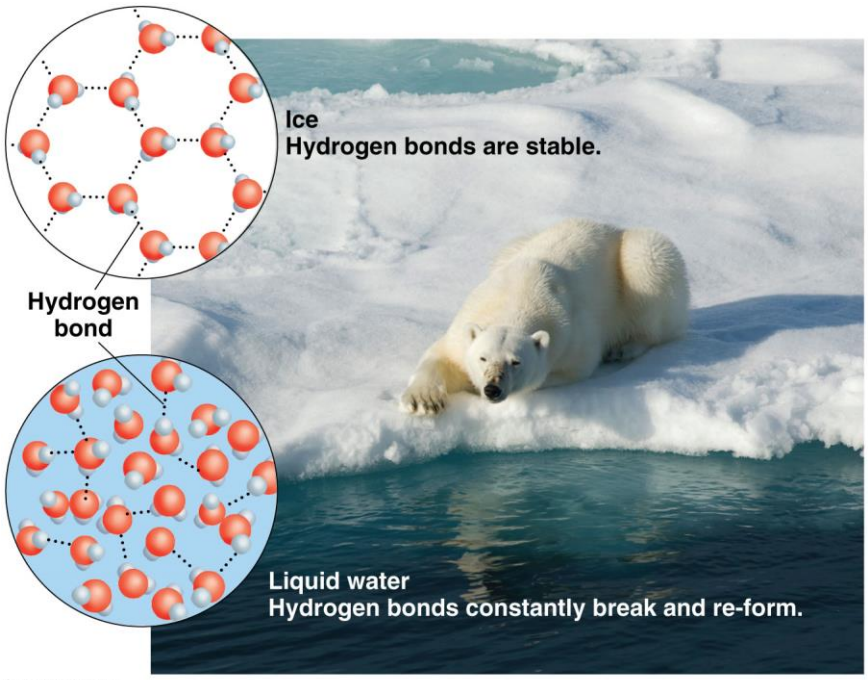
Ice
Hydrogen bonds are stable.
Hydrogen bond
Liquid water
Hydrogen bonds constantly break and re-form.
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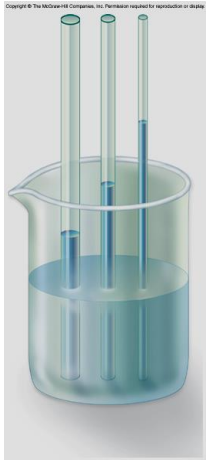
III. Water

c. cohesion --> molecules stick together, 內聚力
adhesion -> attraction to other polar substance
important for water transportation 附著力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III. Water

c. cohesion --> molecules stick together,
adhesion -> attraction to other polar substance
important for water transportation


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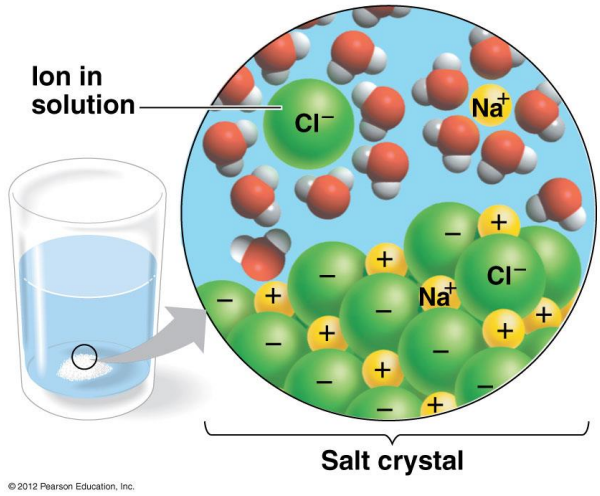
III. Water

d. ideal solvent --> chemical reaction to occur


Ion in solution
Cl⁻
Na⁺
Cl⁻
Na⁺
Salt crystal

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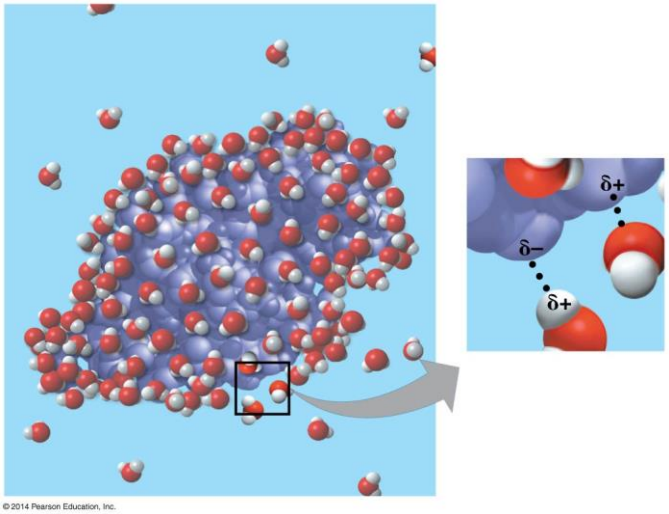
33

e. hydrophobic exclusion

-> organize nonpolar molecules

hydrophilic vs. hydrophobic

skip


δ+
δ−
δ+

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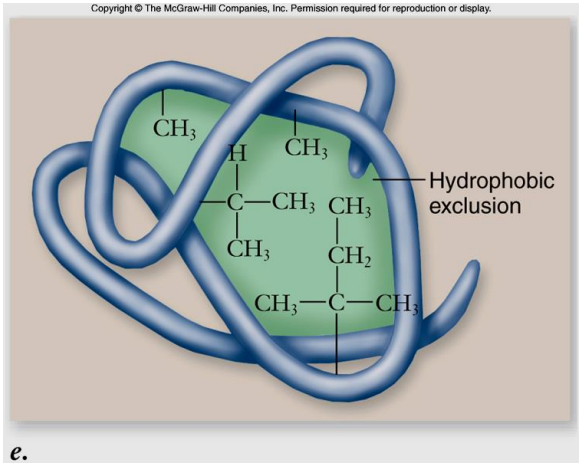
34

e. hydrophobic exclusion
-> organize nonpolar molecules
hydrophilic vs. hydrophobic

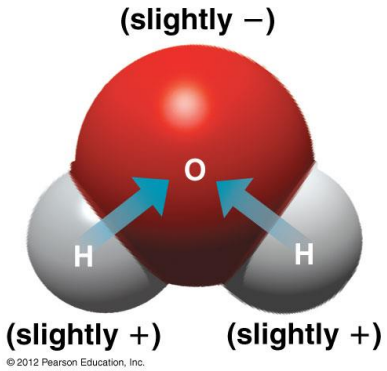
skip


Copyright © The McGraw-Hill Companies, Inc. Permission required for reproduction or display.
CH3
H
CH3
C—CH3
CH3
CH3
CH2
CH3—C—CH3
Hydrophobic exclusion
e.

35

III. Water

§ All of the above are due to the polarity and H-bond of water molecules


(slightly −)
O
H
H
(slightly +)
(slightly +)
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3). Acid, base & buffer

H_2O <--> $H^+ + OH^-$

the balance of H^+ and OH^- is critical to life

a. acid: H^+ donor, HCl --> $H^+ + Cl^-$

base: H^+ acceptor, NaOH --> $Na^+ + OH^-$

b. pH value: the acidity of a solution

$pH = - \log [H^+]$

pure water, $[H^+]$: 10^{-7} mole / liter, neutral

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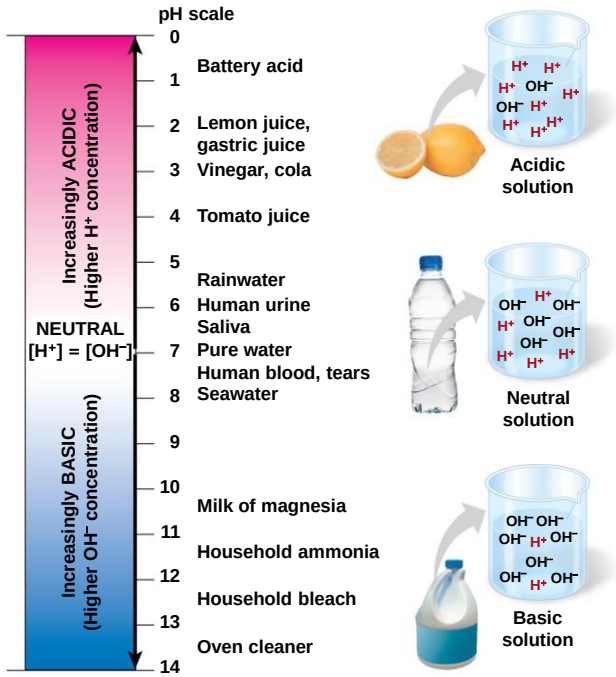
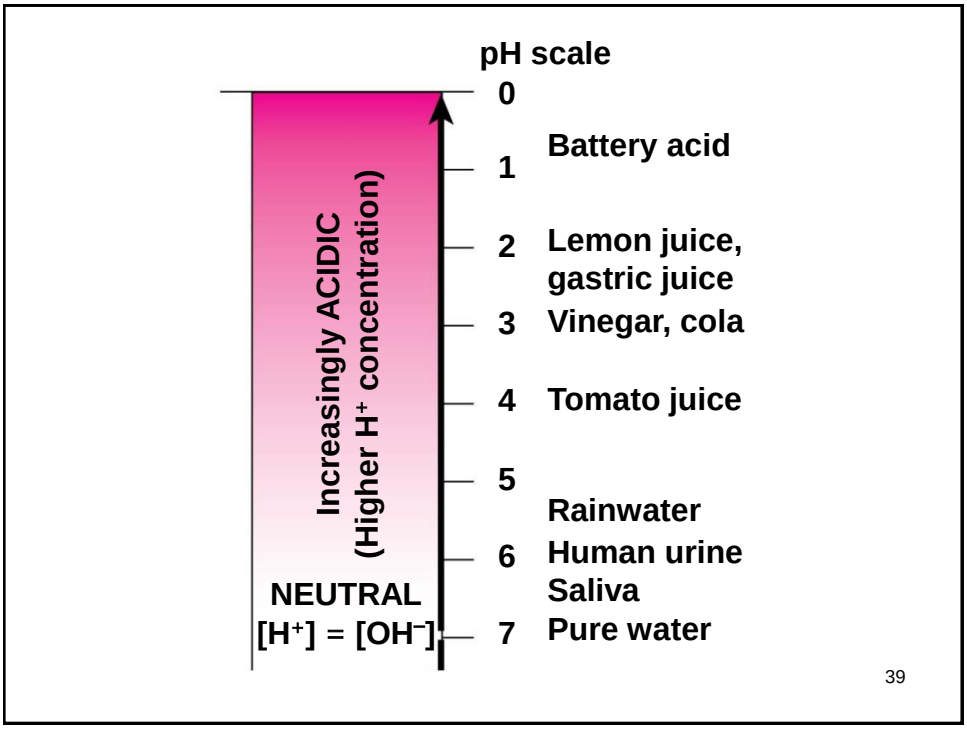
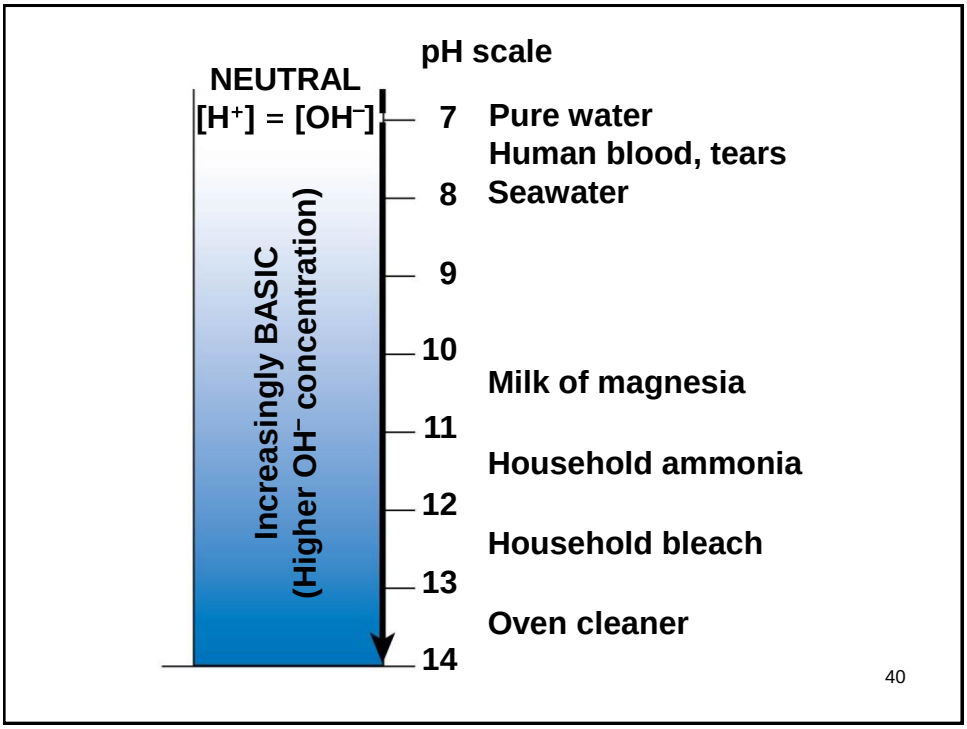

pH scale
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Increasingly ACIDIC (Higher H+ concentration)
NEUTRAL [H+] = [OH–]
Increasingly BASIC (Higher OH– concentration)
Battery acid
Lemon juice, gastric juice
Vinegar, cola
Tomato juice
Rainwater
Human urine
Saliva
Pure water
Human blood, tears
Seawater
Milk of magnesia
Household ammonia
Household bleach
Oven cleaner
Acidic solution
Neutral solution
Basic solution

38


pH scale
0
1
2
3
4
5
6
7
Battery acid
Lemon juice, gastric juice
Vinegar, cola
Tomato juice
Rainwater
Human urine
Saliva
Pure water
Increasingly ACIDIC (Higher H+ concentration)
NEUTRAL
[H+] = [OH–]

39


pH scale
NEUTRAL
[H+] = [OH–]
7
8
9
10
11
12
13
14
Pure water
Human blood, tears
Seawater
Milk of magnesia
Household ammonia
Household bleach
Oven cleaner
Increasingly BASIC (Higher OH– concentration)

40

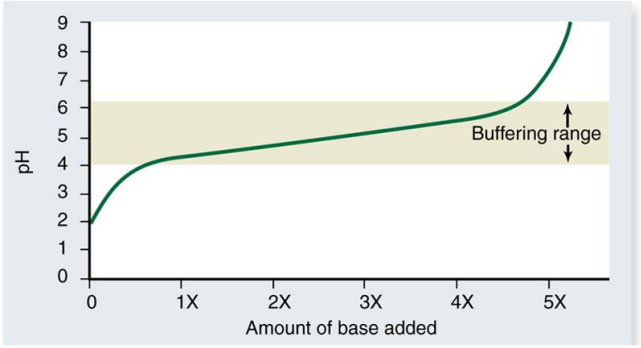
3). Acid, base & buffer

H_2O --> H^+ + OH^-

the balance of H^+ and OH^- is critical to life

c. buffers:

substances that minimizes changes in pH, by accepting or donating H^+;


pH
9
8
7
6
5
4
3
2
1
0
Buffering range
0
1X
2X
3X
4X
5X
Amount of base added

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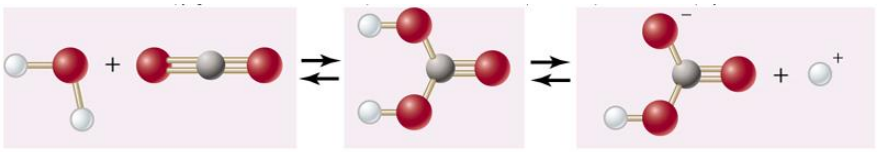
c. buffers:

biological fluids contain buffers to keep pH stable

a drop of acid into 1 liter water 7.0 -> 2.0

in human blood: 7.4 -> 7.3


Water (H_2O)
+
Carbon dioxide (CO_2)
Carbonic acid (H_2CO_3)
Bicarbonate ion (HCO_3^-)
+
Hydrogen ion (H^+)

碳酸　　碳酸氫根

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§ Acid precipitation
- rain or snow with a pH below 5.6 (up to 2 or 3)
- burning of fossil fuels
  -> sulfur oxides, nitrogen oxides react with water
  -> sulfuric and nitric acids

damage caused by acid precipitation



§ Ocean acidification
-> decrease carbonate ion ($H^+ + CO_3^{2-}$)
-> affect skeleton or shell production of coral, salmon, and other fishes

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