Metabolism

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Lecture Outline

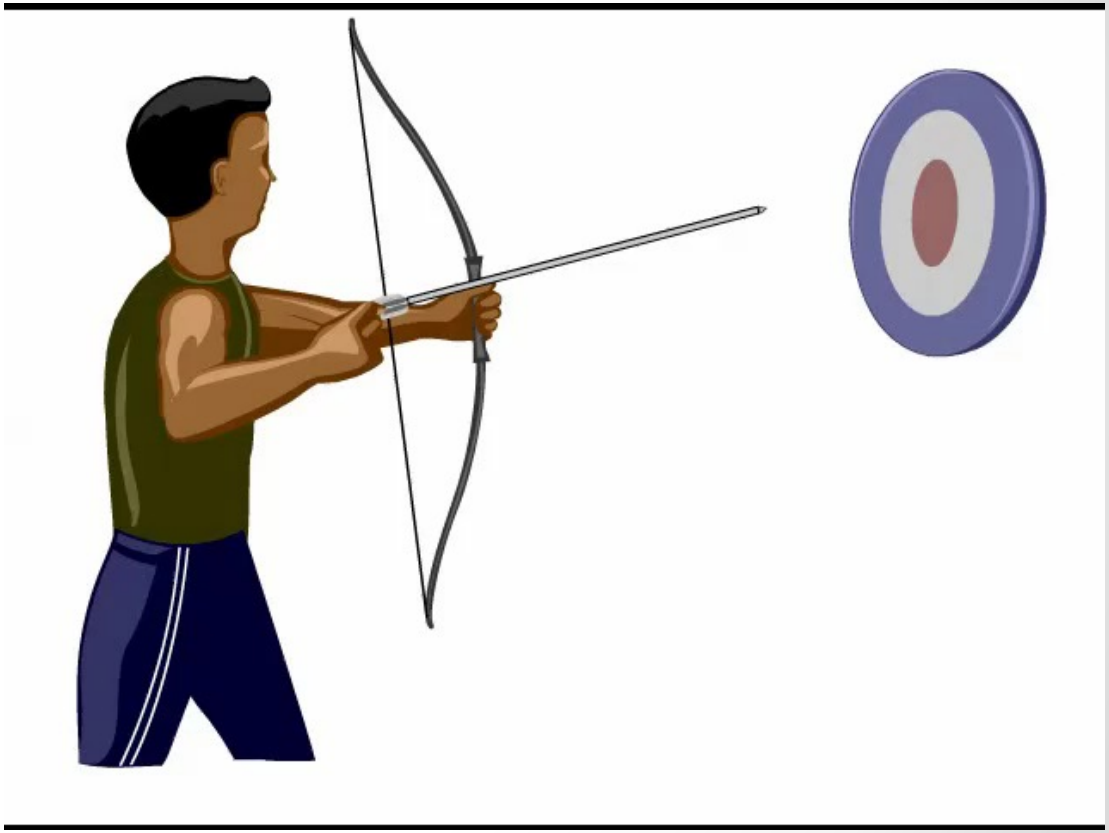
- The laws of thermodynamics 热力学定律
- Enzymes 酶
- ATP
- **Cellular respiration 细胞呼吸**

The Energy of Life

- The living cell is a miniature **chemical factory** where thousands of reactions occur
- Some organisms convert energy to light, as in bioluminescence 生物发光

Energy

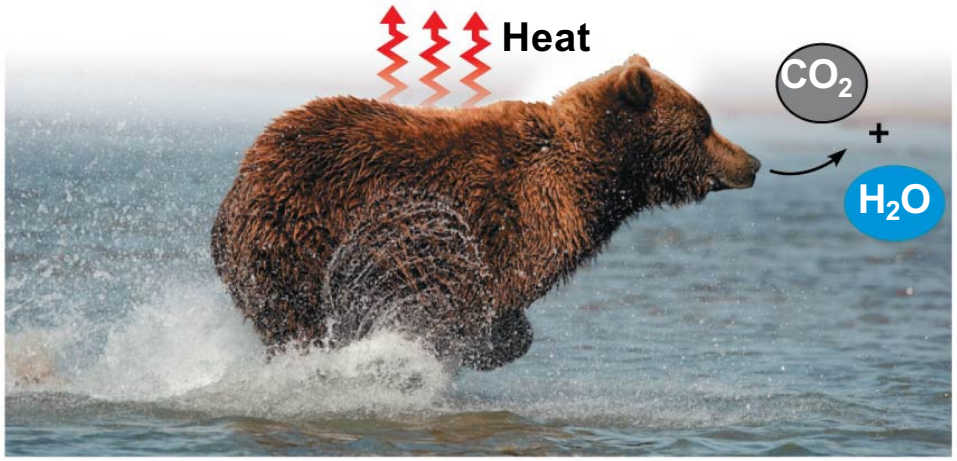
- **Kinetic energy** 动能 is energy associated with motion
- **Heat (thermal energy)** 热能 is kinetic energy associated with random movement of atoms or molecules
- **Potential energy** 势能 is energy that matter possesses because of its location or structure
- **Chemical energy** 化学能 is potential energy available for release in a chemical reaction



The 1st and 2nd Laws of Thermodynamics

- According to the **first law of thermodynamics**, the energy of the universe is constant
  - *Energy can be transferred and transformed, but it **cannot be created or destroyed***
- According to the **second law of thermodynamics**
  - *Every energy transfer or transformation increases the **entropy** 熵 (disorder) of the universe*

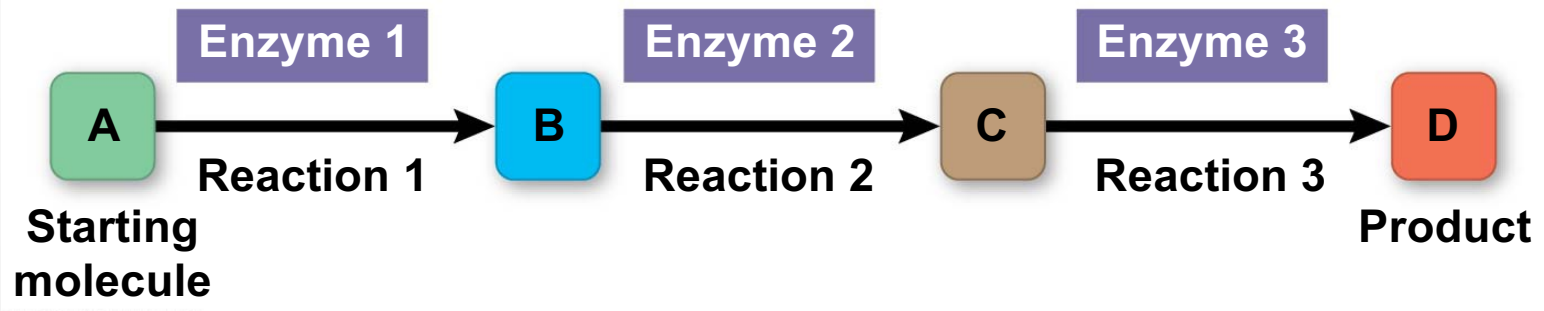
(a) First law of thermo-dynamics



(b) Second law of thermodynamics

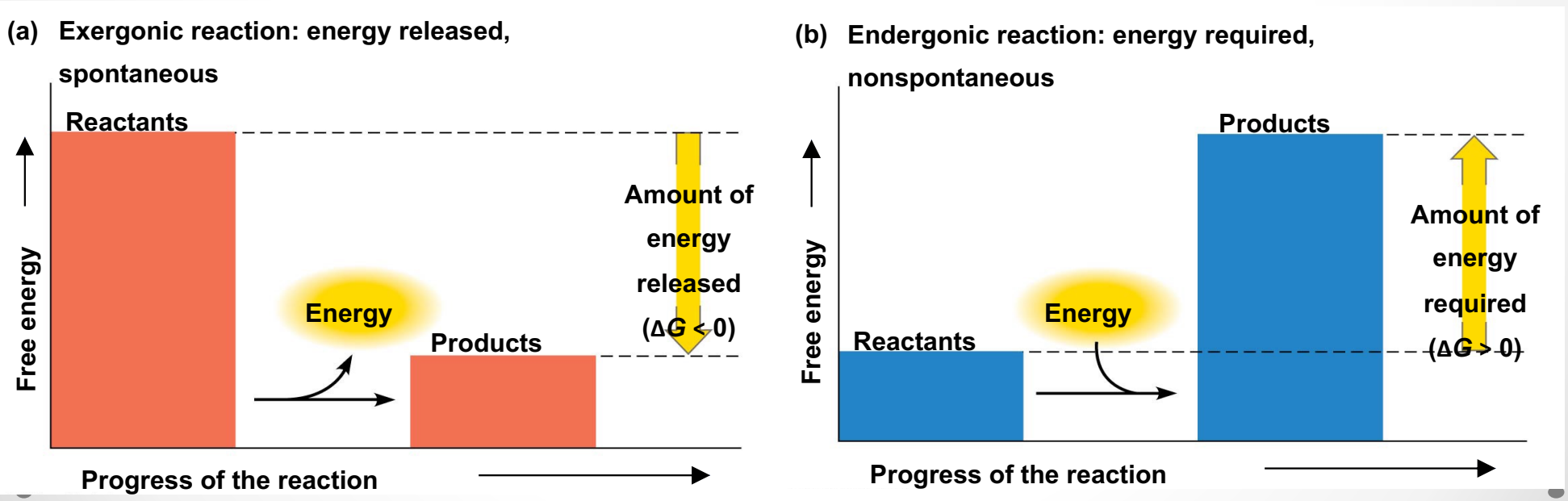
Metabolism 代谢

- **Metabolism** is the totality of an organism’s chemical reactions
- A **metabolic pathway** 代谢通路 begins with a starting molecule and ends with a **product**, and each step is catalyzed by a specific **enzyme**
- **Catabolism (分解代谢)** releases energy, and **anabolism (合成代谢)** consumes energy



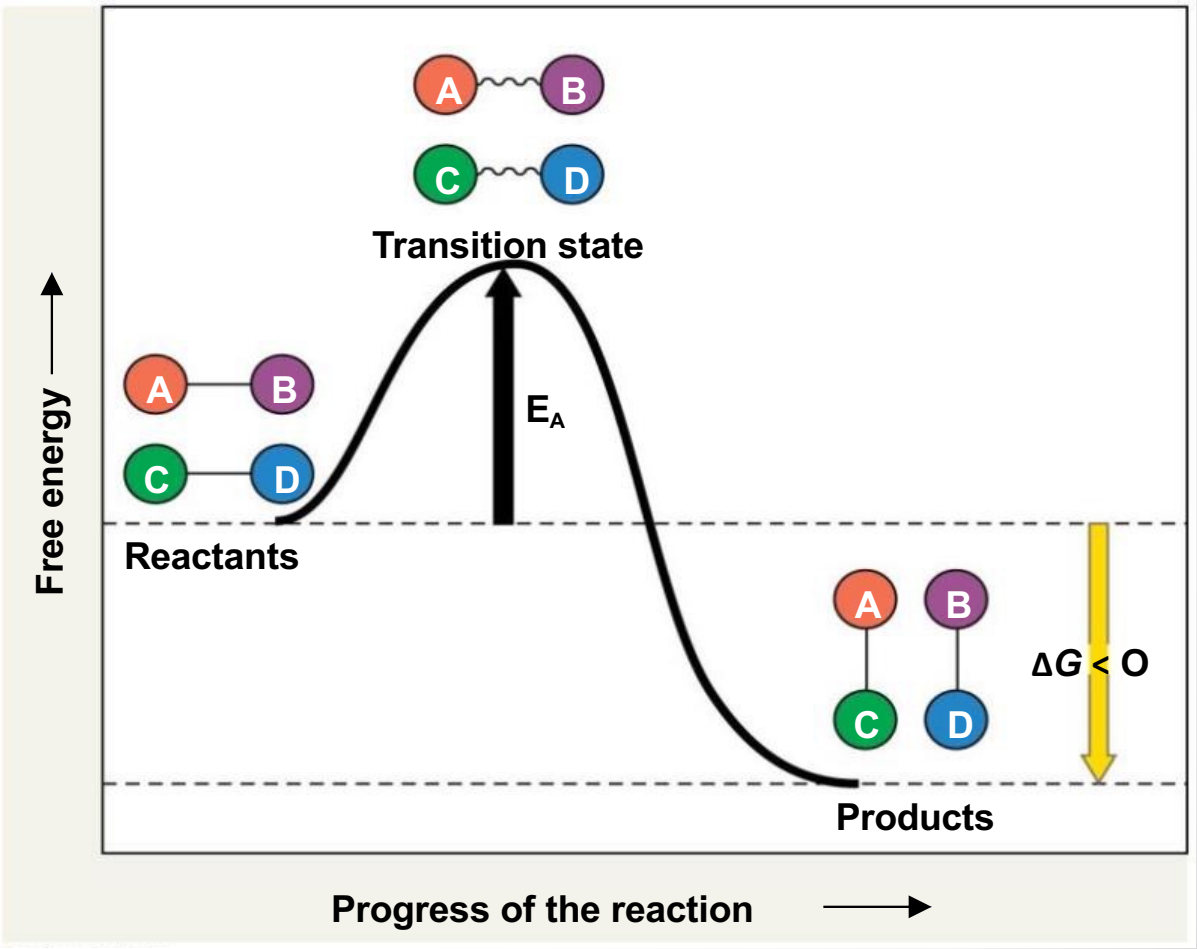
Free-Energy Change, ΔG

- **Gibbs Free Energy**: **G**. 吉布斯自由能
- ΔG: G(products产物)-G(reactants反应物)
- An **exergonic reaction 放能反应** ΔG<0
- An **endergonic reaction 吸能反应** ΔG>0



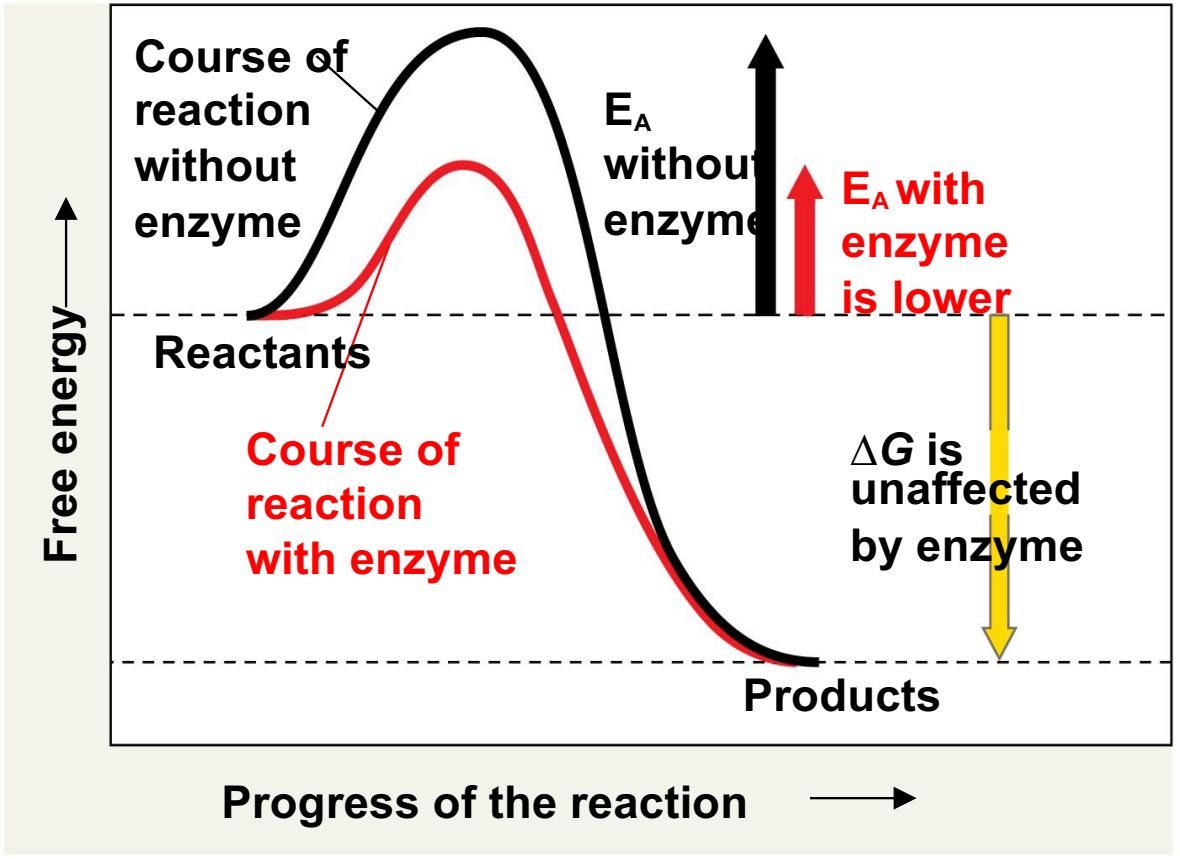
Exergonic reaction 放能反应

- Biochemical reactions that are energetically favored **DO NOT** happen spontaneously. WHY?
  - **Intermediate state 中间态:** much higher free energy than reactants
  - E_A: **energy of activation** 活化能



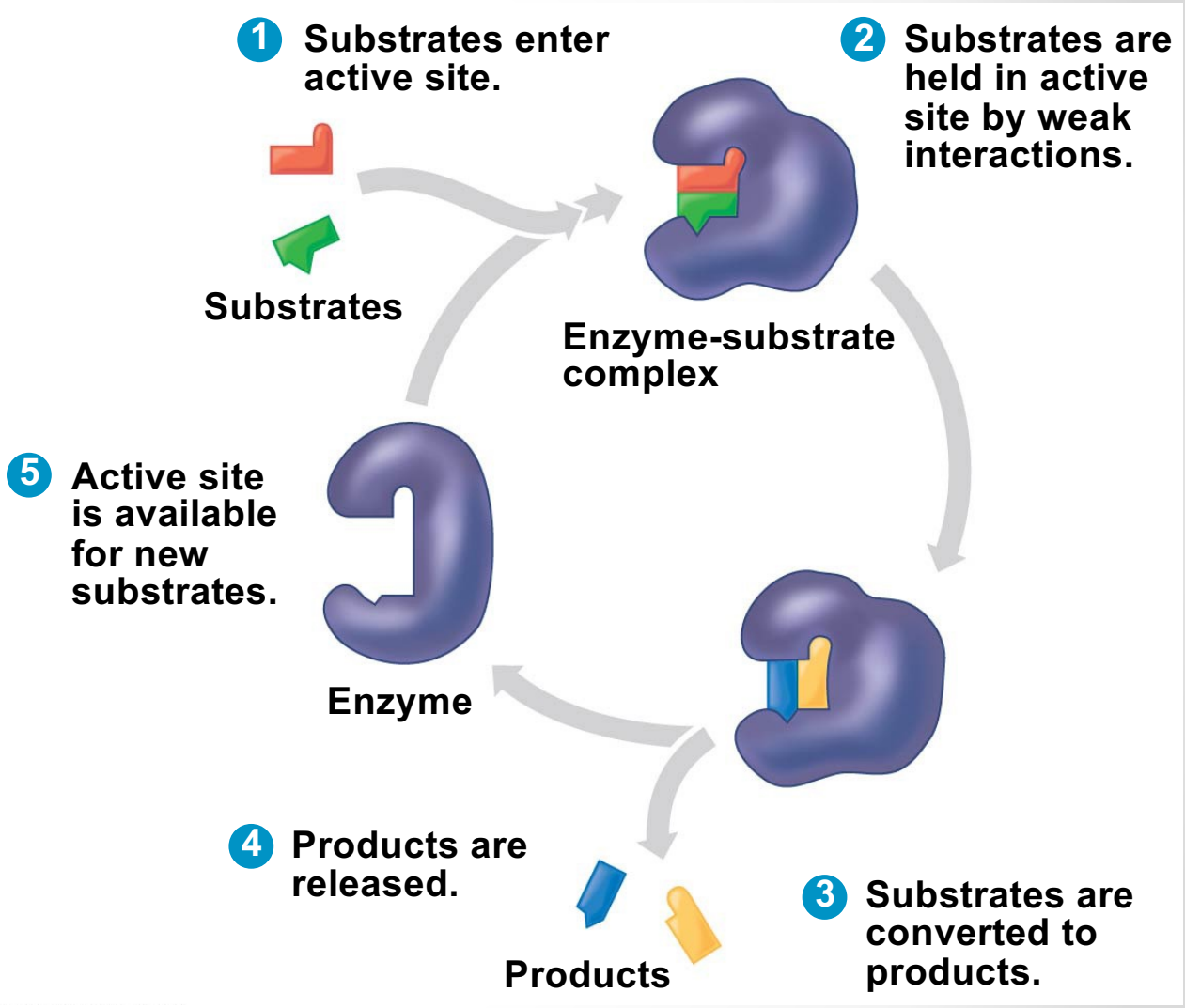
How Enzymes Speed Up Reactions

- Enzymes **DO NOT** change free energy of reactants or products
- Enzymes **DO NOT** affect ΔG
- Enzymes **DO NOT** affect equilibrium
- Enzymes catalyze (speed up) reactions by **lowering the E_A barrier**

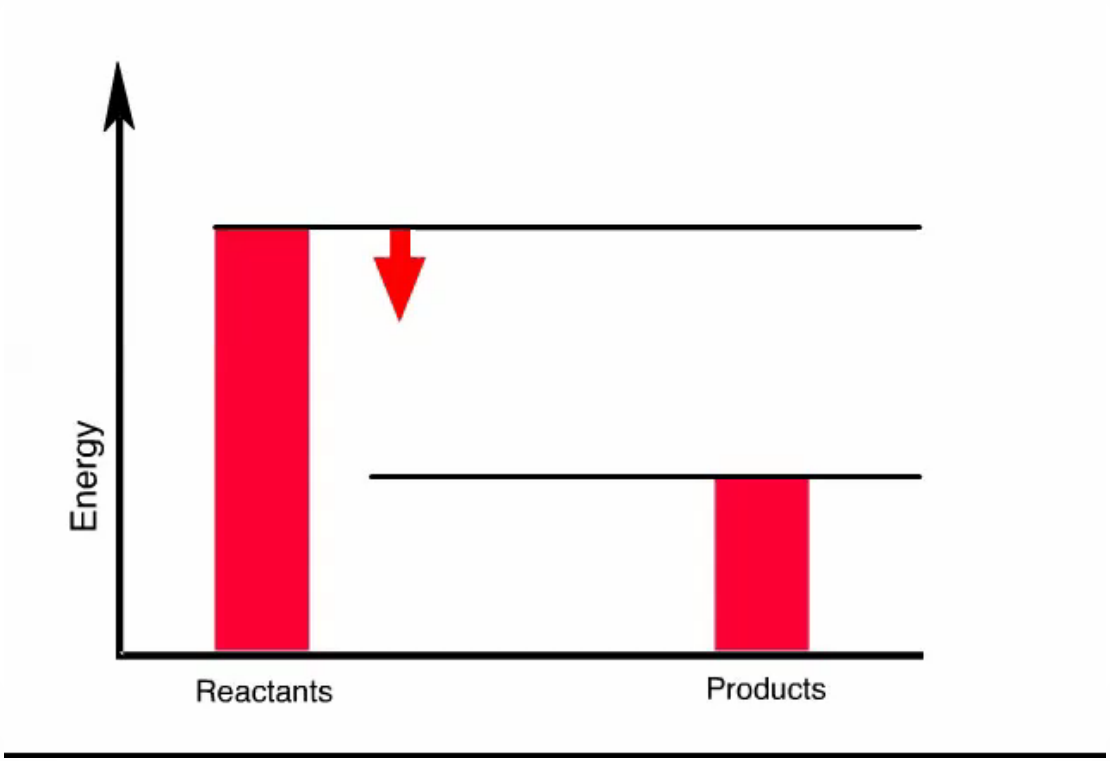


Enzymes

- The reactant that an enzyme acts on is called **substrate 底物**
- The enzyme binds to its substrate, forming an **enzyme-substrate complex 酶-底物复合体**
- The reaction catalyzed by each enzyme is **very specific 高特异性**
- The **active site 活性位点** is the region on the enzyme where the substrate binds



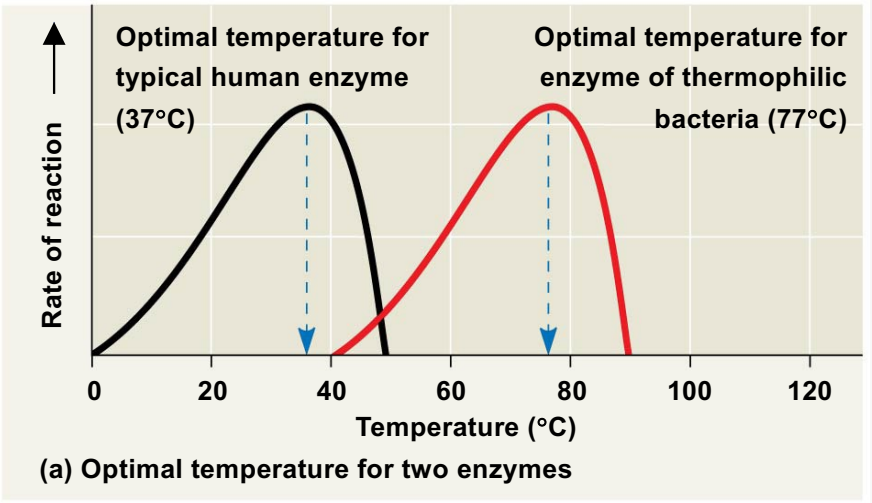
Animation: How Enzymes Work



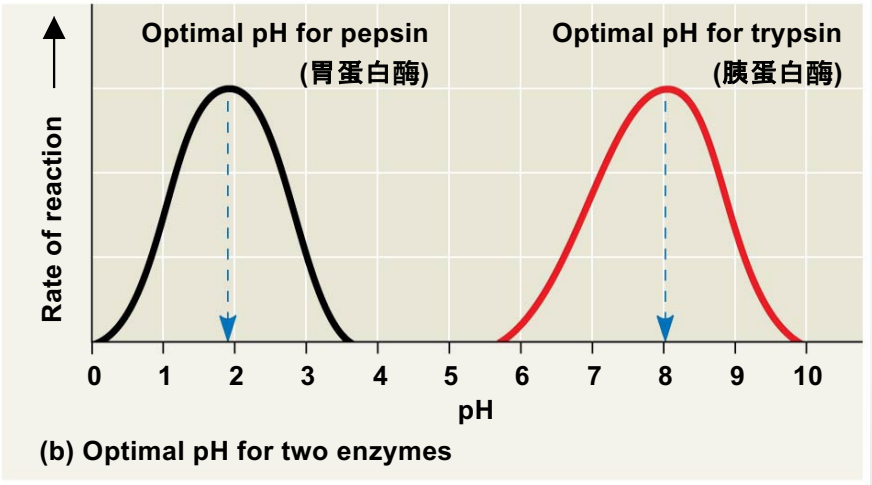
Effects of Temperature and pH

- Each enzyme has an optimal **temperature** and **pH** in which it can function

- Optimal conditions favor the **most active shape** for the enzyme molecule



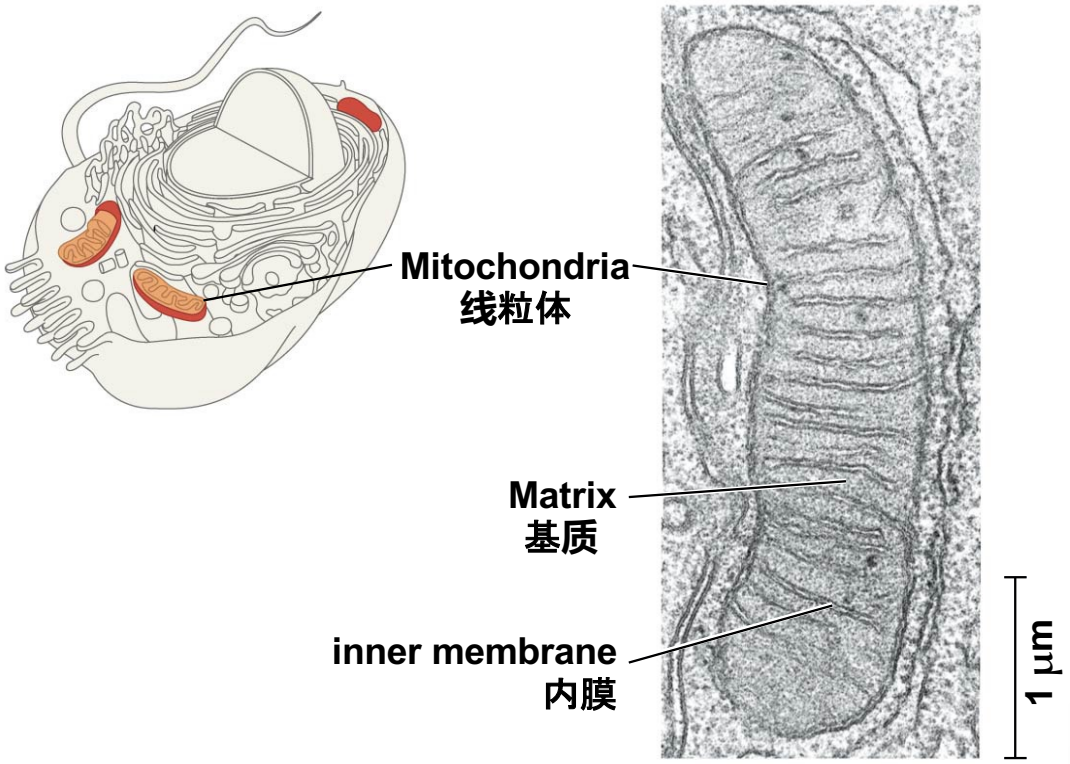
(a) Optimal temperature for two enzymes



(b) Optimal pH for two enzymes

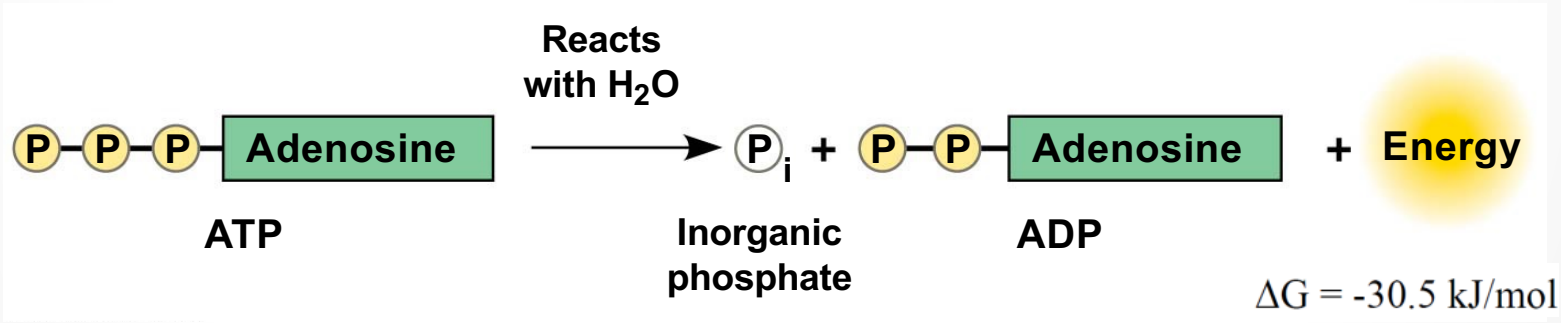
Enzymes in the Cell

- Enzymes for **cellular respiration** are located in **mitochondria线粒体**

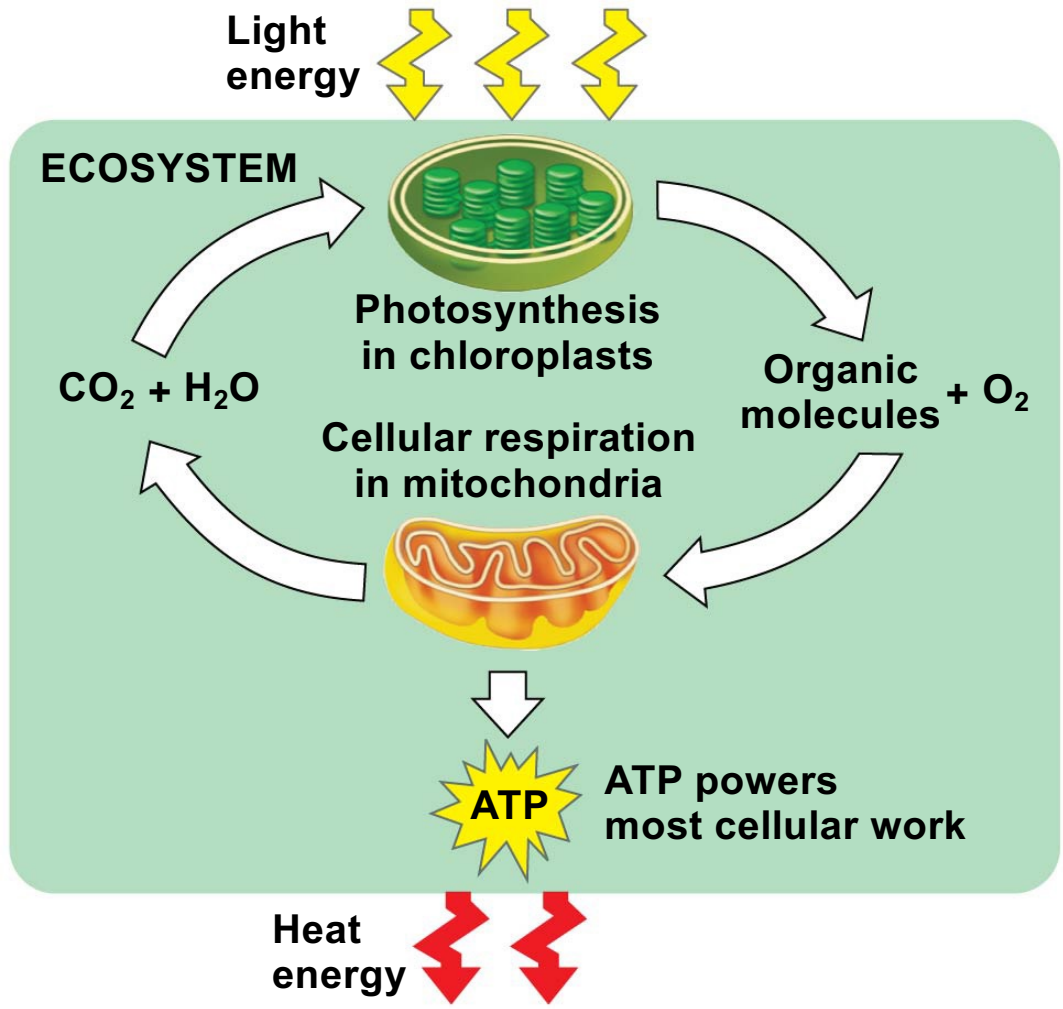


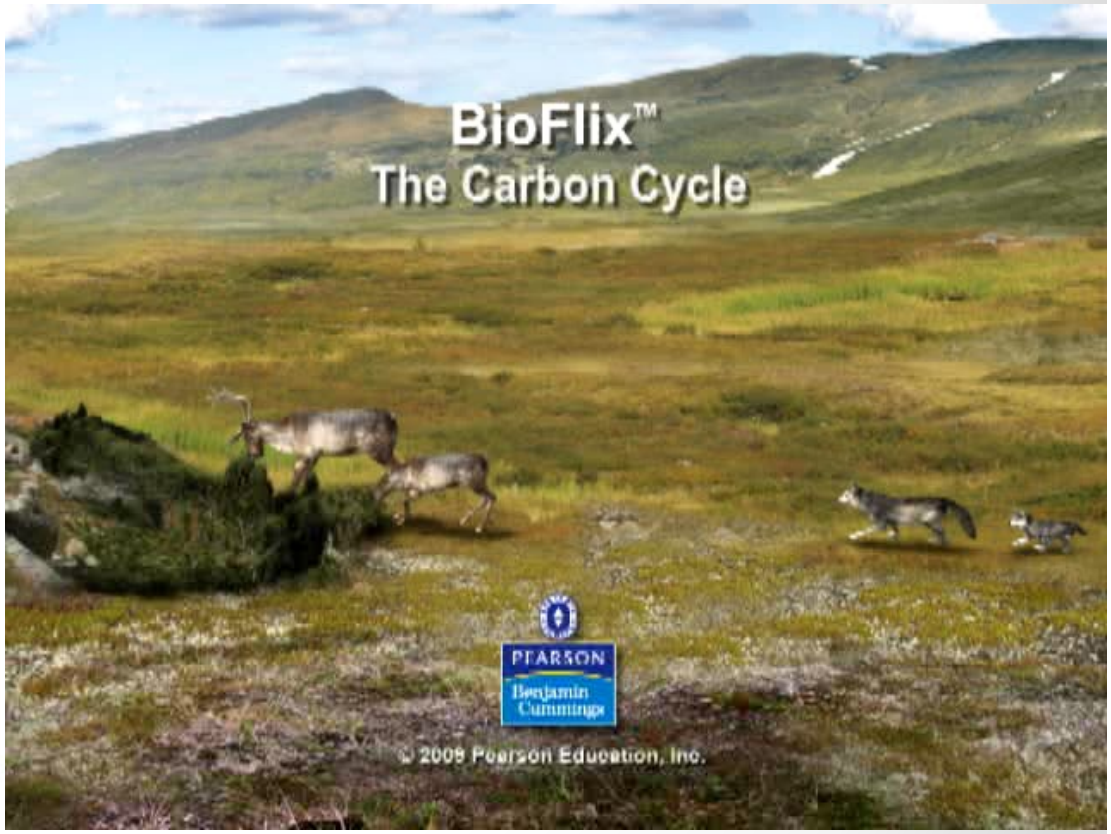
ATP (三磷酸腺苷)

- **Adenosine triphosphate (ATP)：** “能量货币”
- ATP stores the potential to react with water, a reaction that releases energy to be used by the cell (**ATP->ADP**, release energy: 30.5kJ/mol)



The carbon cycle





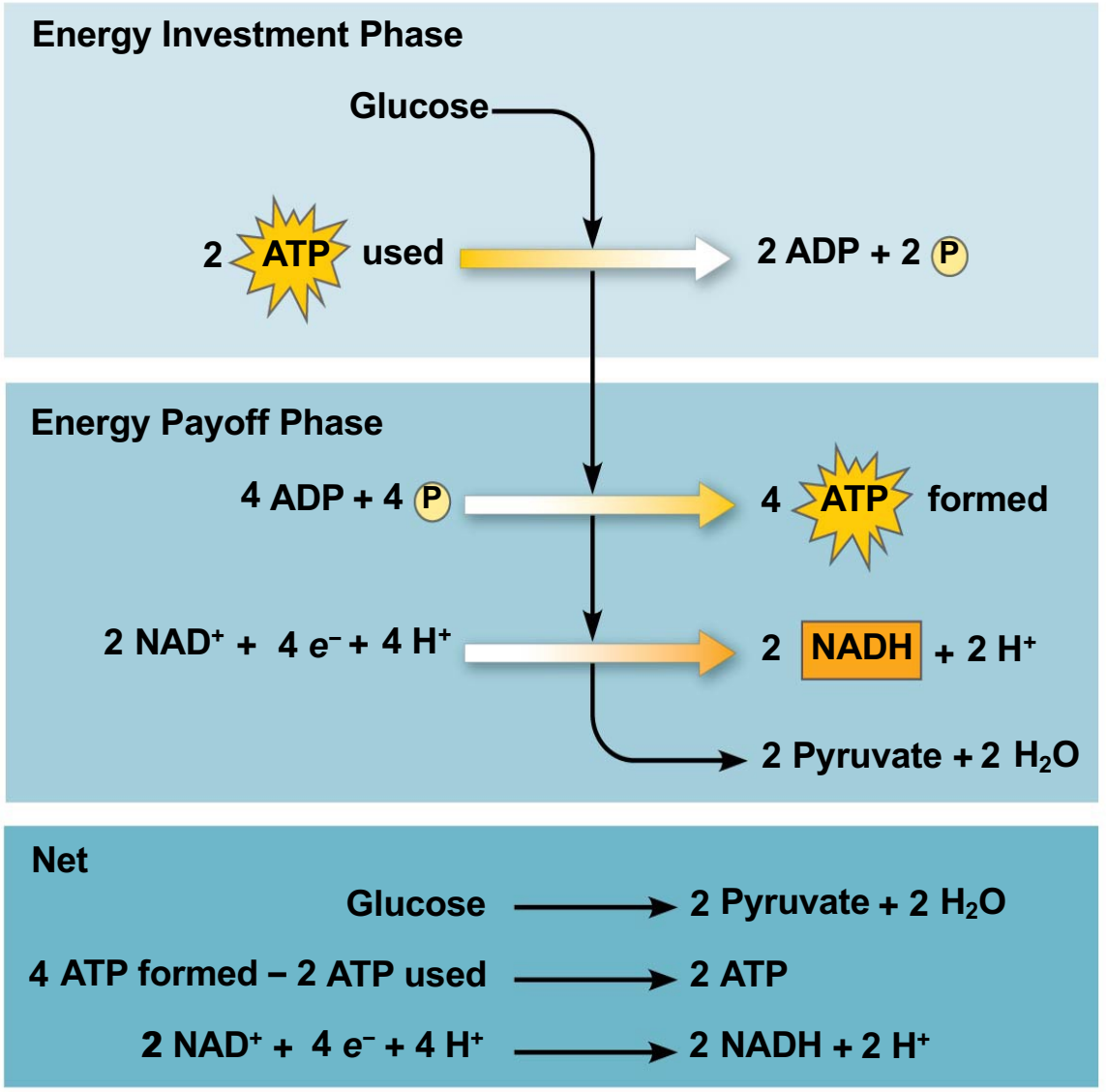
Cellular Respiration 细胞呼吸

- Step1：Glycolysis 糖酵解 (breaks down glucose into two molecules of pyruvate and produce ATP; **O_2 not needed**)

- Step 2: Pyruvate oxidation 丙酮酸氧化, citric acid cycle柠檬酸循环 and Oxidative phosphorylation 氧化磷酸化 (**O_2 needed**)

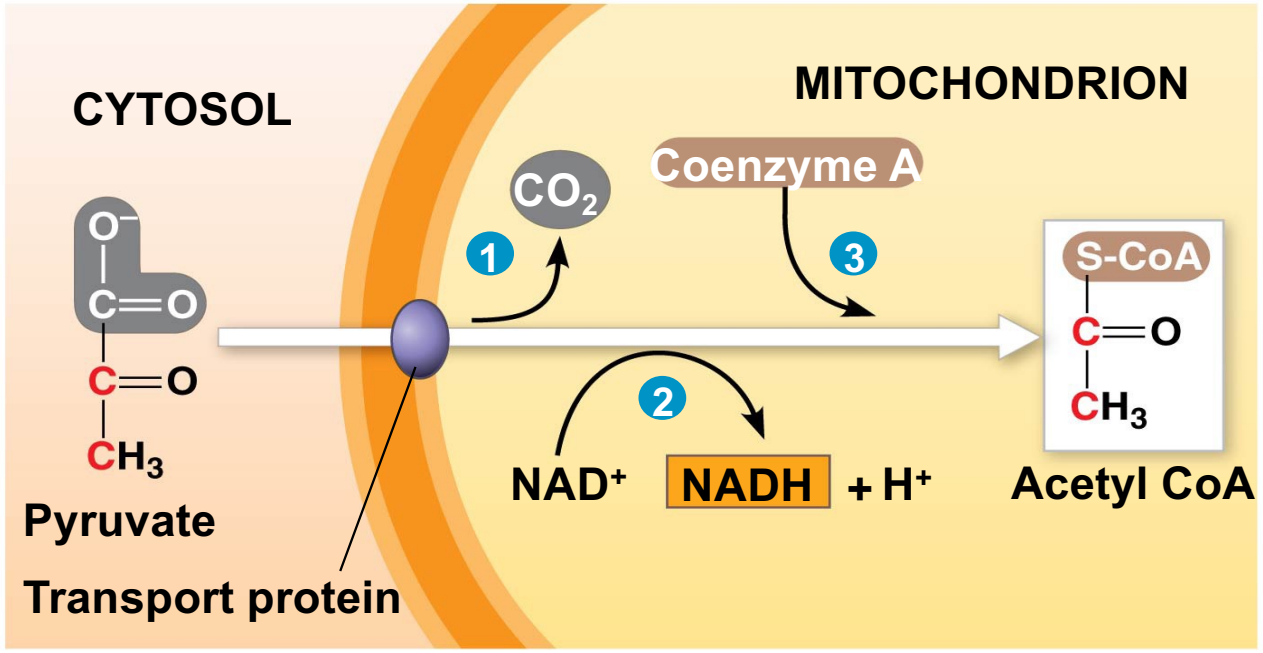
Glycolysis 糖酵解

- Glycolysis breaks down **glucose** 葡萄糖 into two molecules of **pyruvate** 丙酮酸
- Glycolysis occurs in the **cytoplasm** 细胞质 and has two major phases
  - Energy investment phase
  - Energy payoff phase
- Glycolysis does **NOT require O_2**



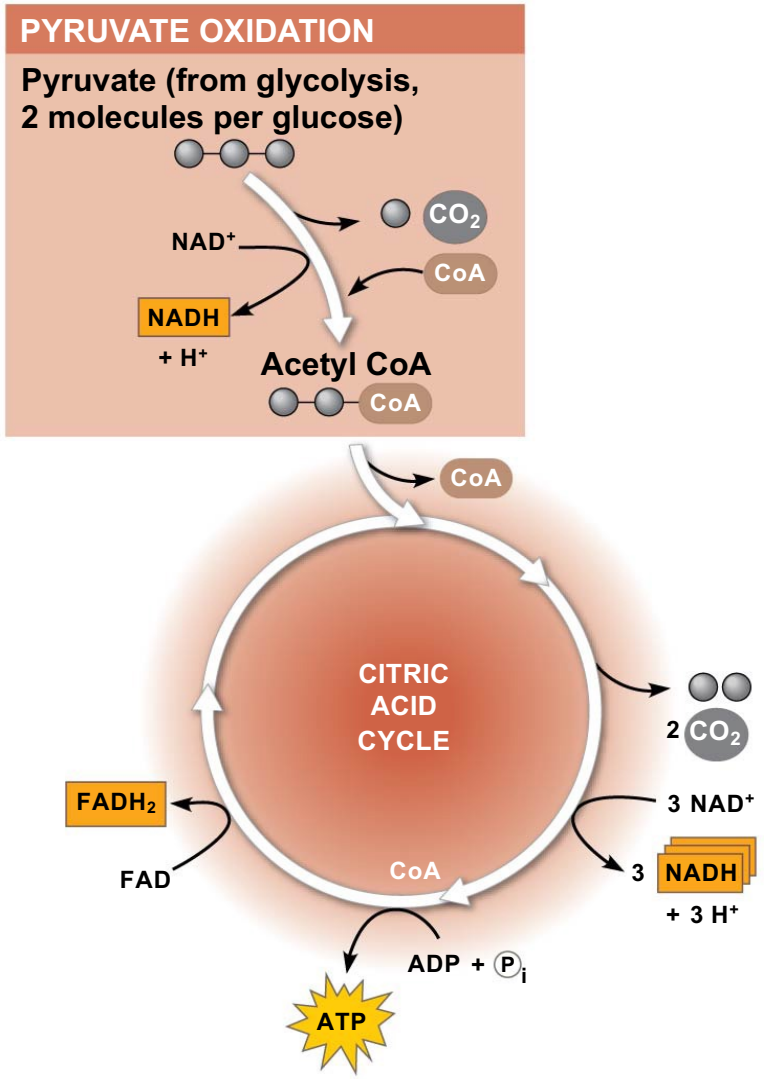
Pyruvate oxidation 丙酮酸氧化

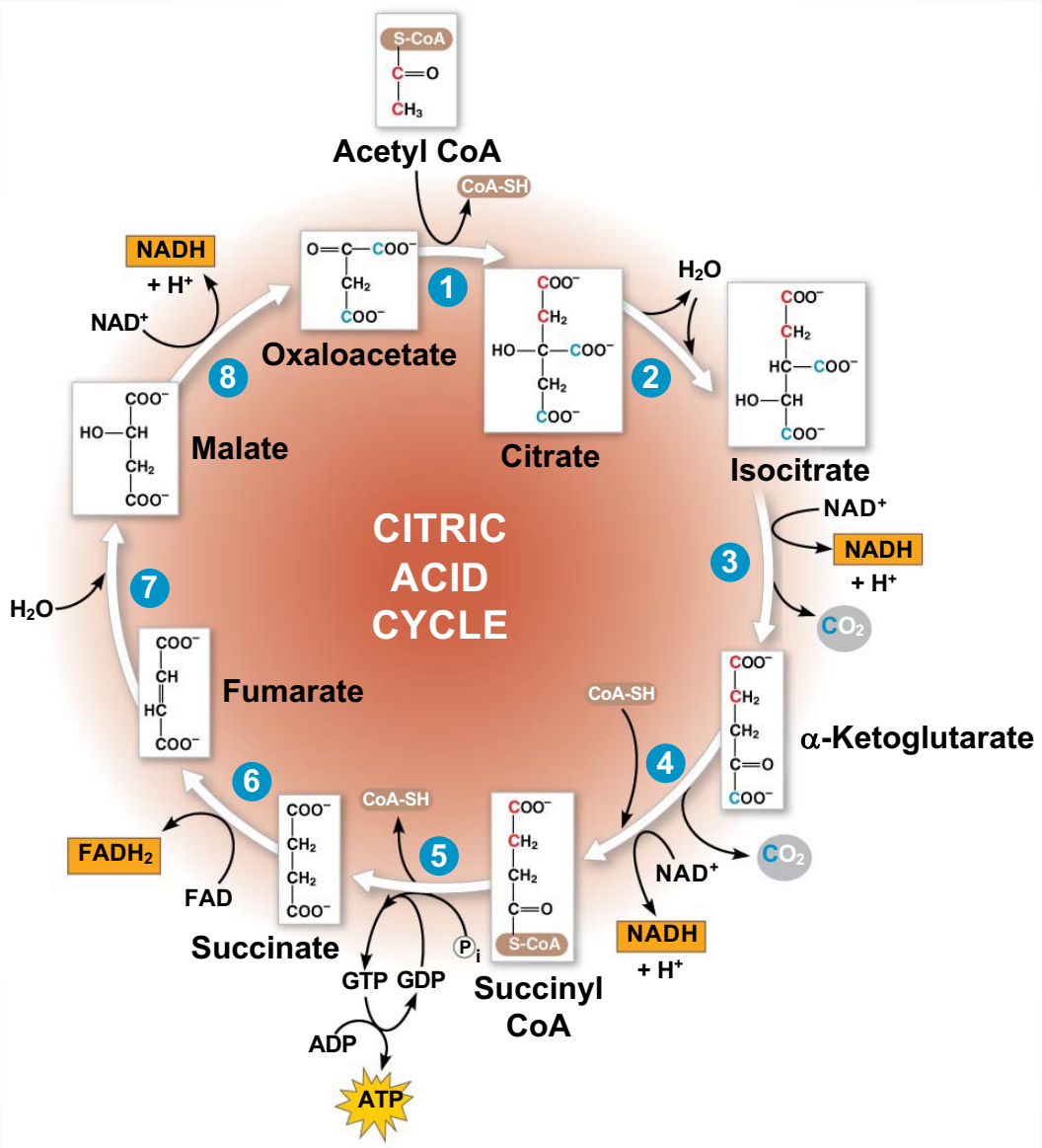
- In the presence of **O_2**, pyruvate 丙酮酸 enters the **mitochondrion** 线粒体 where the oxidation of glucose is completed
- Before the citric acid cycle can begin, pyruvate must be converted to acetyl Coenzyme A (**acetyl CoA,乙酰辅酶A**), which links glycolysis to the **citric acid cycle 柠檬酸循环**



The Citric Acid Cycle
柠檬酸循环

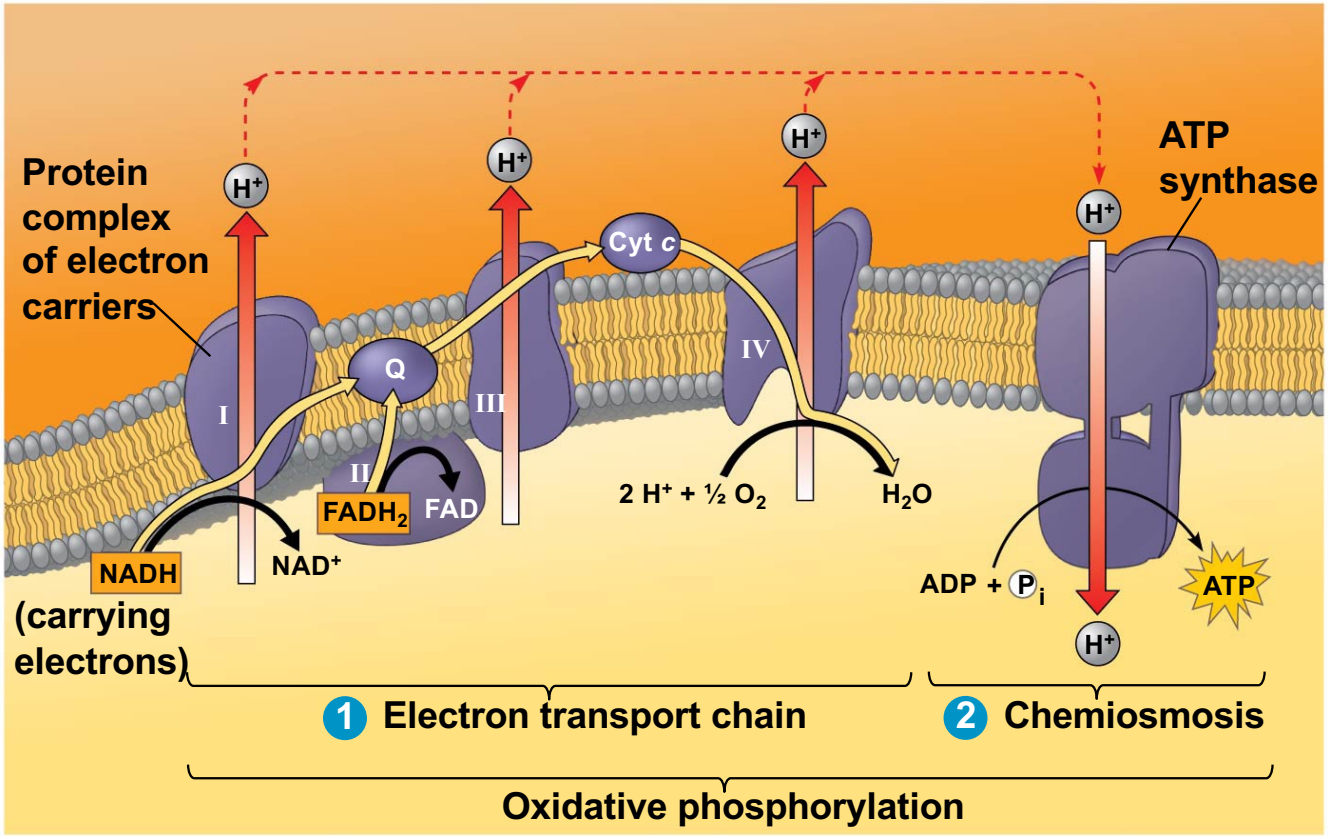
- The citric acid cycle, also called the **Krebs cycle**, completes the break down of **pyruvate** to **CO_2**
- The cycle oxidizes organic fuel derived from pyruvate, generating **1 ATP, 3 NADH,** and **1 $FADH_2$** per turn




CITRIC ACID CYCLE
Acetyl CoA
S-CoA
CoA-SH
Oxaloacetate
Citrate
Isocitrate
α-Ketoglutarate
Succinyl CoA
Succinate
Fumarate
Malate
NADH + H+
NAD+
H2O
CO2
FADH2
FAD
GTP GDP
ADP
ATP
Pi
1
2
3
4
5
6
7
8

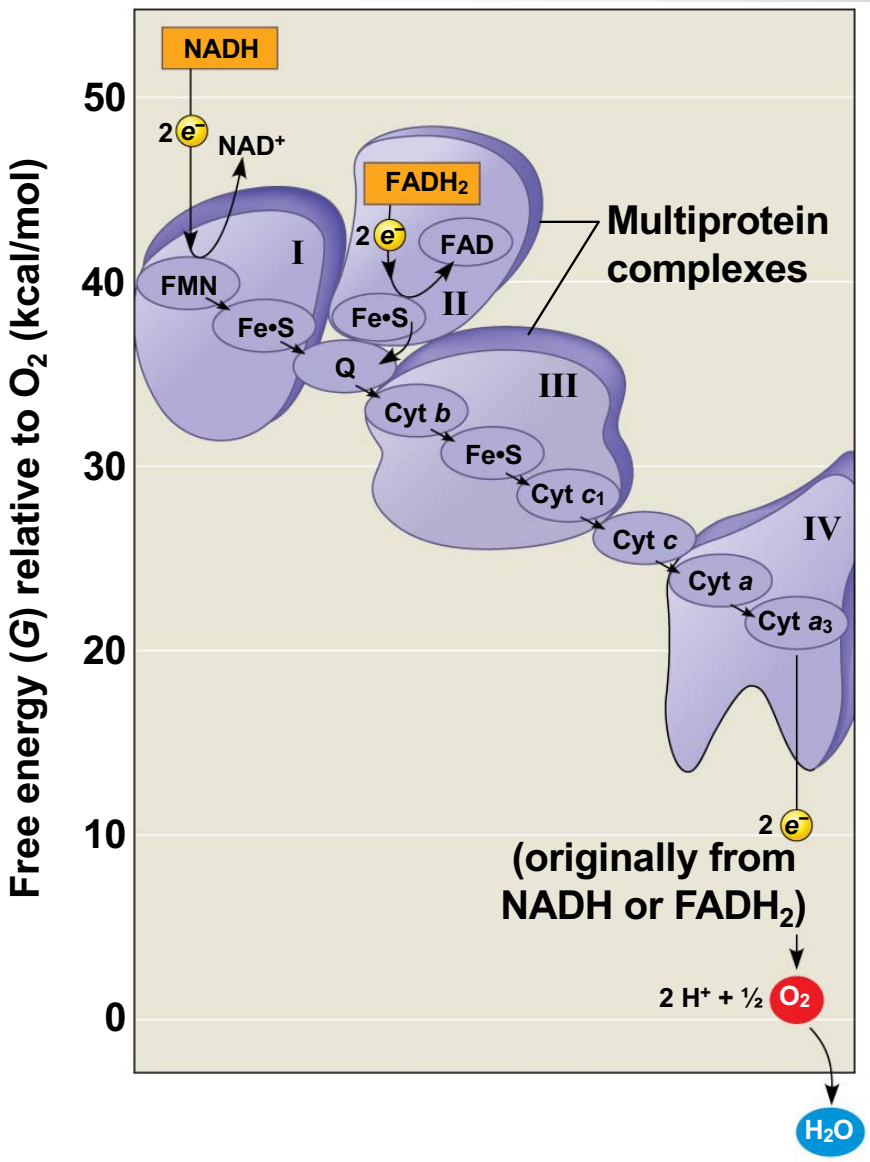
Oxidative phosphorylation 氧化磷酸化

- **NADH** and **$FADH_2$** transfer electrons to the **electron transport chain** 电子传递链, which powers ATP synthesis via **oxidative phosphorylation**氧化磷酸化



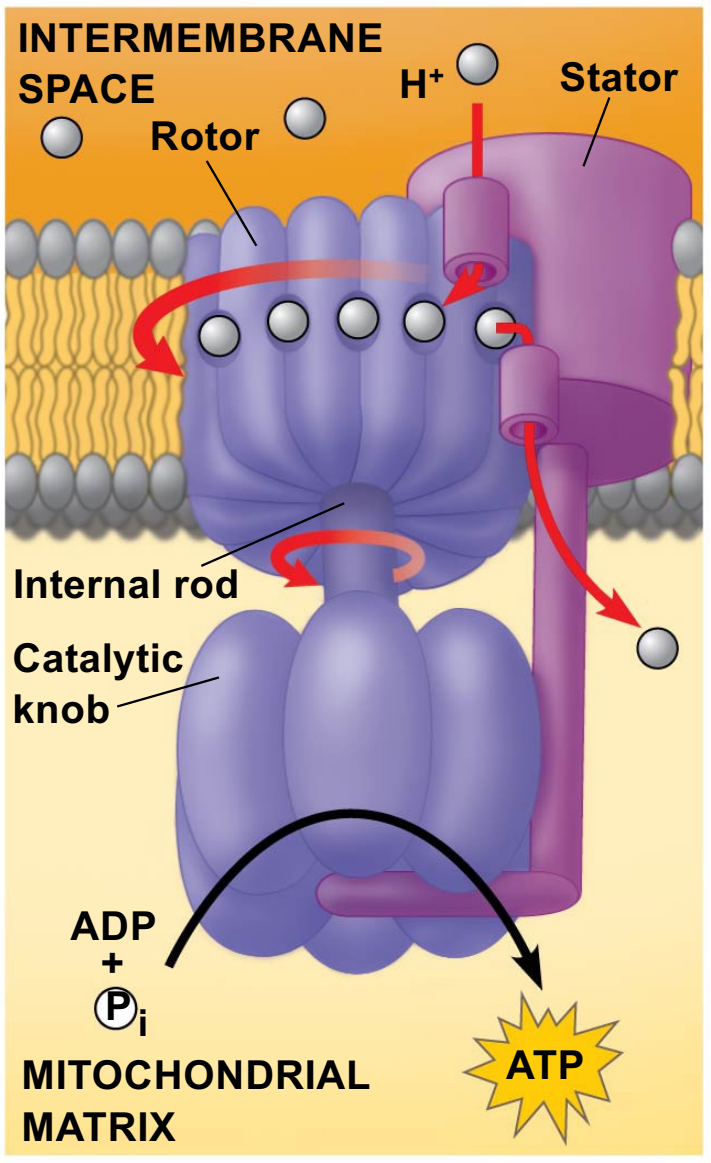
Electron Transport
电子传递链

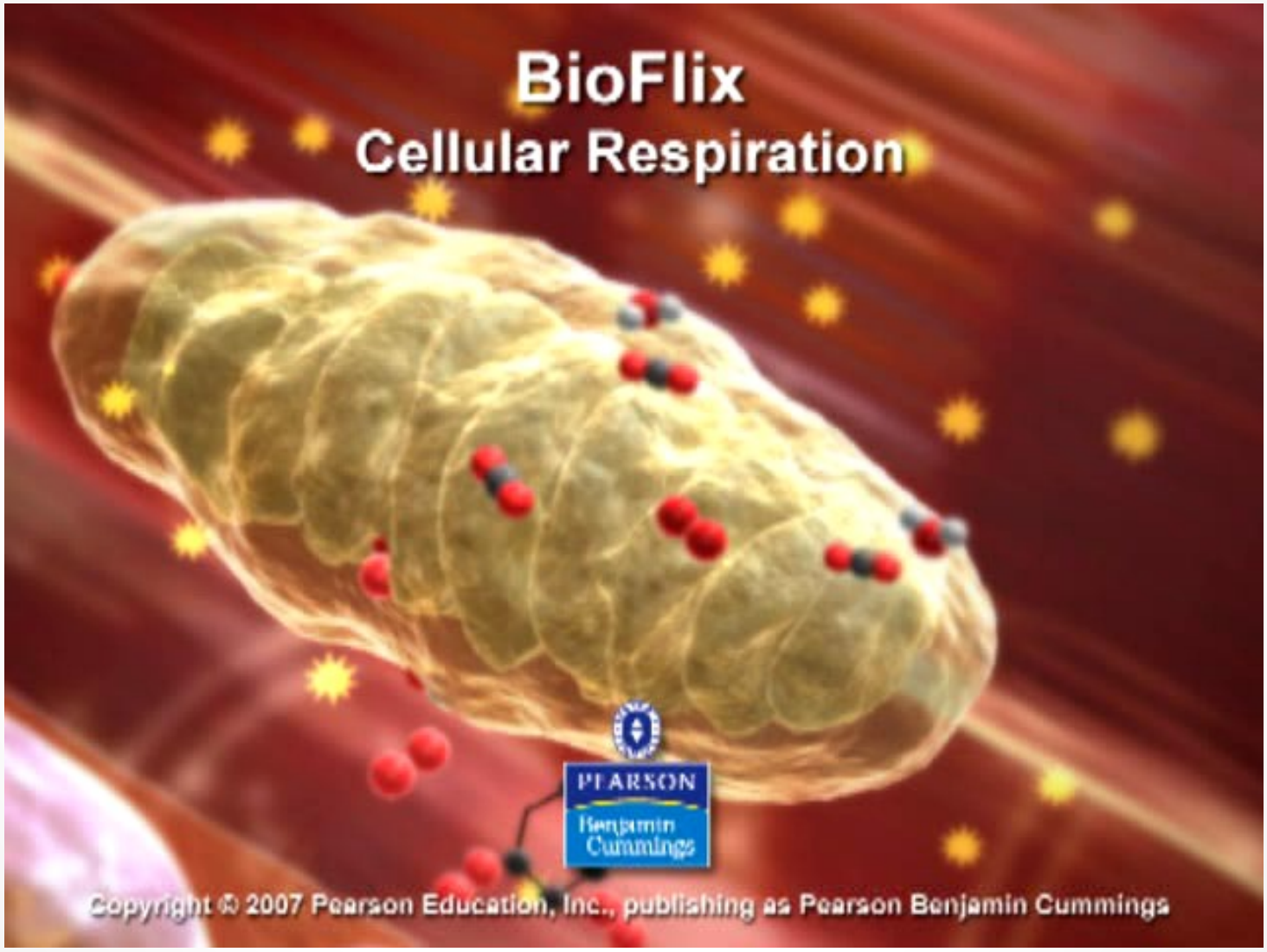
- 电子传递链使电子势能转变为质子跨膜运动，将质子从线粒体基质泵入线粒体内膜中
- 质子跨膜运动，产生电位差
- 质子通过ATP合成酶回返线粒体基质，伴随ATP生成，这一过程又称化学渗透
- $2H^+ + 2e^- + 1/2\ O_2 = H_2O$
- 电子传递链不直接产生ATP



Chemiosmosis 化学渗透

- 圆柱状蛋白质复合物嵌入膜内，充当分子马达。当质子流经过其内部时可推动马达顺时针转动。
- 转轴与分子马达和催化蛋白质相连，可与分子马达一道转动并激活催化蛋白质。
- 催化蛋白质位于基质一侧，可将无机磷酸根连接到ADP上生成ATP。
- Oxidation of **NADH** -> pump 10 H^+ -> **3 ATP**
- Oxidation of **$FADH_2$** -> pump 6 H^+ -> **2 ATP**




BioFlix
Cellular Respiration
PEARSON
Benjamin Cummings
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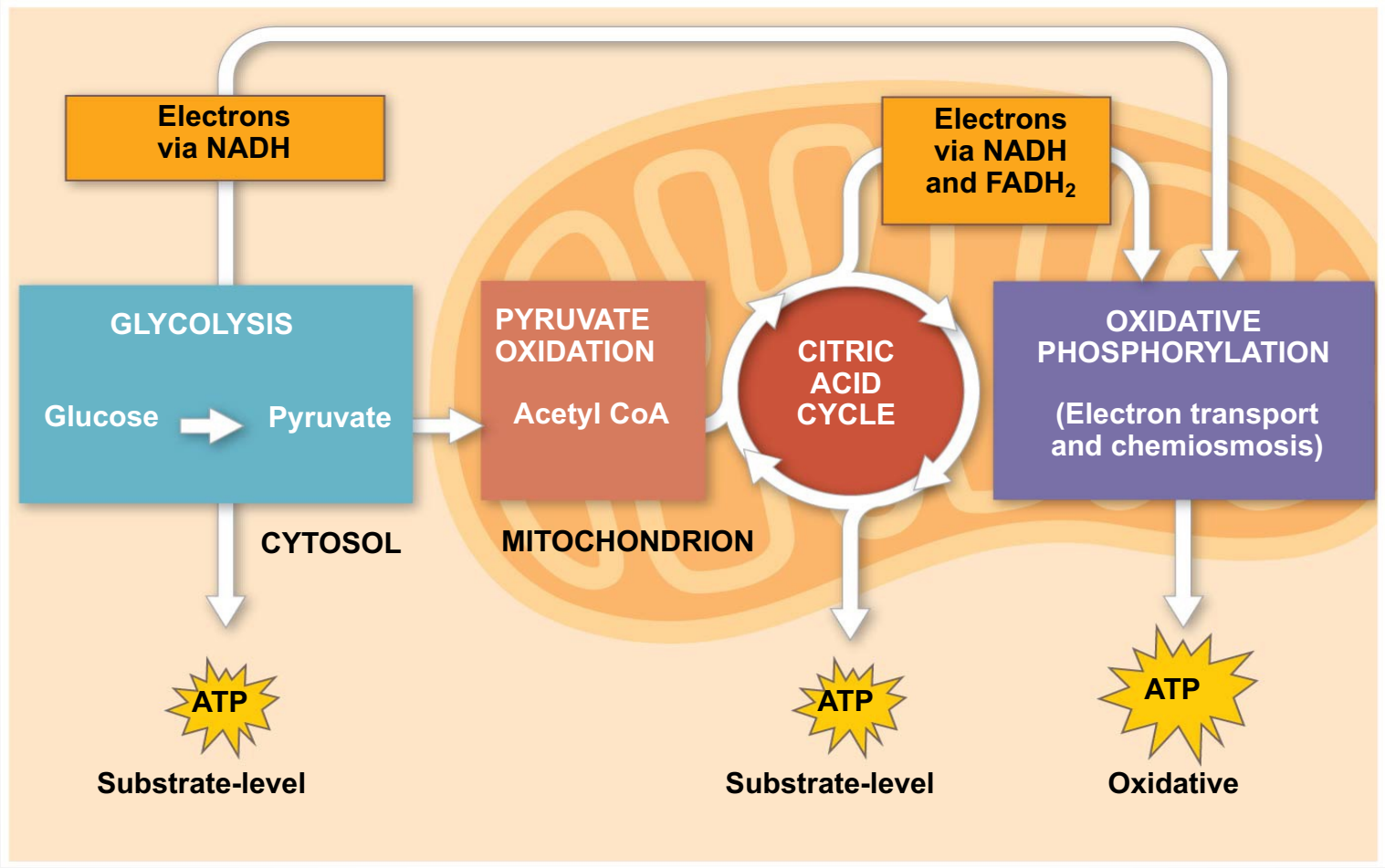
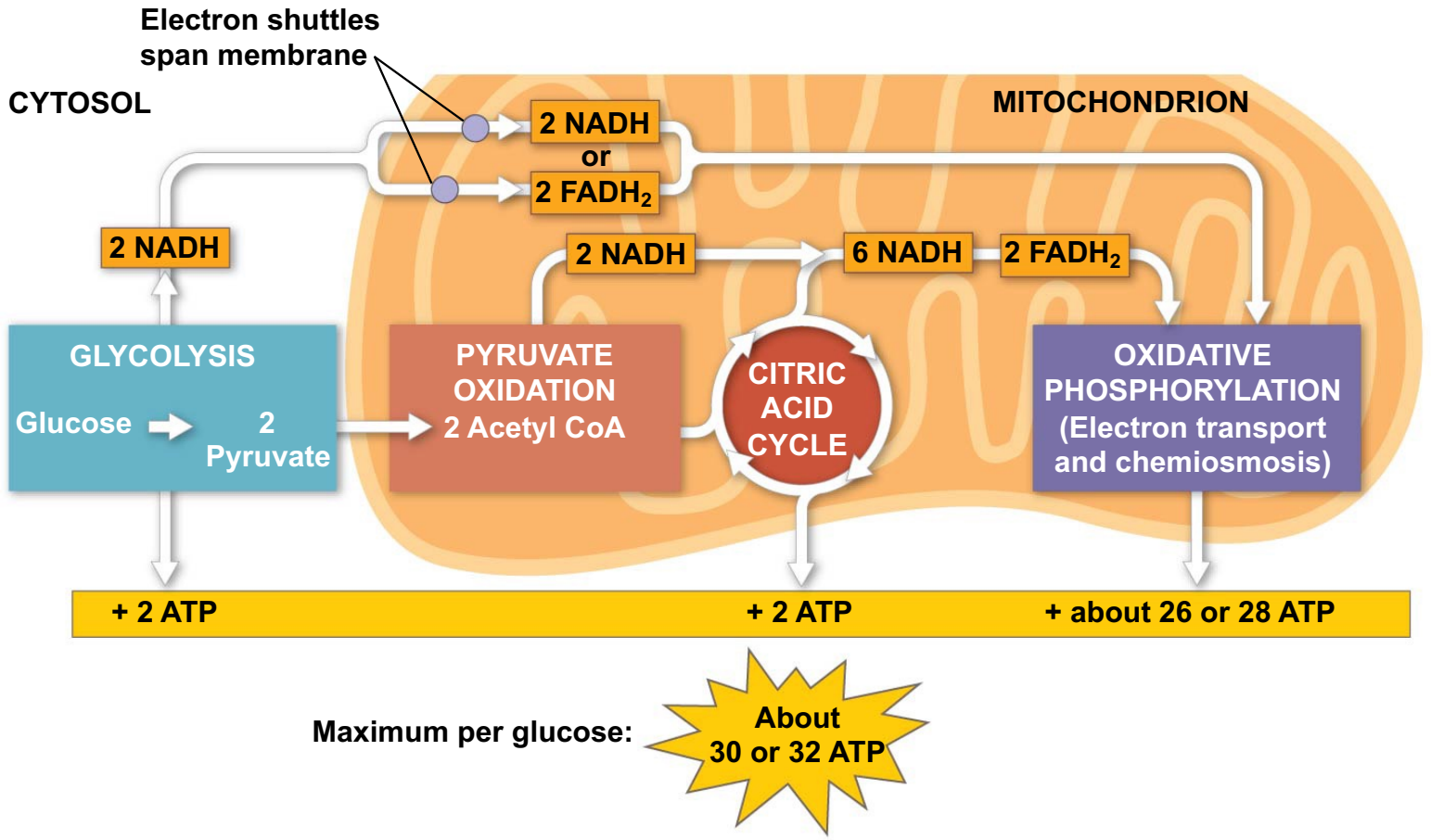
Cellular Respiration

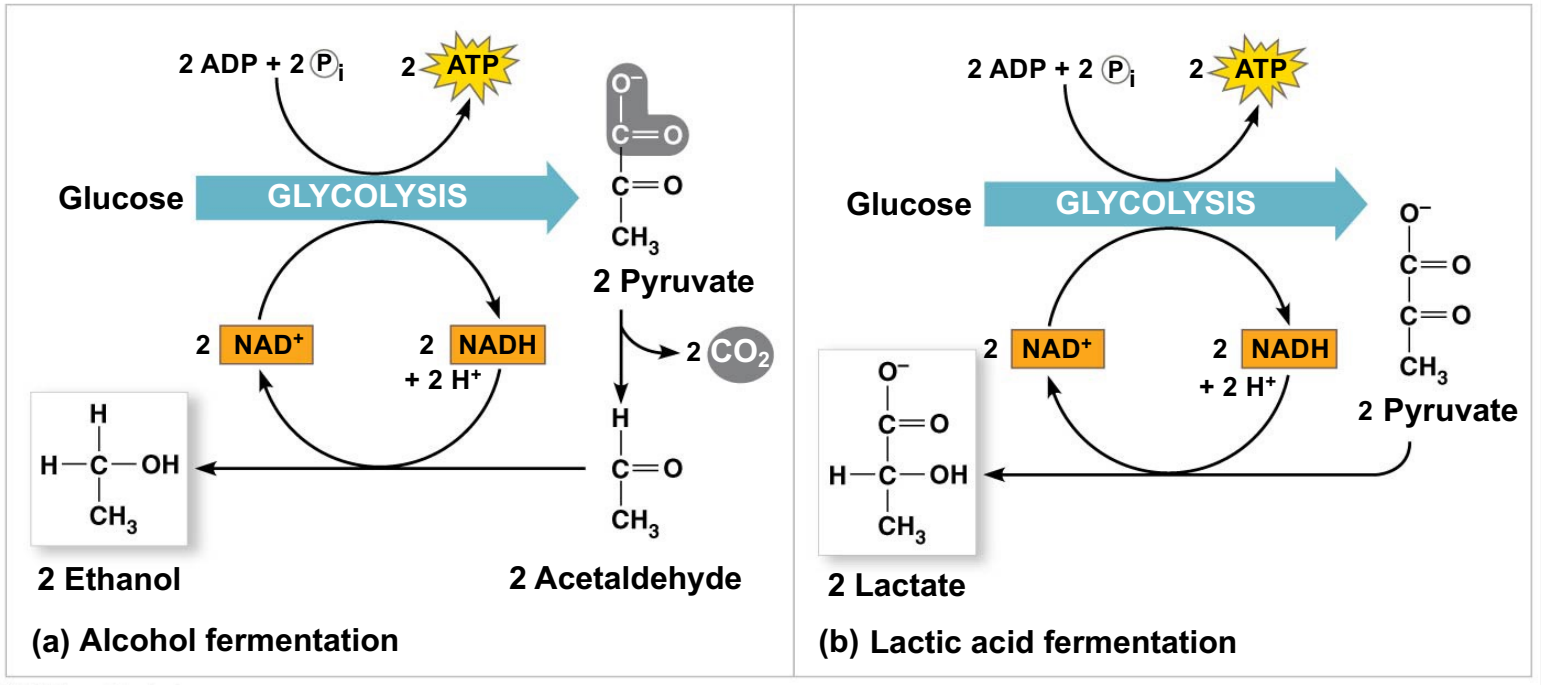


Accounting of ATP production

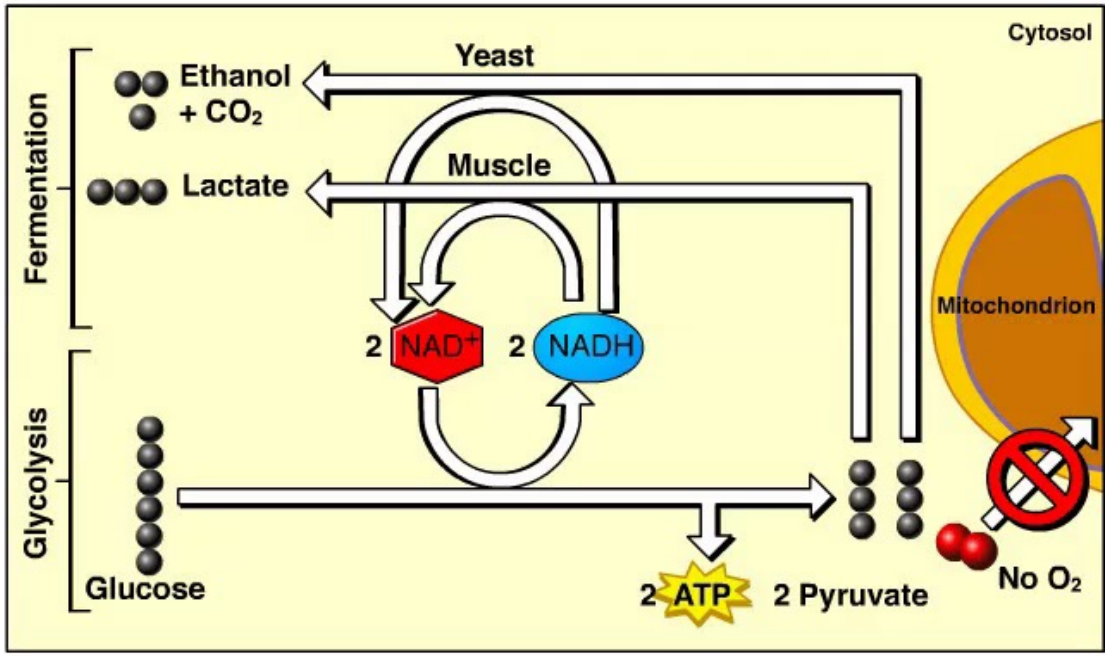


Fermentation: 发酵

- Fermentation: Two common types are **alcohol fermentation** （植物） and **lactic acid fermentation**（动物）

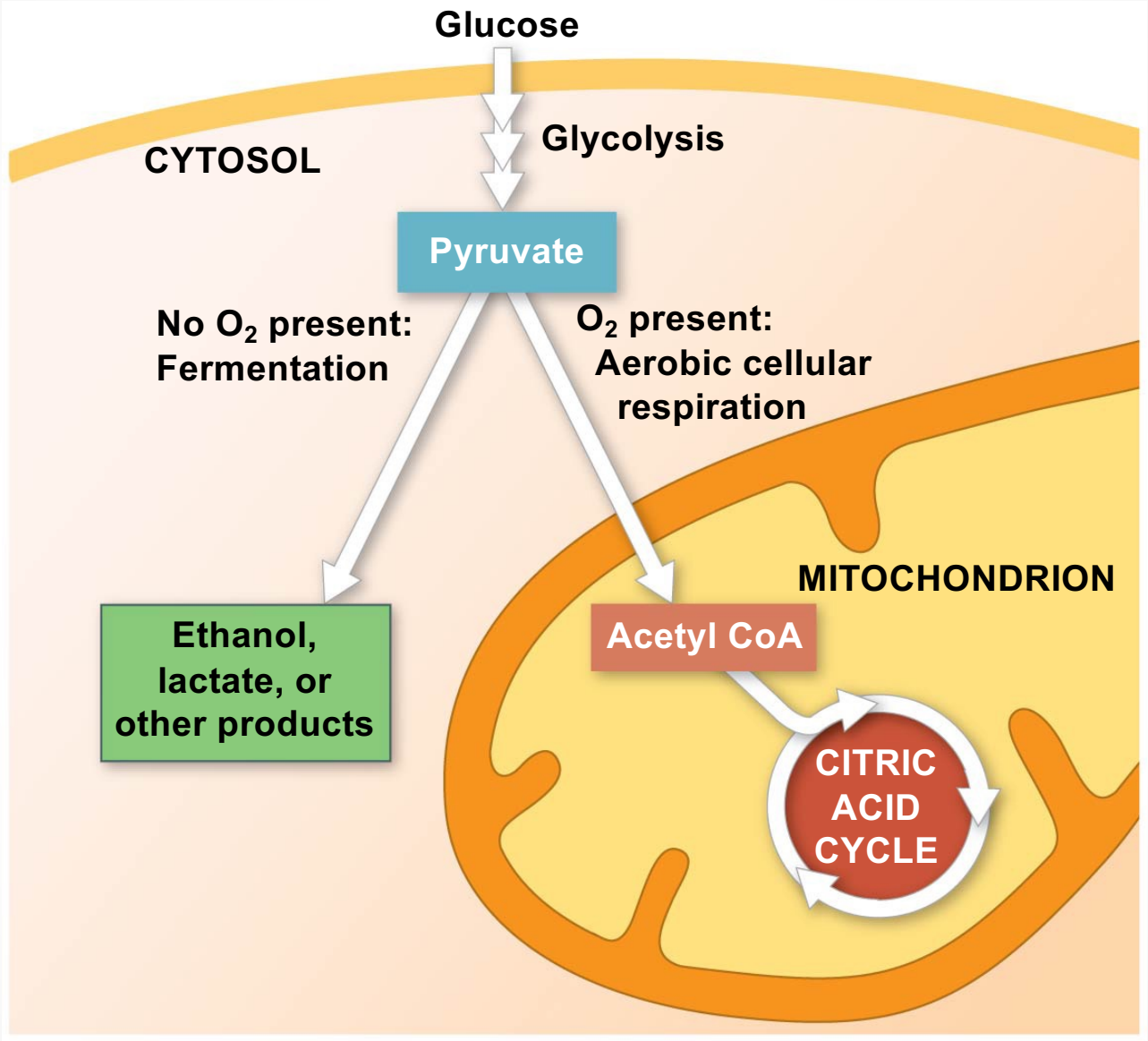


Animation: Fermentation Overview



Fermentation vs. Cellular Respiration

- Use glycolysis (net ATP = **2**) to oxidize glucose
- The processes have different mechanisms for oxidizing NADH:
  - Fermentation: an organic molecule (pyruvate or acetaldehyde) acts as a final electron acceptor
  - Cellular respiration: electrons are transferred to the **electron transport chain**
- Fermentation: **2** ATP per glucose molecule
- Cellular respiration: **30** ATP per glucose molecule;


Glucose
CYTOSOL
Glycolysis
Pyruvate
No O_2 present:
Fermentation
O_2 present:
Aerobic cellular
respiration
MITOCHONDRION
Ethanol,
lactate, or
other products
Acetyl CoA
CITRIC
ACID
CYCLE

The Versatility of Catabolism

- Glycolysis accepts a wide range of **carbohydrates** 碳水化合物
- **Proteins** must be digested to amino acids; amino groups can feed glycolysis or the citric acid cycle
- **Fats** are digested to glycerol 甘油 (-> glycolysis) and fatty acids 脂肪酸 (-> acetyl CoA)
- 1g fat can produce more than twice as much ATP as 1g carbohydrate