The Working Cell (Slide 12)

§1 Energy

1. Basic energy concepts

1° Energy is defined as the capacity to cause change.

2° Kinetic energy (动能) is the energy of motion

3° Potential energy (势能) is stored energy, energy that an object has because of its location or structure.

2. Laws of thermodynamics (rules underlining energy use)

1° The first law of thermodynamics known as conservation of energy explains that it is not possible to destroy or create energy.

2° The second law of thermodynamics states that the universal tendency of things to become disordered (the degree of disorder is always increasing in the universe).

Why human body is highly organized when the disorder of the universe is always increasing?

The answer is a cell takes energy from its environment to generate order. In turn, the cell releases energy as heat to the environment, giving it what it wants and making it more disordered.

3. Heat

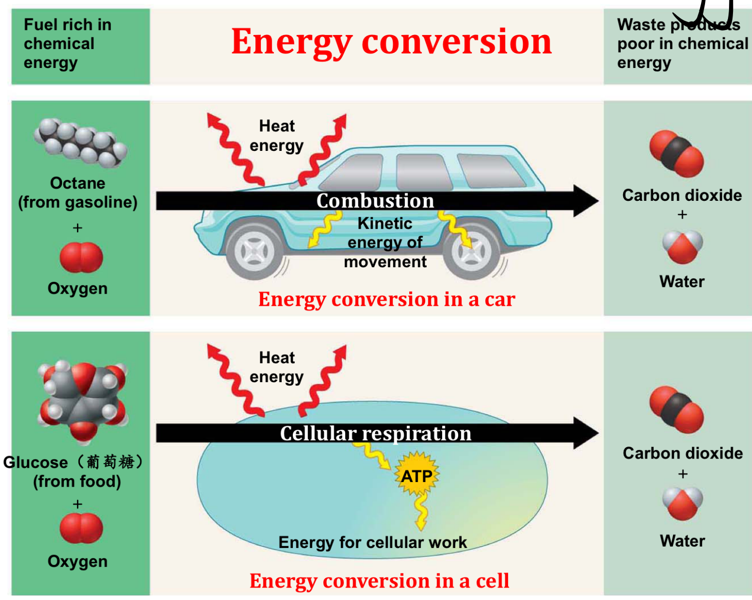
1° Heat is a type of kinetic energy contained in the random motion of atoms and molecules (energy in its most disordered, chaotic form.)

2° All energy conversions generate some heat.

4. Chemical Energy

1° The molecules of food, gasoline, and other fuels have a form of potential energy called chemical energy, which arises from the arrangement of atoms and can be released by a chemical reaction.

2° Living cells break organic fuel into smaller waste molecules that have much less chemical energy.



5. Cellular respiration

1° Cellular respiration (细胞呼吸作用) is

① the energy-releasing chemical breakdown of fuel molecules.

② the storage of that energy in a form the cell can use to perform work.

2° Humans convert about 34% ($\frac{1}{3}$) of our food energy to useful work.

3° The rest of energy released by the breakdown of fuel molecules generates body heat.

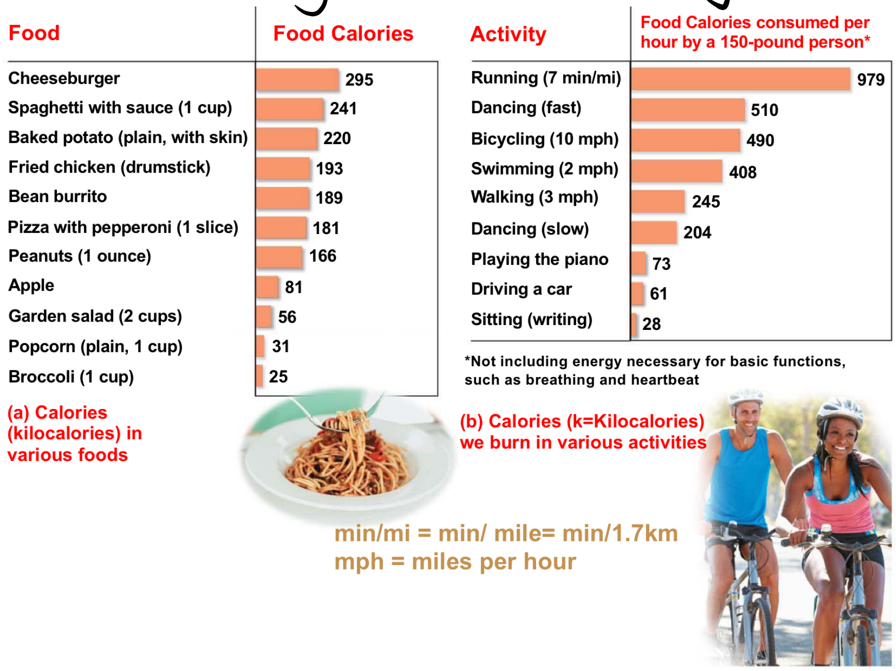
6. Food calories

1° A calorie (cal) (卡路里) is the amount of energy that can raise the temperature of 1 gram of water by 1°C

2° Food Calories are kilocalories (Cal), equal to 1000 calories.

3° The energy of calories in food is used to fuel the activity

4° Fat = 9 Cal/g Proten/Carbonhydrate = 4 Cal/g



§2 Energy Transformations: ATP and Cellular Work

1. ATP

Chemical energy released by the breakdown of organic molecules during cellular respiration is used to generate molecules of ATP (Adenosine Triphosphate) (三磷酸腺苷)

2. How ATP works

ATP

1° acts like an energy shuttle

2° stores energy obtained from food.

3° releases it later as needed.

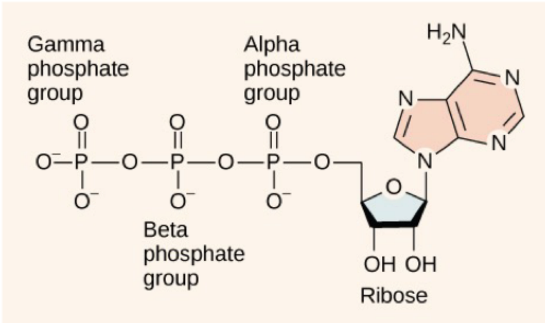
3. The structure of ATP

1° ATP consists of an organic molecule called adenosine (腺苷) plus a tail of three phosphate groups (磷酸基团)

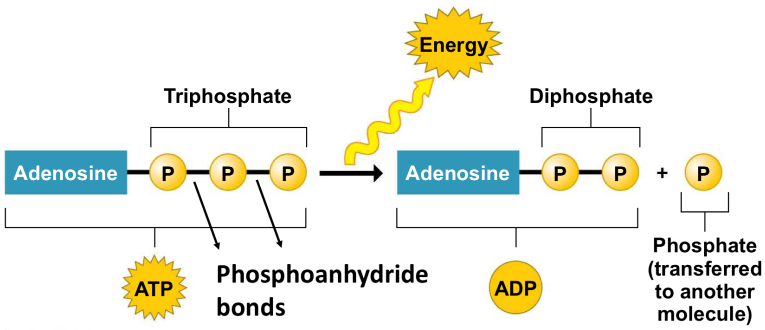
2° ATP is broken down to ADP (adenosine diphosphate)

(二磷酸腺苷), and a phosphate group, releasing energy.

3° At pH 7, all phosphate groups carry negative charges.



triphosphate **adenosine**



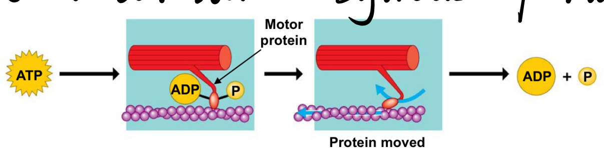
4. ATP Power

1° The release of the phosphate at the tip of the triphosphate tail makes energy available to cells.

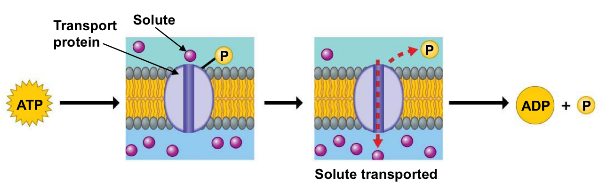
2° Mechanical work: muscle concentration, beating of cila and fragella ......

3° Transport work: pump substances accross the plasma membrane.

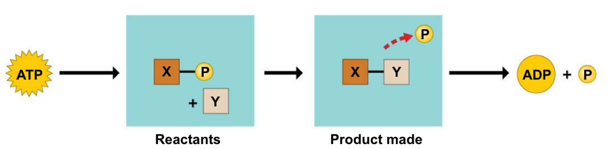
4° Chemical work: Sythesis of macromolecules.



(a) Motor protein performing mechanical work (moving a muscle fiber)



(b) Transport protein performing transport work (importing a solute)



(c) Enzymes performing chemical work (promoting a chemical reaction)

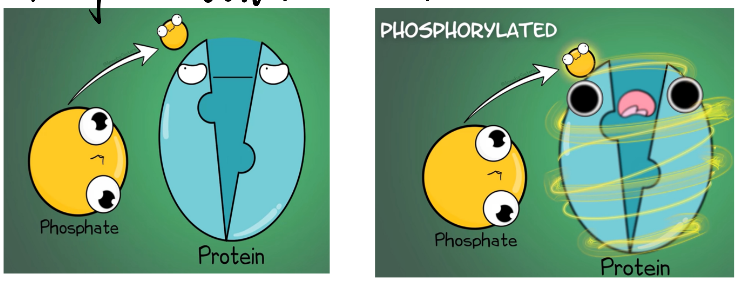
5. How does ATP energize cellular activities: phosphate transfer.

Step 1: Transferring a phosphate group to the molecule

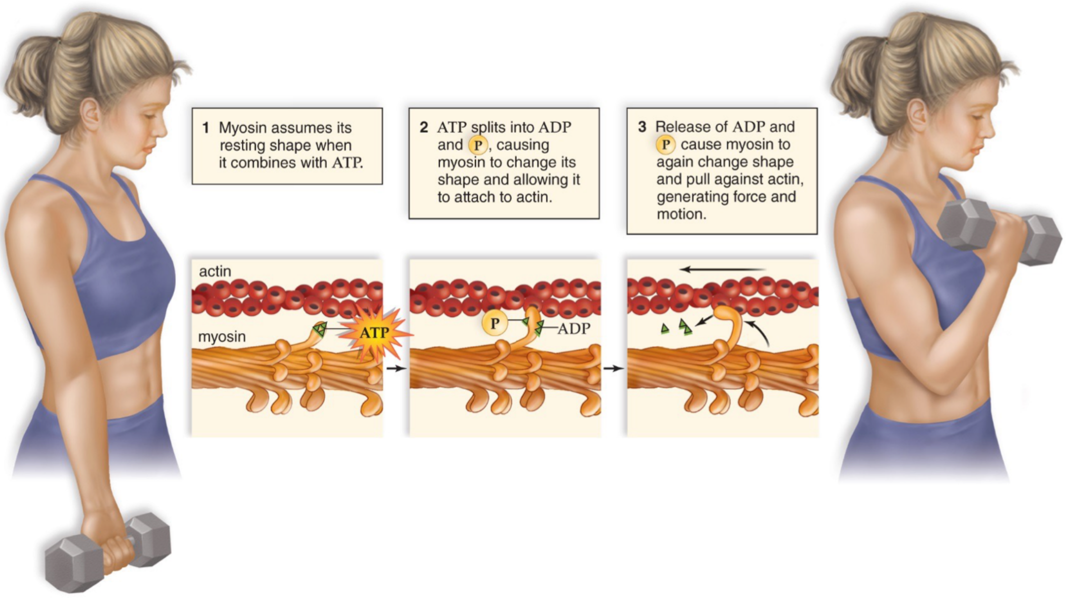
Step 2: Phosphorylated (被磷酸化的) molecules
(change electron distribution, conformation)

Step 3: Molecules become more reactive, high energy state.

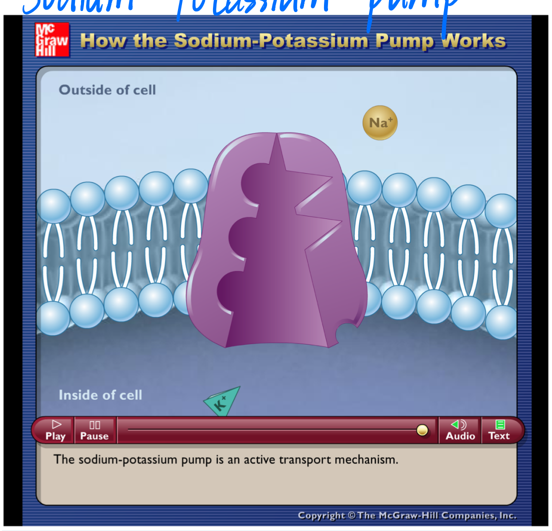
Step 4: Perform cellular work.



Phosphorylation results in a conformational change in the structure in many proteins. Phosphorylated molecules are more reactive, less stable.



6. Sodium-Potassium pump



Note: In this process, ATP transfers one of its phosphate groups to the pump protein, forming ADP and a phosphorylated "intermediate" form of the pump. The phosphorylated pump is unstable in its original conformation (facing the inside of the cell), so it becomes more stable by changing shape, opening towards the outside of the cell and releasing sodium ions outside. When extracellular potassium ions bind to the phosphorylated pump, they trigger the removal of the phosphate group, making the protein unstable in its outward-facing form. The protein will then become more stable by returning to its original shape, releasing the potassium ions inside the cell.

7. Energy in chemical reaction

1° Reactants are substances that participate in a reaction

2° Products are substances that form as a result of a reaction.

3° Free energy is the energy can be harnessed to do work or drive chemical reactions.

4° Chemical reactions proceed spontaneously only in the direction that leads to a loss of energy.

8. Gibbs free energy ΔG (吉布斯自由能)

1° ΔG = change in free energy

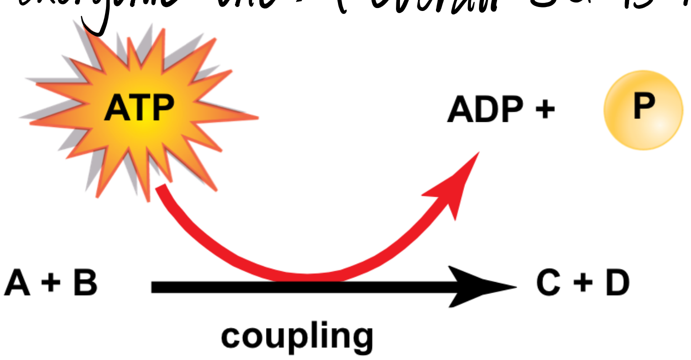
2° $\Delta G < 0$: Exergonic reactions (放能反应), spontaneous, such as hydrolysis of ATP.

3° $\Delta G > 0$: Endergonic reactions (吸能反应), requires energy, such as synthesis of macromolecules.

9. Coupled reactions (偶联反应)

The energy released by an exergonic reaction is used to drive an endergonic reaction.

So a very endergonic reaction can occur if it is paired with a very exergonic one. (Overall ΔG is negative)

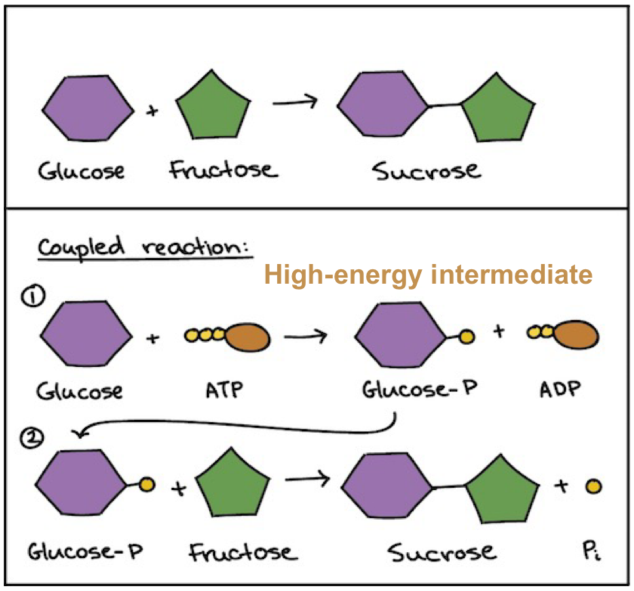


1. Glucose + Fructose → Sucrose (ΔG = +27 kJ/mol)

2. ATP + H_2O → ADP + Pi (ΔG =-30 kJ/mol)

Overall reaction:

Glucose + Fructose + ATP + H_2O → Sucrose + ADP + Pi (ΔG =-3 kJ/mol)



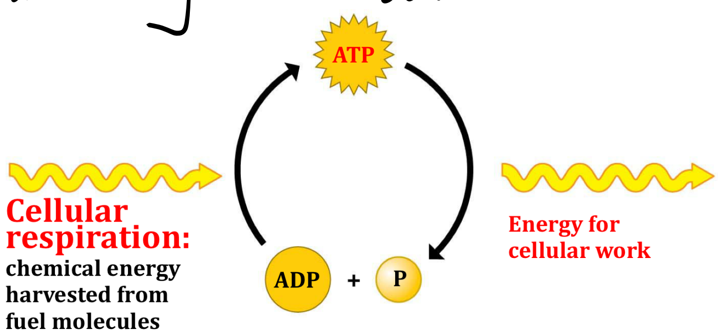
$\Delta G < 0$

$\Delta G < 0$

10. The ATP cycle

Cells spend ATP continuously.

Up to 10 million ATPs are consumed and recycled each second in a working muscle cell.



§3 Enzymes

1. Enzymes

1° Biological catalysts which assist metabolism (新陈代谢)

2° Usually proteins, can be RNA

3° Some enzymes are highly specific for reactions

Other enzymes act on a range of target molecules which contain the type of bond or chemical groups that the enzyme targets.

4° Substrate (底物) fits into active site of enzymes

5° Promote transition state (过渡状态) and lower activation energy (反应活化能)

2. Transition state

A–B + C–D ⟶ A---C / B---D ⟶ A–C + B–D

original state / transition state / final state

high energy & unstable

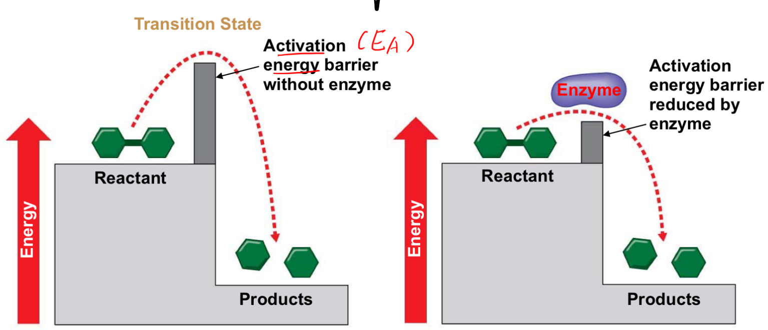
3. Activation energy

Activation energy is the energy that must be invested to start a reaction, by

1° activating the reactants

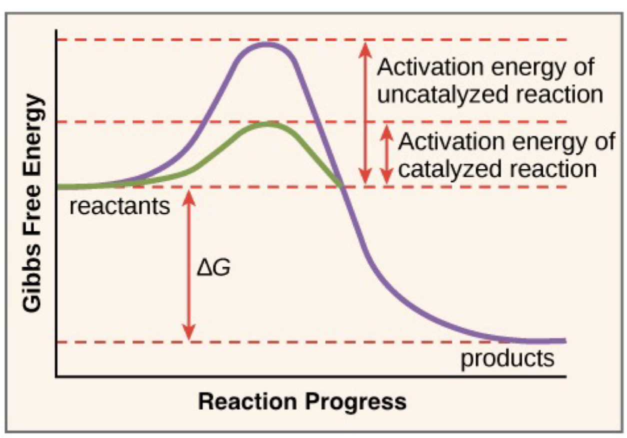
2° triggering a chemical reaction.

Enzymes reduce the amount of activation energy required to break the bonds of reactant molecules.



(a) Without enzyme (b) With enzyme

An exergonic reaction refers to a reaction where energy is released. $\Delta G < 0$



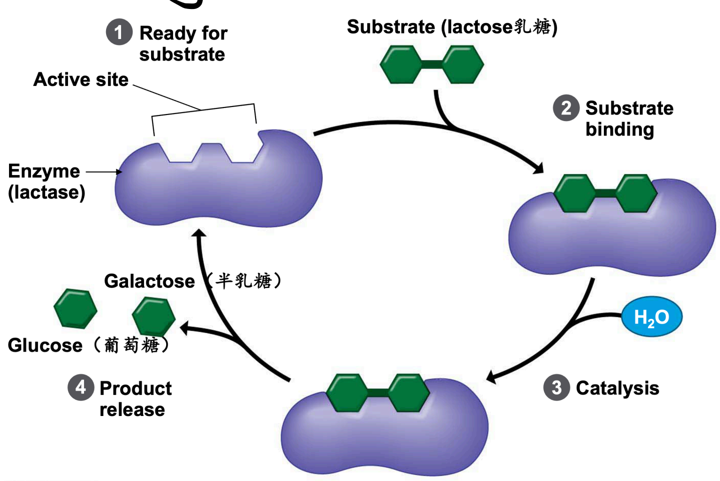
4. Induced fit theory (诱导契合学说)

1° The active site of an enzyme has a shape and chemistry that fits the substrate molecule.

2° This interaction is called induced fit because the entry of the substrate induces the enzyme to change shape slightly, making the fit between the substrate and active site snugger.

3° After the products are released from the active site, the enzyme can accept another molecule of its substrate.

* Many enzymes are named for their substrates, but with an -ase ending.



5. Enzyme inhibitor (酶抑制剂)

1° Certain molecules inhibit a metabolic reaction by

① binding to and enzyme and

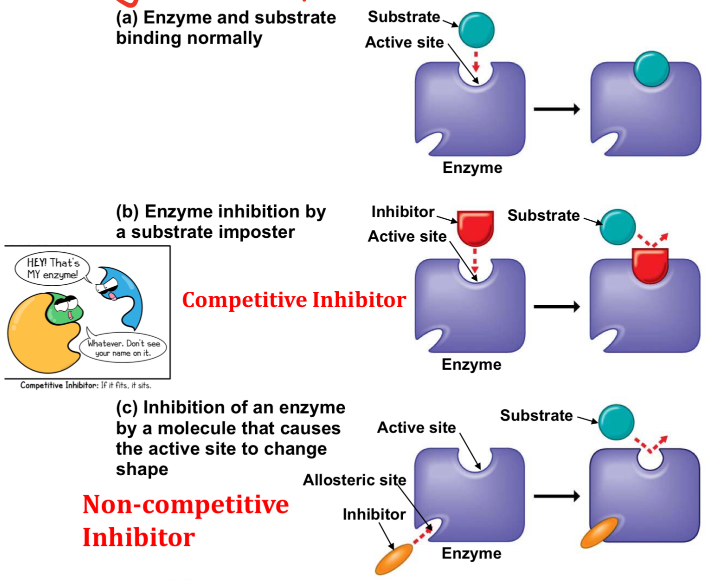
② disrupting its function

2° Competitive inhibitor and non-competitive (allosteric) inhibitor

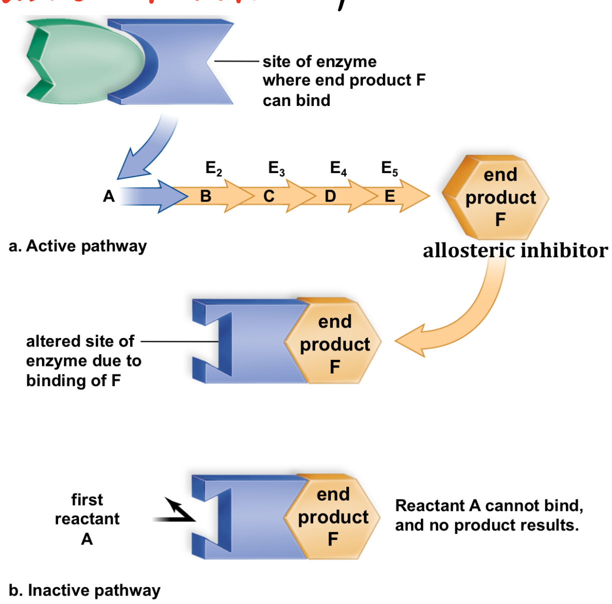
① Some are substrate impostors that plug up the active site.

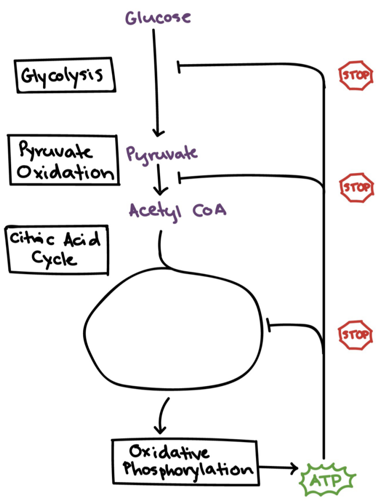
② Other inhibitors bind to the enzyme at a site remote from the active site, but the binding change the enzyme's shape so that the active site no longer accepts the substrate.

In each case, an inhibitor disrupts the function of an enzyme by altering its shape.



3° In some cases, the binding of an inhibitor is reversible. If a cell is producing more of a certain product than it needs, that product may reversibly inhibit an enzyme required for its production, keeping the cell from wasting resources that could be put to better use.
(Activity of almost every cell enzyme is regulated by feedback inhibition)





ATP is an allosteric inhibitor of some of the enzymes involved in [cellular respiration](), a process that makes ATP.

4° Many beneficial drugs work by inhibiting enzymes.

① Penicillin (青霉素) blocks the active site of an enzyme that bacteria use in making cell walls.

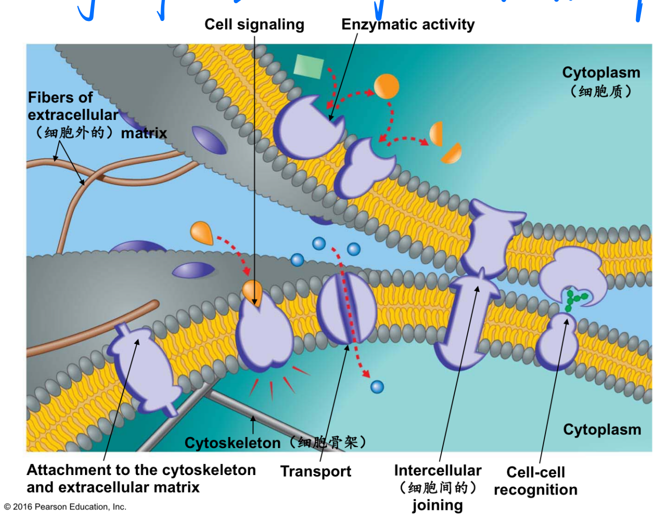
② Ibuprofen (布洛芬) inhibits an enzyme involved in sending pain signals.

③ Many cancer drugs inhibit enzymes that promote cell division.

④ Many toxin (毒素) and poisons also work as inhibitors, e.g. Cyanide (氰化物) inhibits mitochondrial enzyme cytochrome C oxidase (细胞色素C氧化酶)

§4 Membrane Function and Traffic of Small Molecules

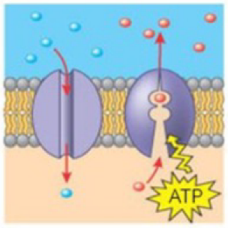
1. Six major functions of membrane proteins



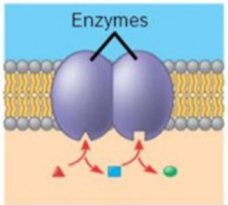
Of all the major functions of these membrane proteins, one of the most important is the regulation of transport in and out of the cell.

Six Major Functions of Membrane Proteins

(a) **Transport. (left)** A protein that spans the membrane may provide a hydrophilic channel across the membrane that is selective for a particular solute. **(right)** Other transport proteins shuttle a substance from one side to the other by changing shape. Some of these proteins hydrolyze ATP as an energy source to actively pump substances across the membrane.



(b) **Enzymatic activity.** A protein built into the membrane may be an enzyme with its active site exposed to substances in the adjacent solution. In some cases, several enzymes in a membrane are organized as a team that carries out sequential steps of a metabolic pathway.



(c) **Signal transduction.** A membrane protein may have a binding site with a specific shape that fits the shape of a chemical messenger, such as a hormone. The external messenger (signal) may cause a conformational change in the protein (receptor) that relays the message to the inside of the cell.

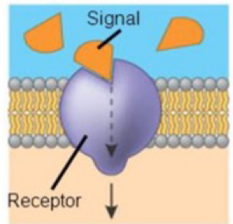
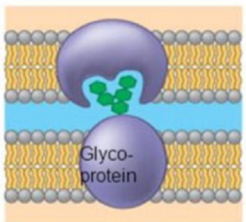


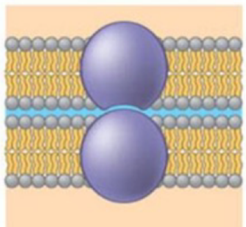
Figure 7.9

Six Major Functions of Membrane Proteins

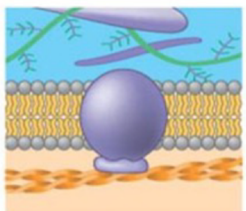
(d) **Cell-cell recognition.** Some glyco-proteins serve as identification tags that are specifically recognized by other cells.



(e) **Intercellular joining.** Membrane proteins of adjacent cells may hook together in various kinds of junctions, such as gap junctions or tight junctions



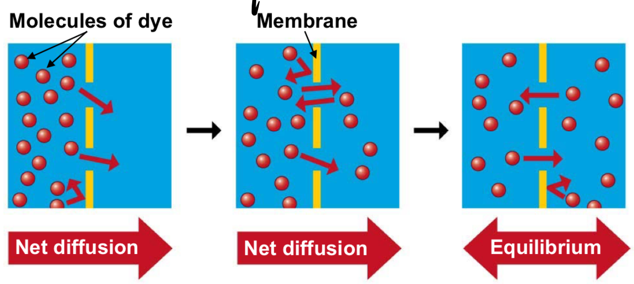
(f) **Attachment to the cytoskeleton and extracellular matrix (ECM).** Microfilaments or other elements of the cytoskeleton may be bonded to membrane proteins, a function that helps maintain cell shape and stabilizes the location of certain membrane proteins. Proteins that adhere to the ECM can coordinate extracellular and intracellular changes



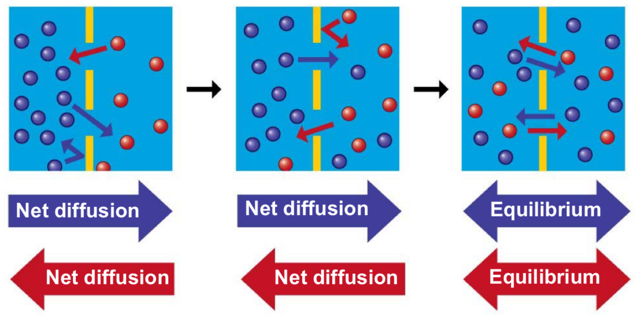
2. Diffusion (扩散作用)

Molecules constantly vibrate and wander randomly.

Diffusion is the movement of molecules spreding out evenly into the available space



(a) Passive transport of one type of molecule



(b) Passive transport of two types of molecules

3. Osmosis (渗透作用)

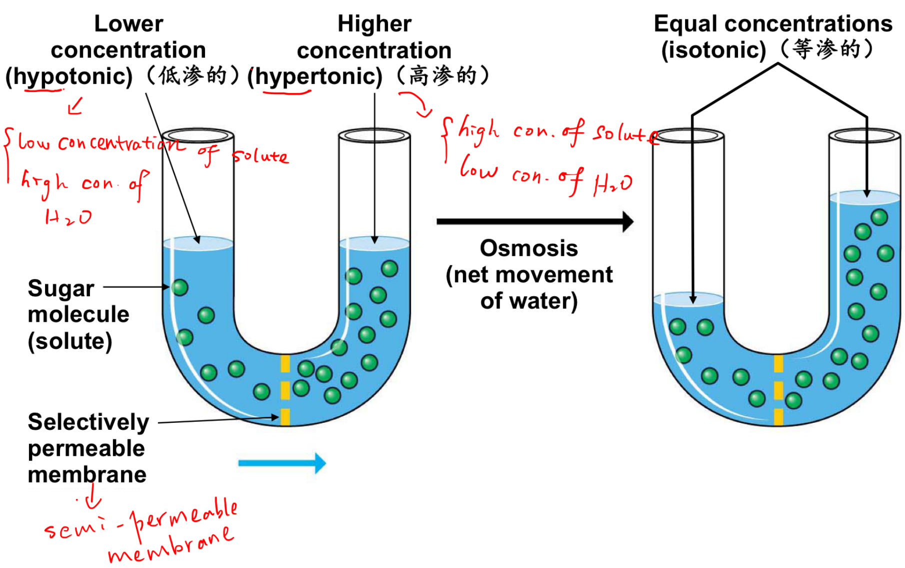
1° The diffusion of water across a selectively permeable membrane (半透膜) is osmosis.

2° Compared to another solution,

① a hypertonic (高渗的) solution has a higher concentration of solute.

② a hypotonic (低渗的) solution has a lower concentration of solute

③ a isotonic (等渗的) solution has an equal concentration of solute



4. Water balance

1° The control of water balance is called osmoregulation (渗透调节)

2° Water balance in animal cells:

① remove excessive water in hypotonic environment.

② excrete excessive salts in hypertonic environment

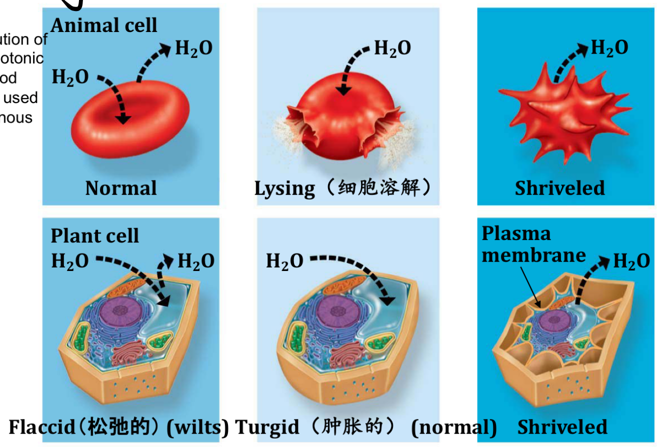
3° Water balance in plant cells:

① Plant cells have rigid cell walls.

② Plant cells are healthiest in a hypotonic environment with a net inflow of water, which expends their cell walls without bursting.

③ As a plant cell loses water, it shrivels and its plasma membrane may pull away from the cell wall, which usually kills the cell.

0.9% solution of NaCl is isotonic to red blood cells. It is used in intravenous solutions.



(a) Isotonic solution
(b) Hypotonic solution
(c) Hypertonic solution

- Kwashiorkor is severe form of malnutrition associated with a deficiency in dietary protein.
- Kwashiorkor is characterized by leaky cell membranes that permit the movement of potassium and other intracellular ions to the extracellular space.
- The increased osmotic load in the gastro-intestinal system causes water movement and edema (abdominal swelling).

5. Passive transport (被动运输): diffusion across membranes

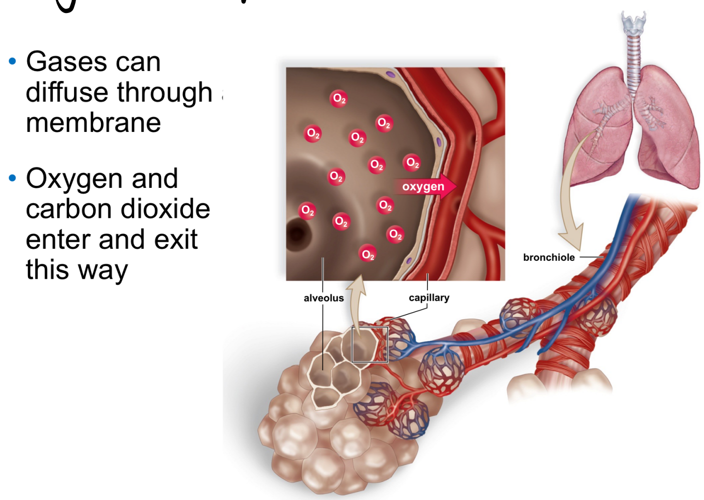
1° Way of transport: diffusion

2° without input of energy.

3° A substance diffuses down its concentration gradient (浓度梯度) from where the substance is more concentrated to where it is less concentrated.

4° The examples of diffusion:

Small gases, lipid-soluble molecule (steroids), H_2O ……



5° Facilitated diffusion (协助扩散)

Substances that do not cross membranes spontaneously, or otherwise cross very slowly, can be transported via proteins that act as corridors for specific molecules.

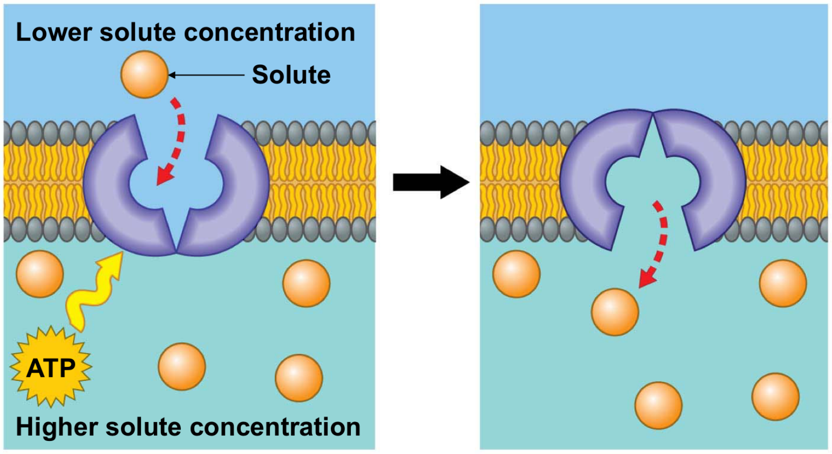
6° Examples of facilitated diffusion:

some sugars, amino acids, H_2O (aquaporins (水通道蛋白))

6. Active transport

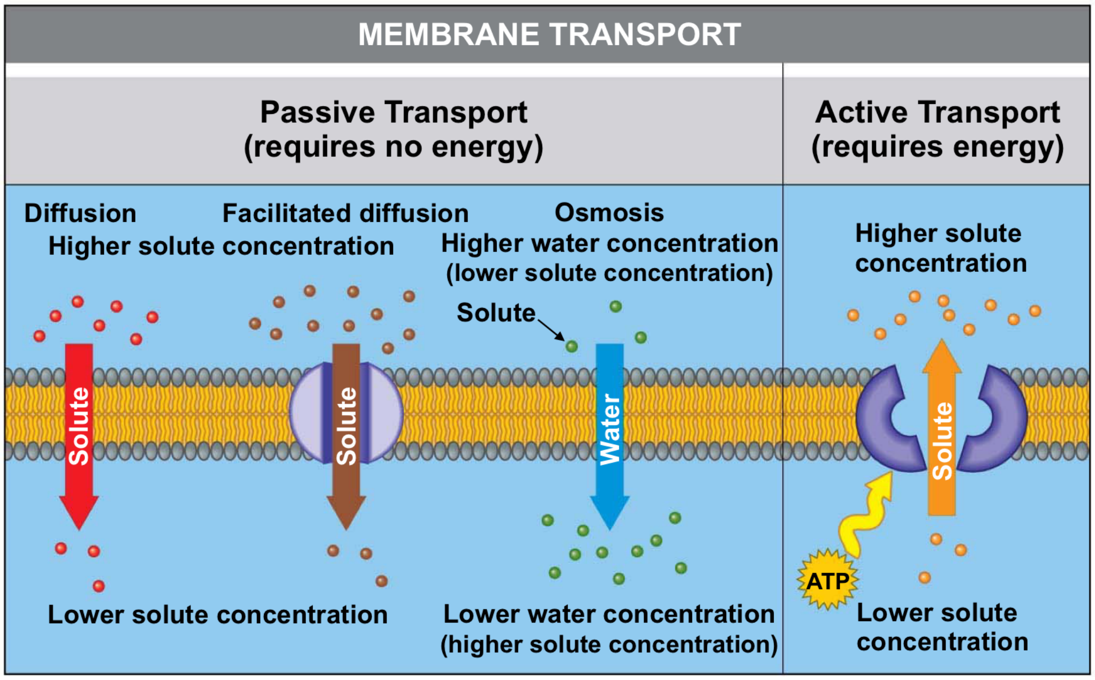
1° Cellular energy (usually provided by ATP) is used to drive a transport protein that pumps a solute against the concentration gradient.

2° Active transport allows cells to maintain internal concentrations of small solutes that differ from environmental concentrations.



Active transport

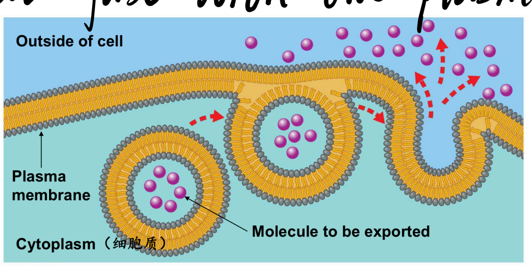
(Additional reference / review slides for student use)



§5 Exocytosis and Endocytosis: Traffic of Large Molecules

1. Exocytosis (胞吐作用)

Exocytosis is the movement of materials out of the cytoplasm of a cell via membranous vesicles (囊泡) or vacuoles (液泡) that fuse with the plasma membrane.

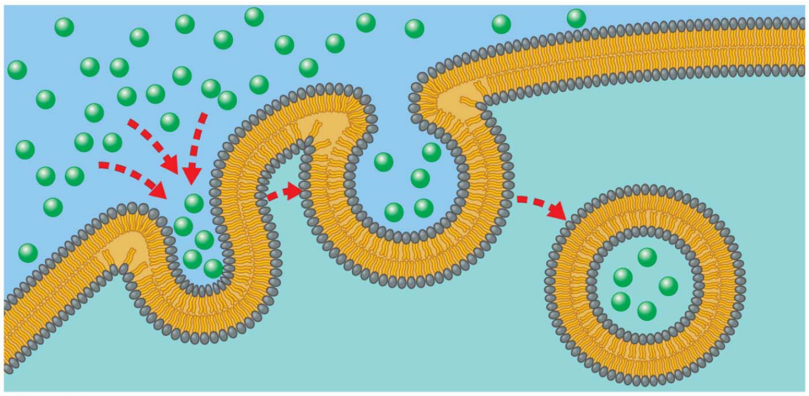


When we cry, cells in our tear glands use exocytosis to export a salty solution containing proteins.

2. Endocytosis (胞吞)

In endocytosis, a cell takes material in via vesicles that bud inward.

For example, in a process called phagocytosis (吞噬作用) ("cellular eating"), a cell engulfs (吞噬) a particle and packages it within a food vacuole (食物泡)



Permeability of the Plasma Membrane

TABLE 4.1 Passage of Molecules Into and Out of the Cell

	Name	Direction	Requirement	Examples
Energy Not Required	Diffusion	Toward lower concentration	Concentration gradient	Lipid-soluble molecules, water, and gases
	Facilitated transport	Toward lower concentration	Channels or carrier and concentration gradient	Some sugars and some amino acids
Energy Required	Active transport	Toward higher concentration	Carrier plus energy	Sugars, amino acids, and ions
	Exocytosis	Toward outside	Vesicle fuses with plasma membrane	Macromolecules
	Endocytosis	Toward inside	Vesicle formation	Macromolecules