Lecture 2
The Material Basis of Life

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Lecture outline

- **Basic chemistry**
- **A small molecule**
- **Macromolecules**

A Chemical Connection to Biology

- Living organisms and their environments are subject to basic laws of **physics** and **chemistry**

The Elements of Life

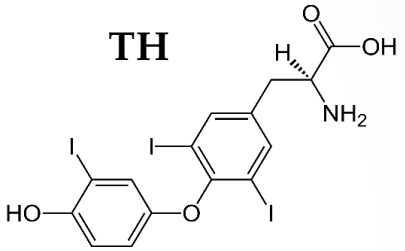
- About 20–25% of the 92 elements are essential to life
- **Carbon, hydrogen, oxygen,** and **nitrogen** make up 96% of living matter (on the planet: <1% total)
- Most of the remaining 4% consists of calcium, phosphorus, potassium, and sulfur
- **Trace elements** 微量元素 are required by in only minute quantities

Element	Symbol	Percentage of Body Mass (including water)	
Oxygen	O	65.0%	96.3%
Carbon	C	18.5%	
Hydrogen	H	9.5%	
Nitrogen	N	3.3%	
Calcium	Ca	1.5%	3.7%
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 (less than 0.01% of mass): Boron (B), chromium (Cr), cobalt (Co), copper (Cu), fluorine (F), iodine (I), iron (Fe), manganese (Mn), molybdenum (Mo), selenium (Se), silicon (Si), tin (Sn), vanadium (V), zinc (Zn)

Iodine 碘

- Thyroid Hormones甲状腺激素
  - Increases heart rate
  - Increases ventilation rate
  - Increases basal metabolic rate
  - Potentiates brain development



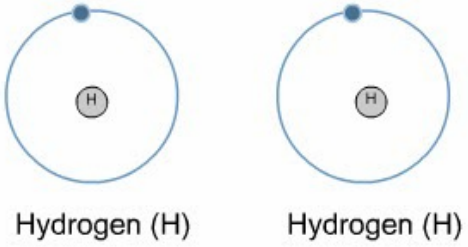
- Iodine is necessary for TH synthesis

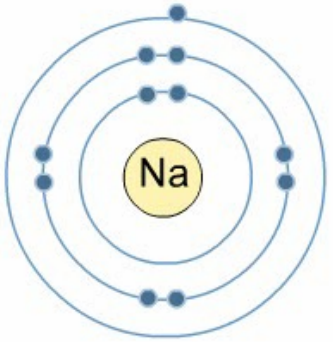

因缺碘而造成的甲状腺肿

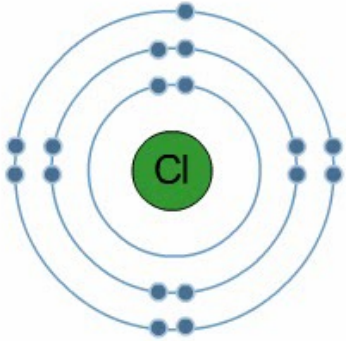
- Source of iodine: food
- Lack of iodine: iodine deficiency disorders， IDD（碘缺乏病）
- Excessive iodine: hyperthyroidism（甲状腺功能亢进）

Chemical bonds

- **covalent bond** 共价键
- **Ionic bond** 离子键

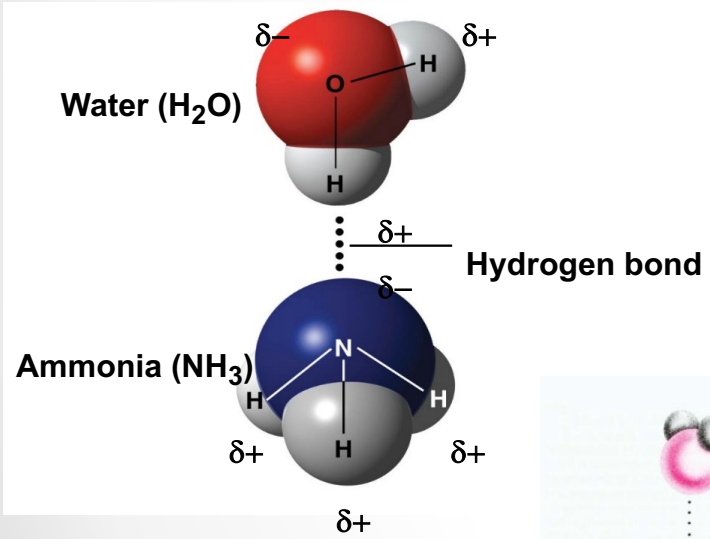


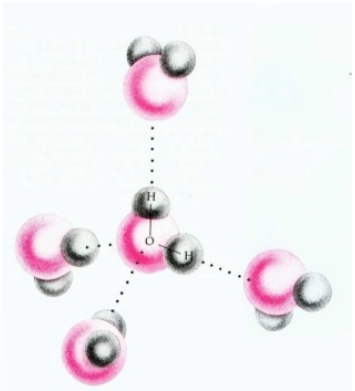




Weak Chemical Bonds

- **Hydrogen bond 氢键**
  - Hydrophilic 亲水性
  - Hydrophobic 疏水性





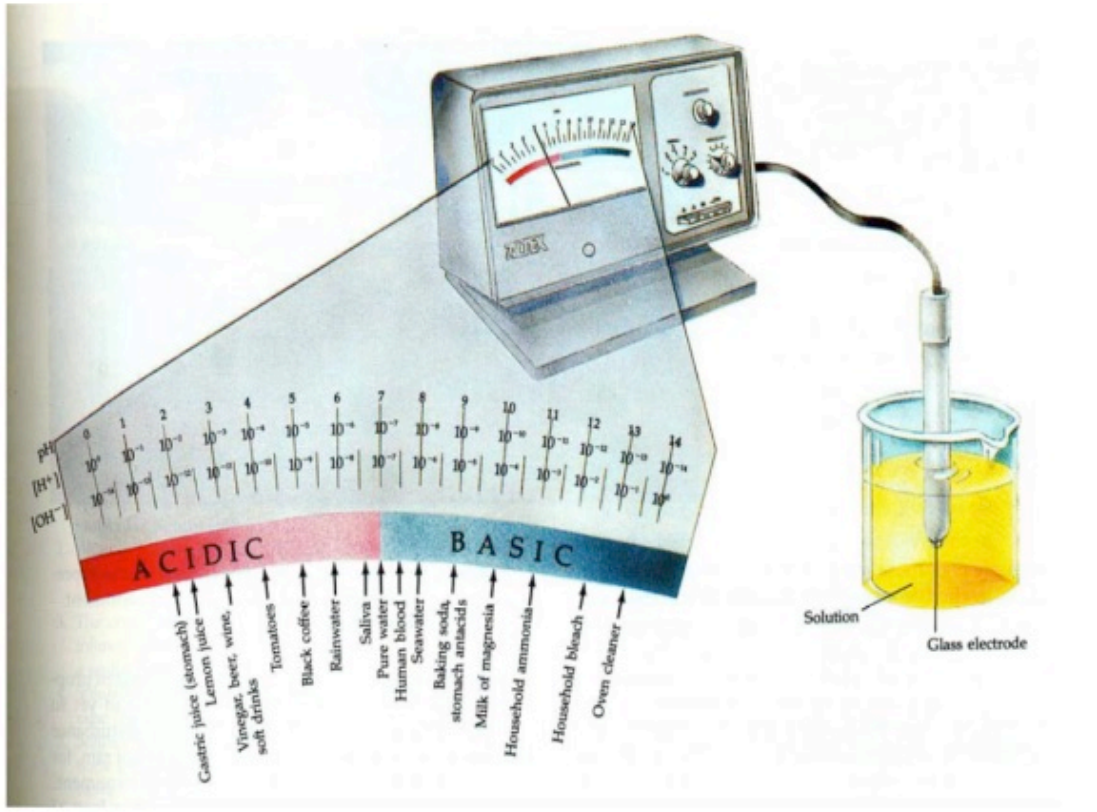
- **Van der Waals interactions范德华力** are attractions between molecules that are close together

A small molecule

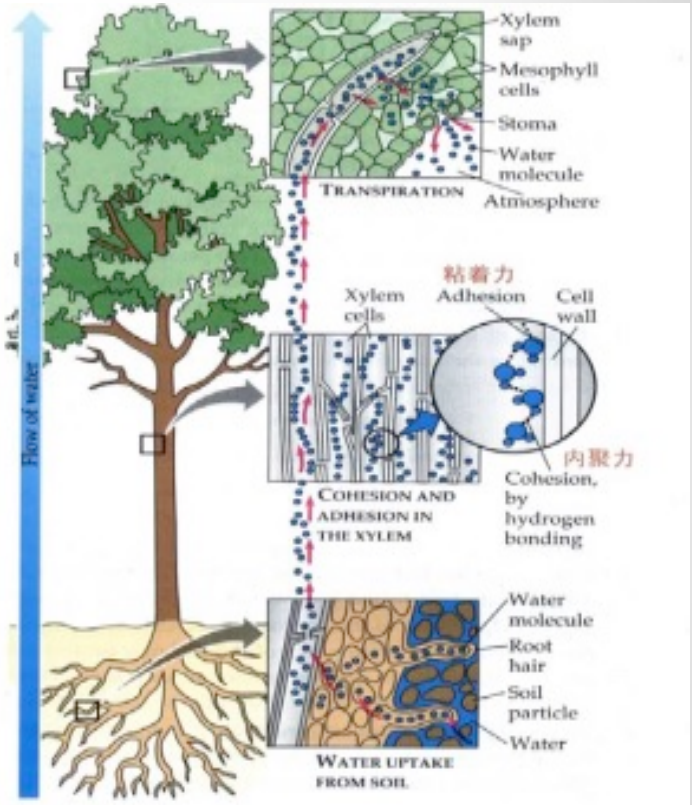
- Four of water’s properties that facilitate an environment for life
  - Versatility as a solvent
  - Cohesive behavior
  - Ability to moderate temperature
  - Expansion upon freezing

pH of common solutions

	pH
胃液	1.6
柠檬汁	2.0
醋, wine	3
番茄汁	4
雨水	5.6
唾液	6.6
纯水	7.0
海水	8
抗胃酸药	9
氨清洁剂	11



Adhesion and Cohesion 粘附作用



1）植物的蒸腾作用对养分输送与水的吸收十分重要；

2）水的蒸腾作用主要利用了水分子的化学特性；

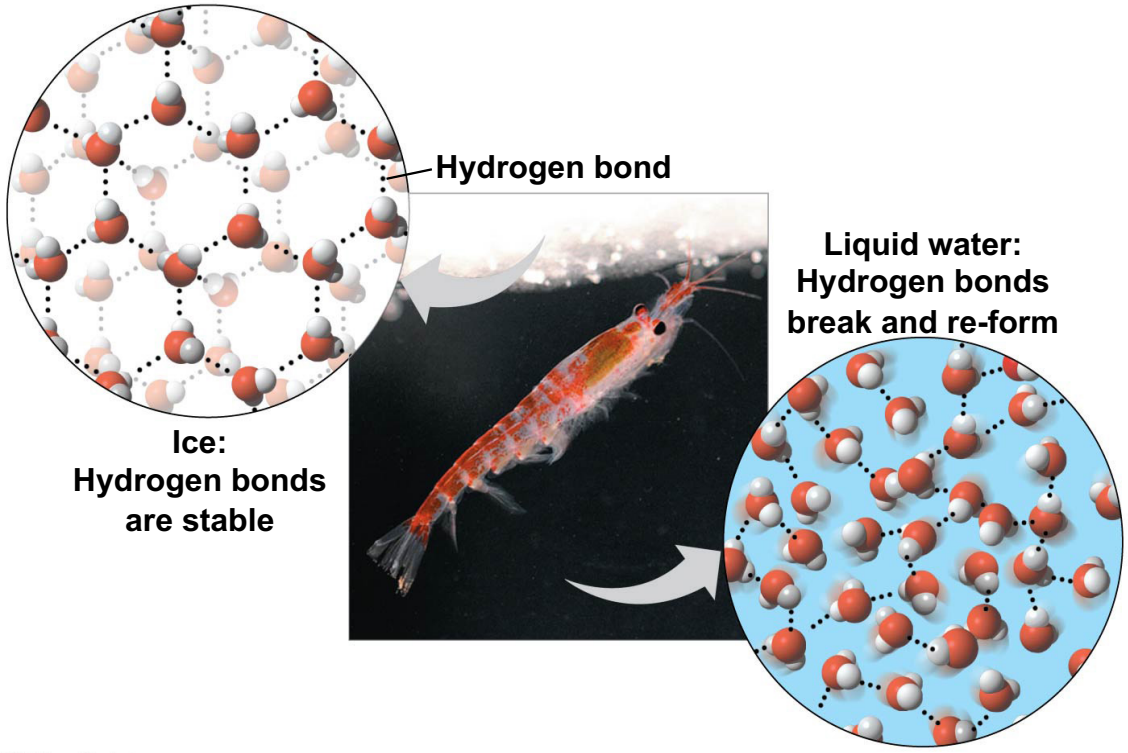
3）水的吸附作用可使土壤涵养水分。

Temperature and Heat

- A **calorie (cal)** is the amount of heat required to raise the temperature of 1 g of water by 1°C
- The "calories" on food packages are actually **kilocalories (kcal)**, where 1 kcal = 1,000 cal
- The high specific heat of water minimizes temperature fluctuations to within limits that permit life （水的特征：高比热）
- Evaporative cooling of water helps stabilize temperatures in organisms and bodies of water（水的特征：高蒸发热）

Floating of Ice on Liquid Water

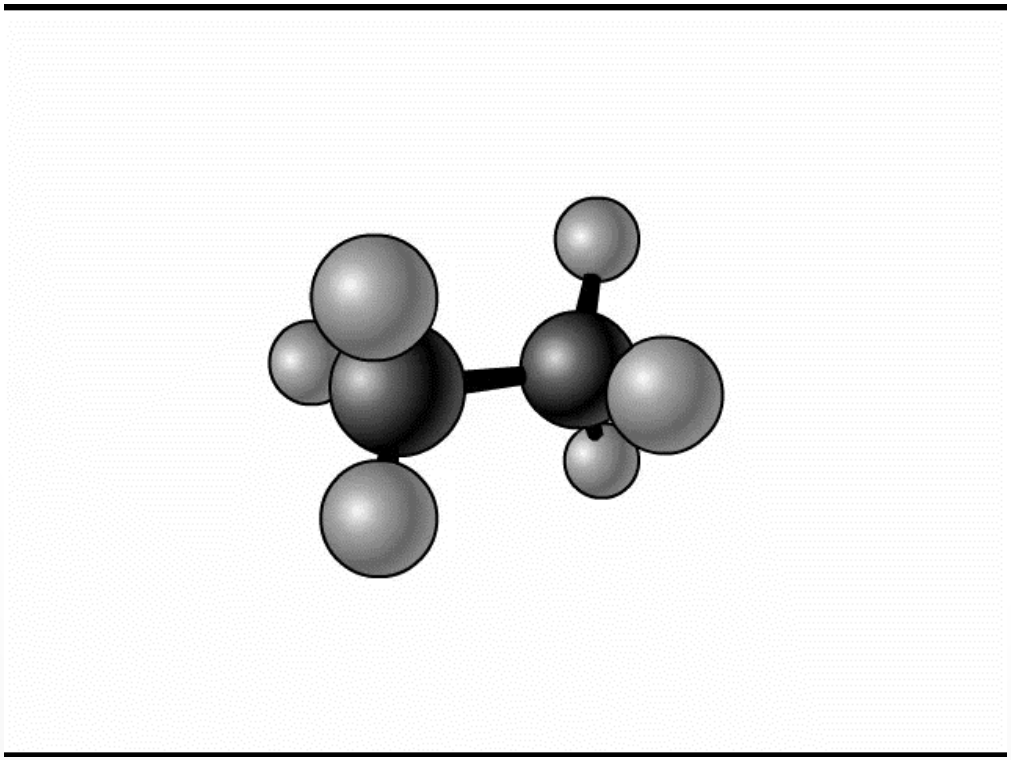
- Ice floats in liquid water because hydrogen bonds in ice are more "ordered," making ice less dense than water
- Water reaches its greatest density at 4°C



Properties of water

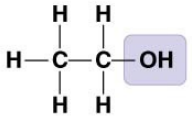
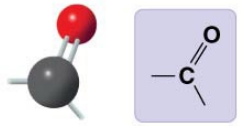
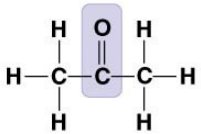
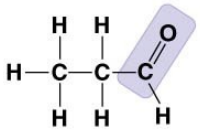
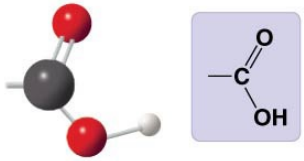
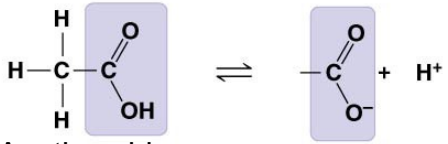
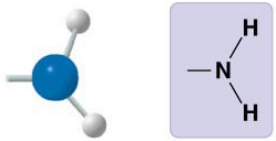
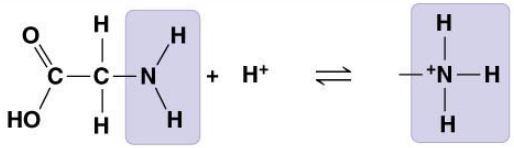
Carbon: The Backbone of Life

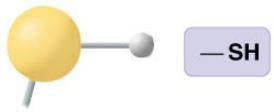
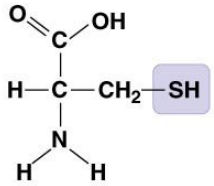
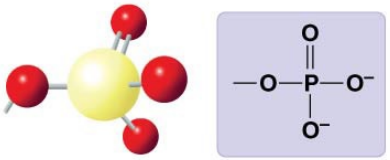
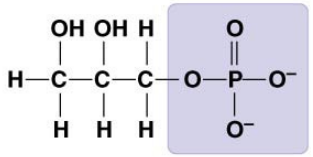
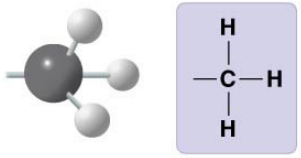
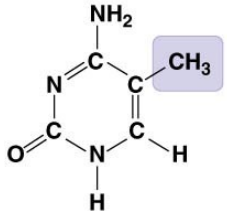
- Living organisms consist mostly of carbon-based compounds
- Proteins, DNA, carbohydrates, and other molecules that distinguish living matter are all composed of carbon compounds



Seven functional groups that are most important in the chemistry of life

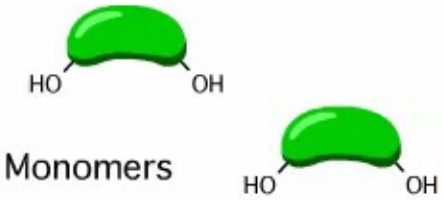
- Hydroxyl group
- Carbonyl group
- Carboxyl group
- Amino group
- Sulfhydryl group
- Phosphate group
- Methyl group

Chemical Group		Examples
Hydroxyl group (—OH) 	羟基（醇） Forms hydrogen bonds with water.	 Ethanol
Carbonyl group (C = O) 	羰基（酮） 醛基（醛）	 Acetone  Propanal
Carboxyl group (—COOH) 	羧基（酸）	 Acetic acid
Amino group ($—NH_2$) 	氨基（胺）	 Glycine

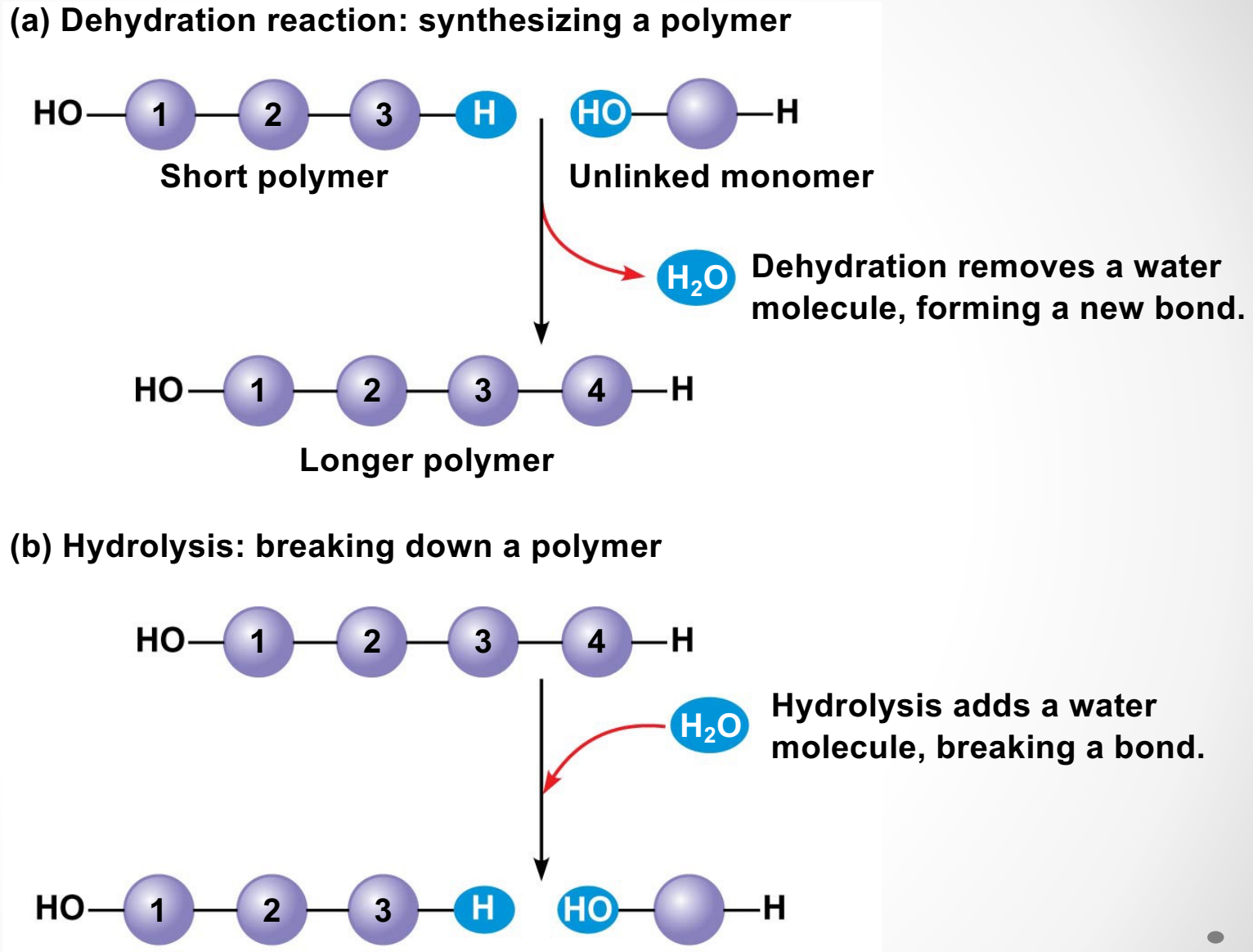
Chemical Group		Examples
Sulfhydryl group (—SH) 	巯基（硫醇） Two -SH groups can form a “cross-link” that stabilizes protein structure.	 Cysteine
Phosphate group ($—OPO_3^{2-}$) 	磷酸基团（磷酸酯） Negative charge. When attached: can react with water, releasing energy.	 Glycerol phosphate
Methyl group ($—CH_3$) 	甲基（甲基化复合物） Affects gene expression. Affects shape and function of sex hormones.	 5-Methyl cytosine

- Polymerization 聚合反应
- Carbohydrate 碳水化合物/糖
- Lipid 脂类化合物
- Protein 蛋白质
- Nucleic acids 核酸
  - DNA （脱氧核糖核酸）
  - RNA （核糖核酸）

Polymers 聚合物



脱水反应
（合成反应）



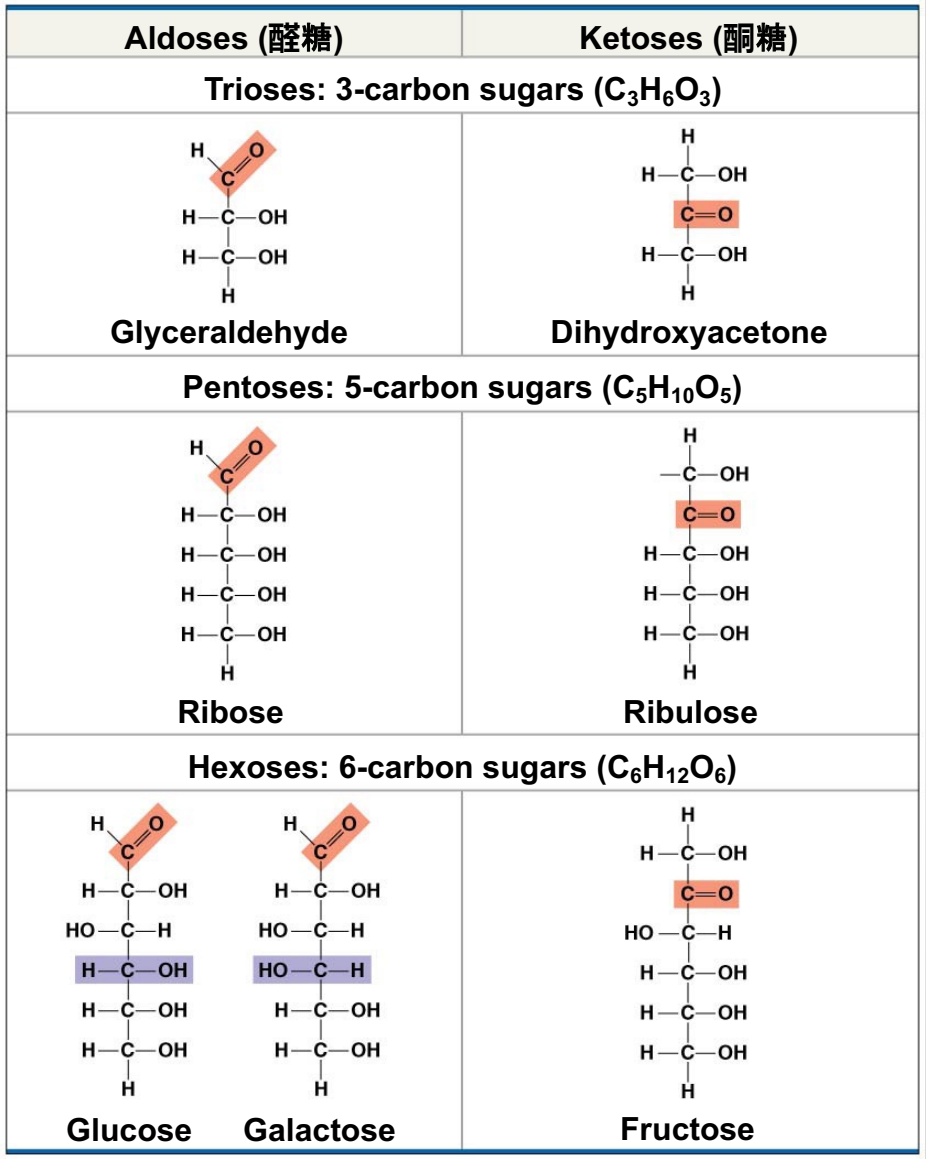
水解反应
（分解反应）

Carbohydrate 碳水化合物: fuel and building material

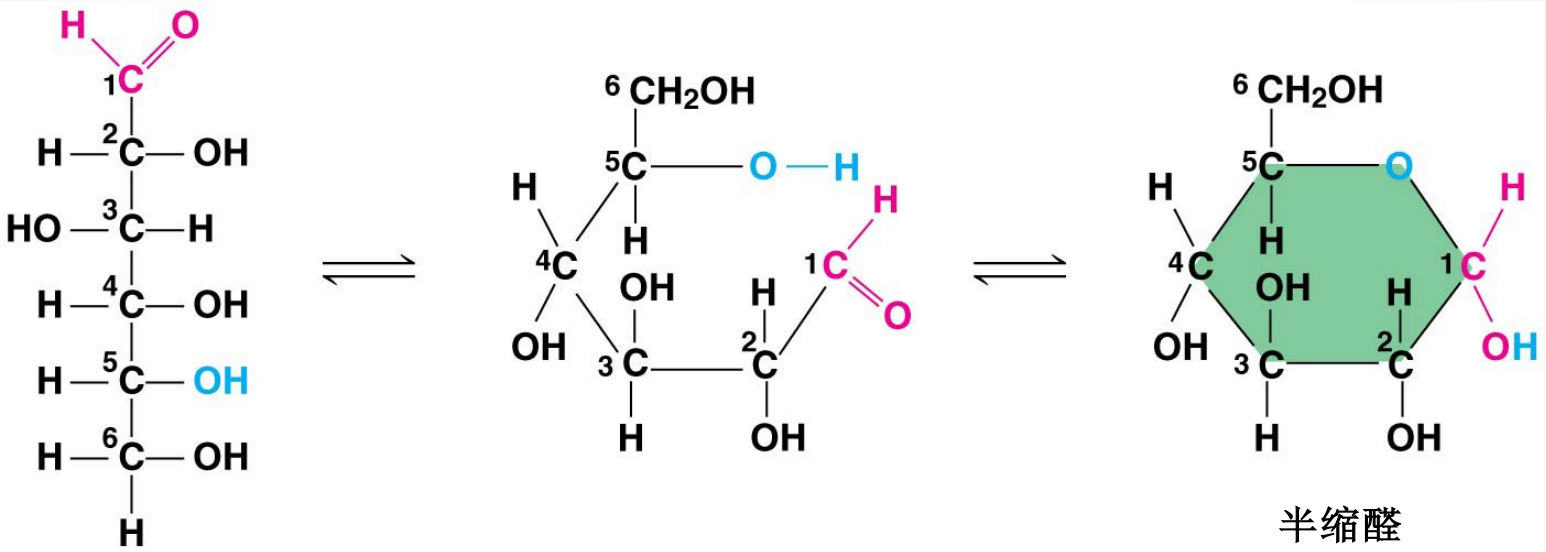
- Monosaccharides or simple sugars 单糖
- Disaccharide 二糖
- Polysaccharide 多糖

Monosaccharide 单糖

- Monosaccharides have molecular formulas that are usually multiples of CH_2O
- Glucose ($C_6H_{12}O_6$) is the most common monosaccharide
- Monosaccharides are classified by
  - The location of the carbonyl group (as aldose 醛糖 or ketose 酮糖)
  - The number of carbons in the carbon skeleton （五碳糖、六碳糖…）

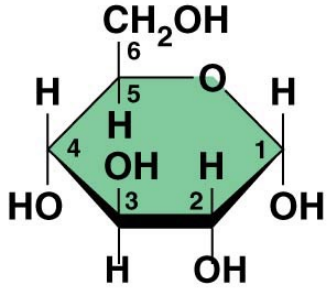


Glucose 葡萄糖



半缩醛

(a) Linear and ring forms



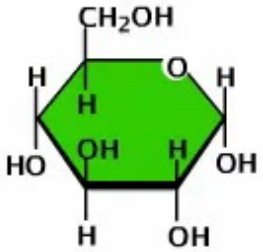
(b) Abbreviated ring structure

Disaccharides 双糖

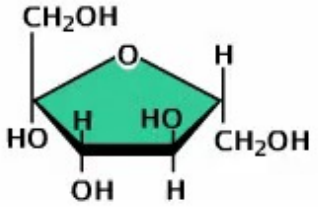
蔗糖

乳糖

麦芽糖



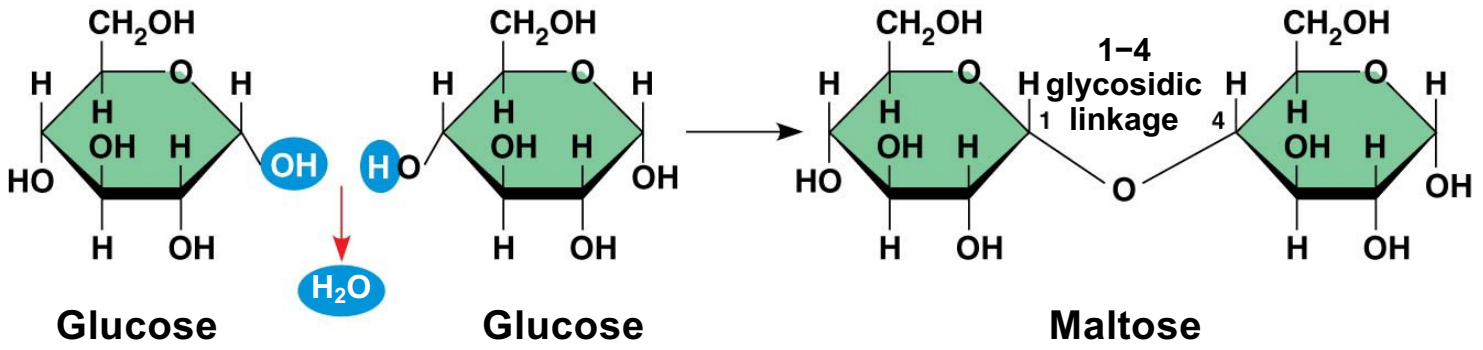
Glucose



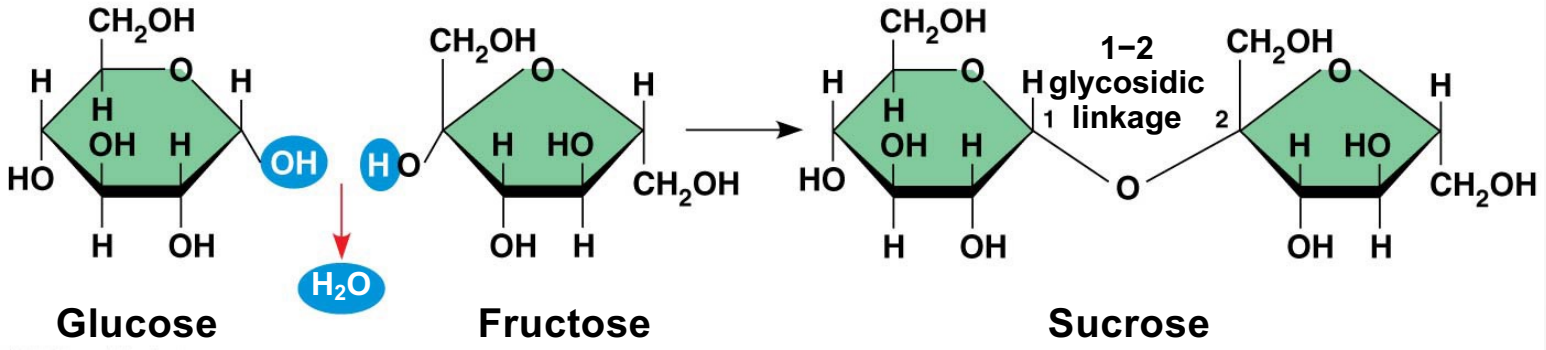
Fructose

Synthesis of Disaccharides

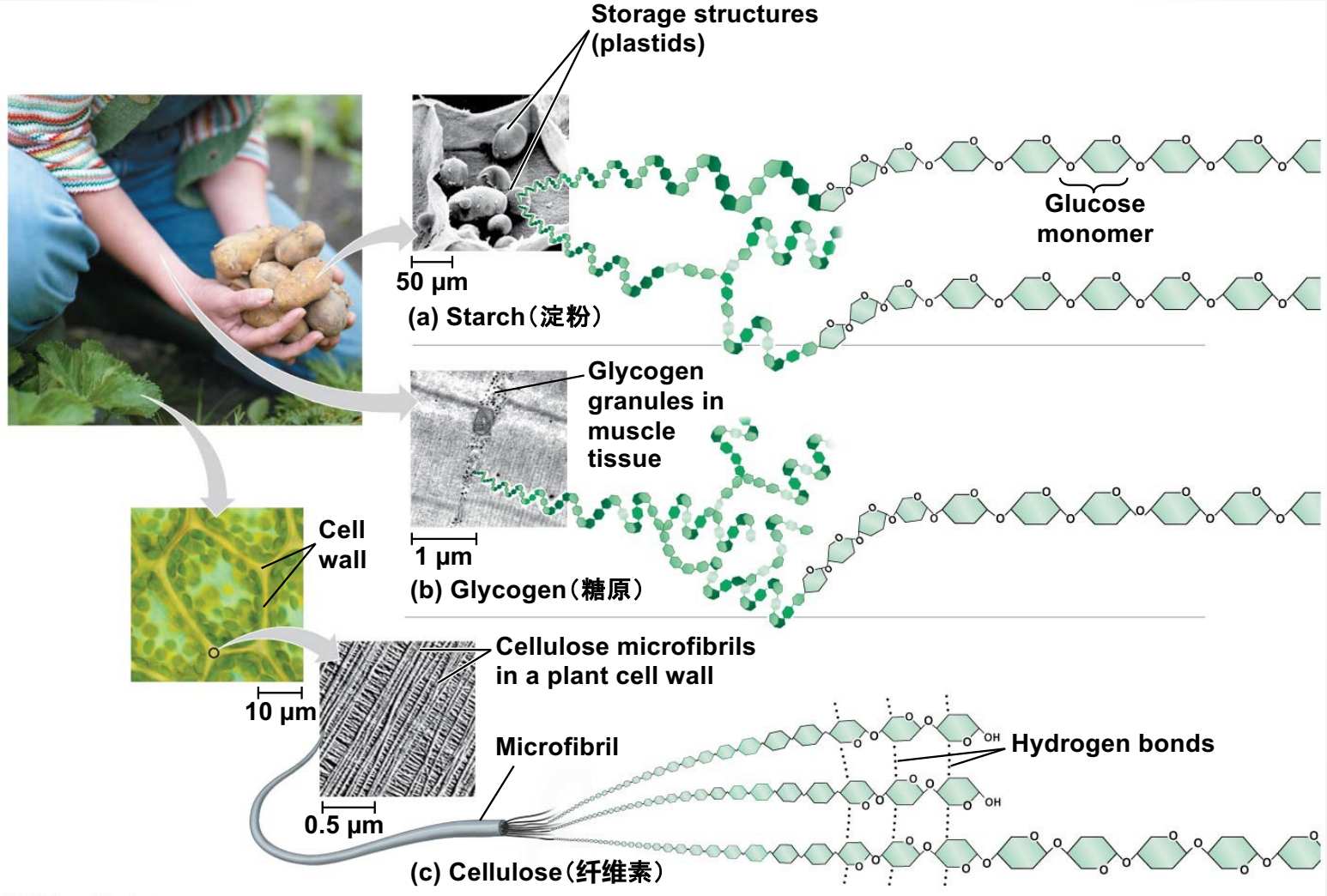
(a) Dehydration reaction in the synthesis of maltose（麦芽糖）



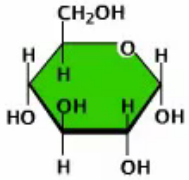
(b) Dehydration reaction in the synthesis of sucrose（蔗糖）



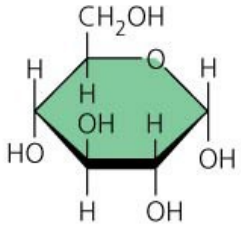
Polysaccharides 多糖



Polysaccharides



Summary: Carbohydrates

Large Biological Molecules	Components	Examples	Functions
Carbohydrates serve as fuel and building material (pp. 68–72)	 Monosaccharide monomer	**Monosaccharides:** glucose, fructose	Fuel; carbon sources that can be converted to other molecules or combined into polymers
		Disaccharides: lactose, sucrose	
		Polysaccharides: • Cellulose (plants) • Starch (plants) • Glycogen (animals) • Chitin (animals and fungi)	• Strengthens plant cell walls • Stores glucose for energy • Stores glucose for energy • Strengthens exoskeletons and fungal cell walls

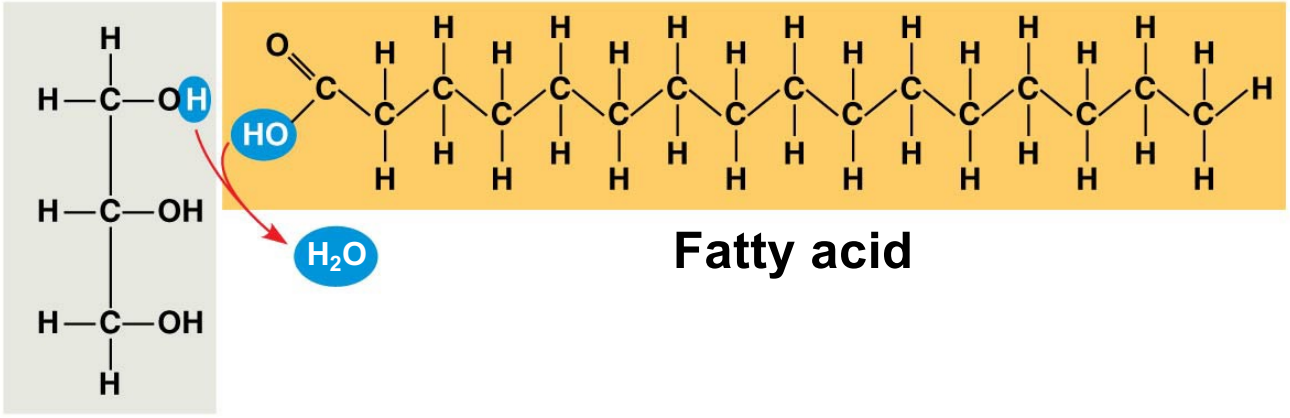
Lipids: diverse hydrophobic molecules

- Lipids are the one class of large biological molecules that does **not** include true polymers
- Lipids are all **hydrophobic** because they consist mostly of hydrocarbons (烃), which form nonpolar covalent bonds.
- The most biologically important lipids are fats 脂肪, **phospholipids** 磷脂, and steroids 类固醇

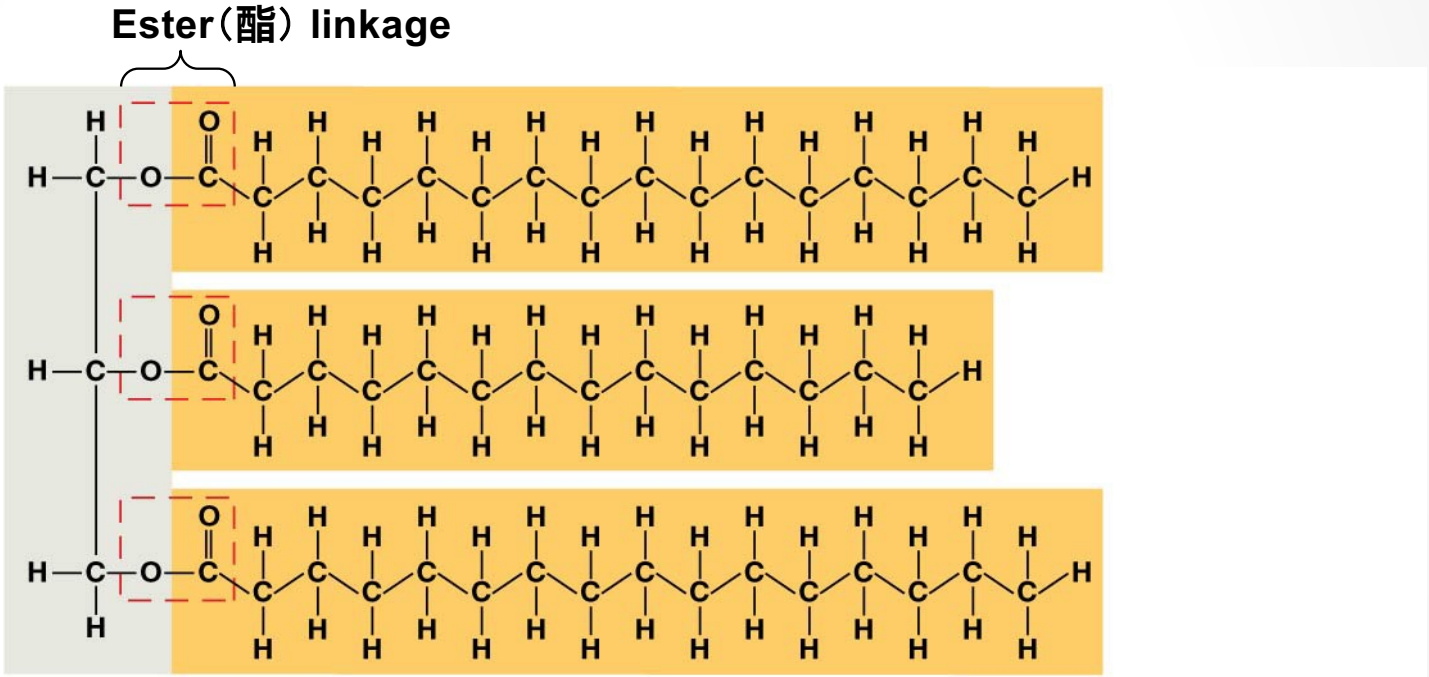
Fats

- Fats are constructed from two types of smaller molecules: glycerol （甘油） and fatty acids （脂肪酸）
- **Glycerol** is a three-carbon alcohol with a hydroxyl group attached to each carbon
- A **fatty acid** consists of a carboxyl group attached to a long carbon skeleton

Esterification
酯化反应



A fat molecule (甘油三酯)



triacylglycerol

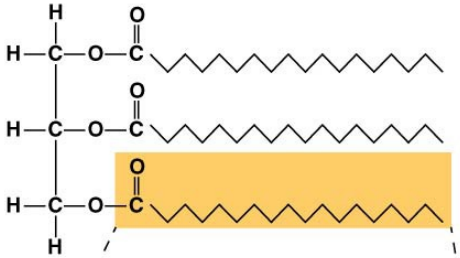
Saturated and unsaturated fats 饱和与不饱和脂肪

- Fatty acids vary in length (number of carbons) and in the number and locations of **double bonds (C=C)**
- **Saturated fatty acids** 饱和脂肪酸 have the maximum number of hydrogen atoms possible and no double bonds
- **Unsaturated fatty acids** 不饱和脂肪酸 have one or more double bonds

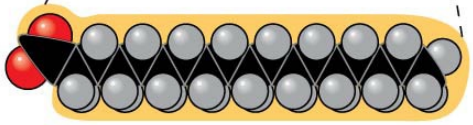
Which is healthier ?

(a) Saturated fat 饱和脂肪

Structural formula of a saturated fat molecule

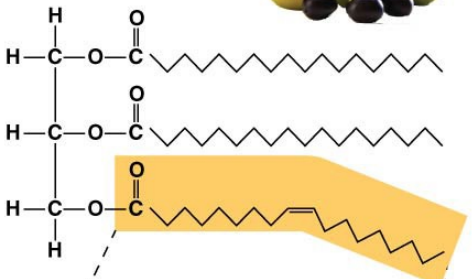


Space-filling model of stearic acid, a saturated fatty acid

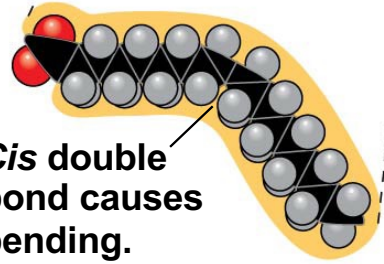


(b) Unsaturated fat 不饱和脂肪

Structural formula of an unsaturated fat molecule



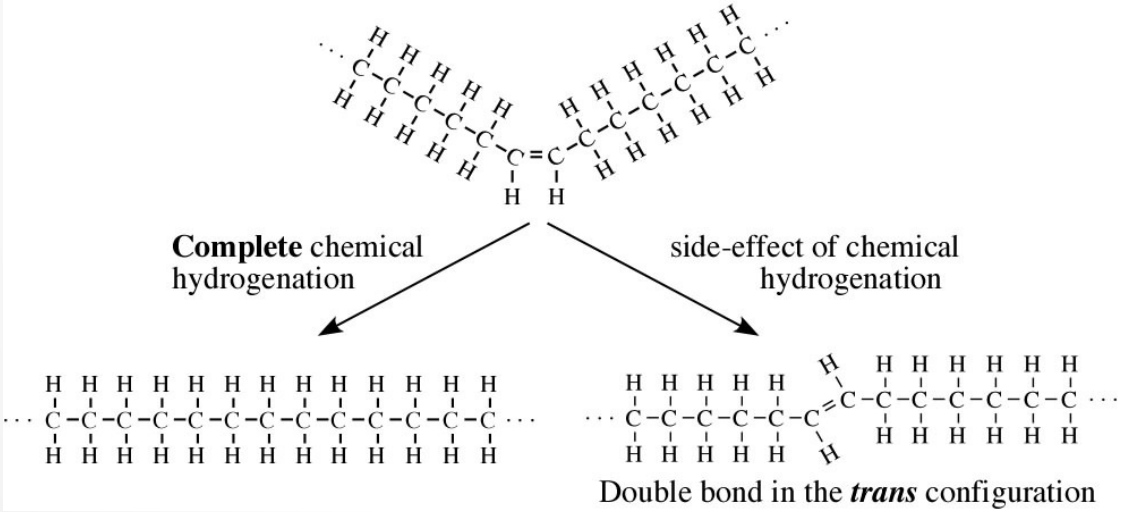
Space-filling model of oleic acid, an unsaturated fatty acid



***Cis* double bond causes bending.**

Trans fats

- **Hydrogenation** 氢化 is the process of converting unsaturated fats to saturated fats by adding hydrogen
- Hydrogenating vegetable oils also creates unsaturated fats with ***trans* double bonds**



What is fat good for?

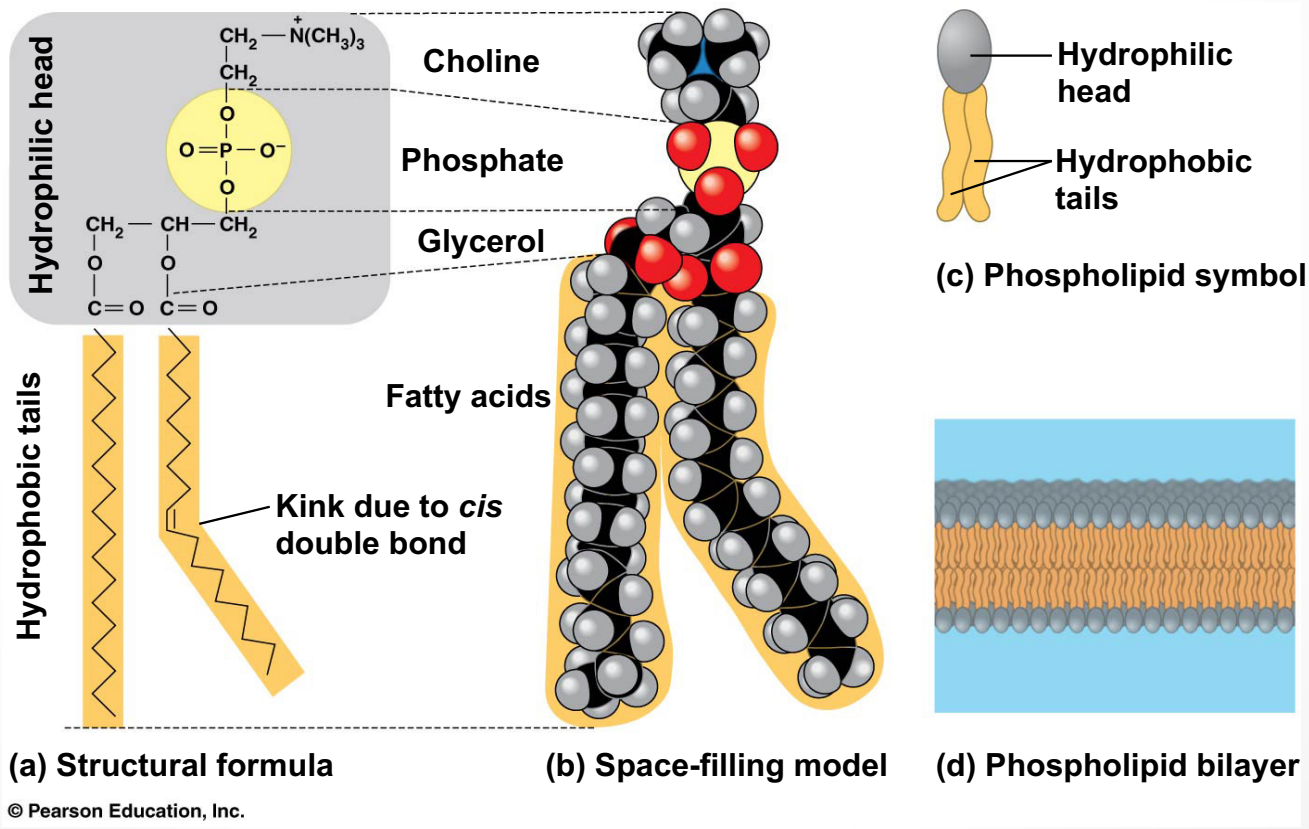
- The major function of fats is **energy storage**
- Fat also cushions vital organs and **maintains body temperature**

Famous for being rescued after being buried in the rubble for **36 days** in the 5-12 Wenchuan earthquake, he was later adopted by the Jianchuan Museum. It was named 猪坚强（Pig Tough） by netizens.

BBC News

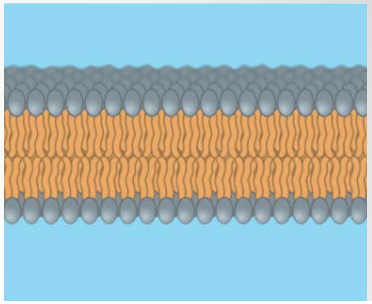
Phospholipids 磷脂

- In a **phospholipid**, two fatty acids (hydrophobic tails 疏水尾部) and a phosphate group (hydrophilic head 亲水头部) are attached to glycerol



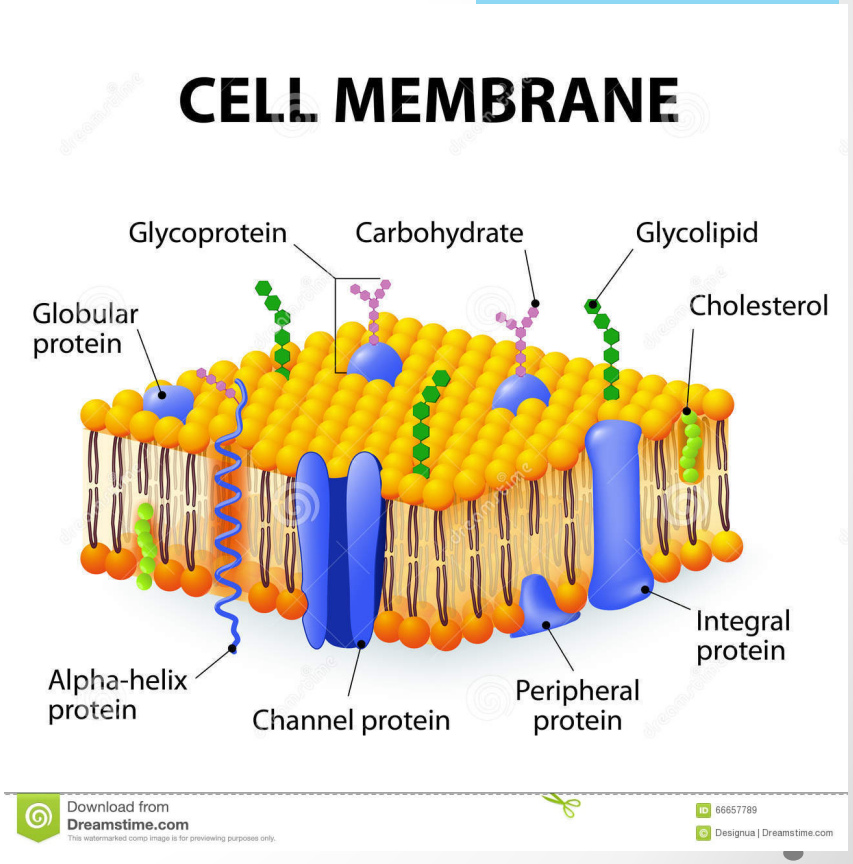
Phospholipid bilayers

磷脂双分子层



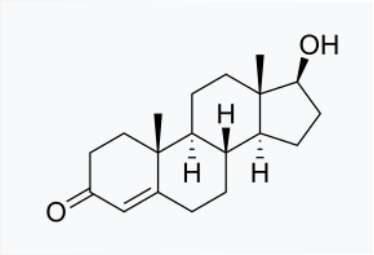
- When phospholipids are added to water, they self-assemble into double-layered structures called bilayers

- At the surface of a cell, phospholipids are also arranged in a bilayer, with the hydrophobic tails pointing toward the interior



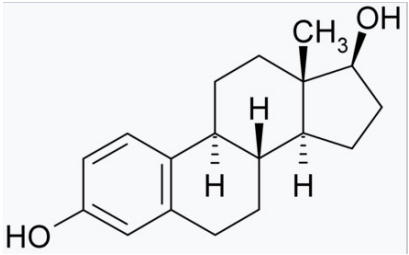
Steroids 类固醇

- **Steroids** are lipids characterized by a carbon skeleton consisting of four fused rings



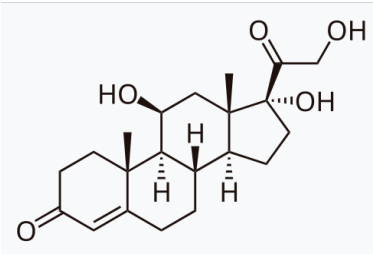
Testosterone
睾酮

雄性激素



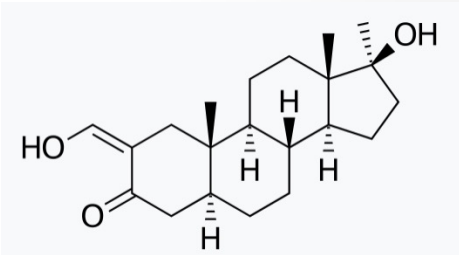
Estrogen
雌二醇

雌性激素



Cotisol
皮质醇

糖皮质激素

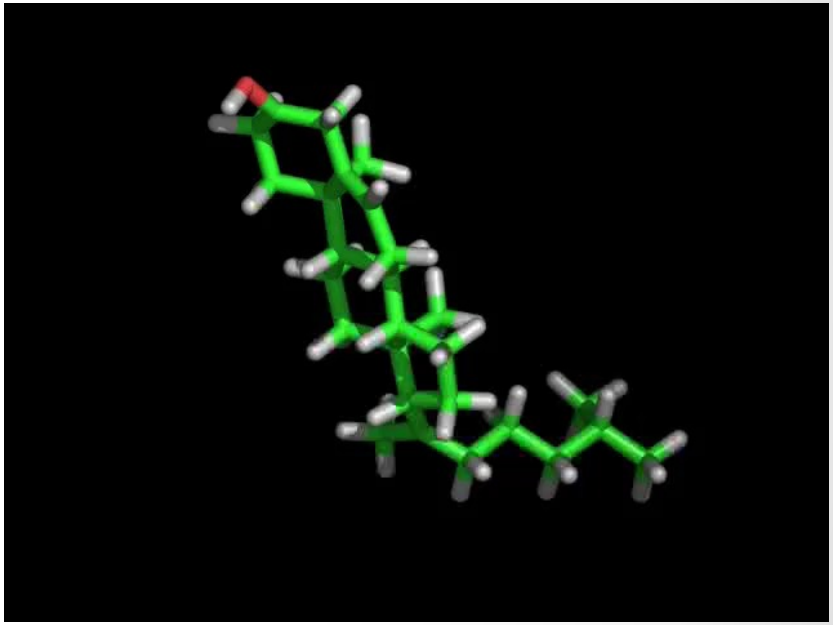


Oxymetholone
康复龙

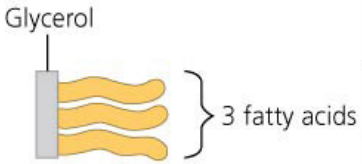
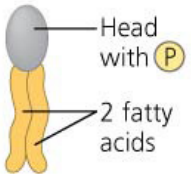
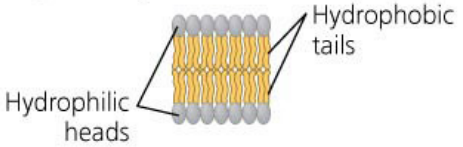
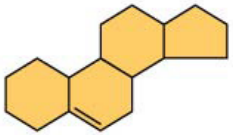
合成类固醇（兴奋剂）

Cholesterol 胆固醇

- An important type of steroids
- Low-Density Lipoprotein (**LDL**) Cholesterol 低密度胆固醇
  - "**bad**" cholesterol.
  - accumulate in the arteries
  - **increase** the risk of heart disease and stroke
  - Optimal: < 100mg/dL
- High-Density Lipoprotein (**HDL**) Cholesterol 高密度胆固醇:
  - "**good**" cholesterol
  - helps remove LDL cholesterol from the bloodstream
  - **reduce** the risk of heart disease and stroke
  - Optimal: > 60mg/dL



Summary: Lipids

Large Biological Molecules	Components	Examples	Functions
Lipids are a diverse group of hydrophobic molecules (pp. 72–75)		**Triacylglycerols** (fats or oils): glycerol + 3 fatty acids	Important energy source  
		**Phospholipids:** glycerol + phosphate group + 2 fatty acids	Lipid bilayers of membranes 
	 Steroid backbone	**Steroids:** four fused rings with attached chemical groups	• Component of cell membranes (cholesterol) • Signaling molecules that travel through the body (hormones)