微生物学
Microbiology

Lecture 8

2017.11.14

CHAPTER 11

Catabolism: Energy Release and Conservation

Outline

- Chemoorganotrophic Fueling Processes
- Chemolithotrophic Fueling Processes
- Phototrophic Fueling Processes

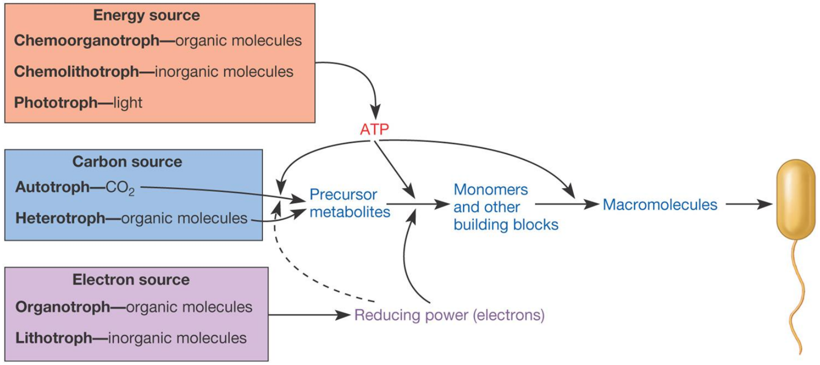
- *It is in the fueling reactions that bacteria display their extraordinary metabolic diversity and versatility. Bacteria have evolved to thrive in almost all natural environments, regardless of the nature of available sources of carbon, energy, and reducing power. . . .The collective*

metabolic capacities of bacteria allow them to metabolize virtually every organic compound on this planet. . . .

—F.C. Neidhardt,

J . L. Ingraham, and M. Schaechter

Fueling Reactions



Energy, electron, and carbon sources all are used to generate **three main products**:

ATP, conserve the energy supplied by an energy source;

Reducing power, serve as a ready supply of electrons for a variety of chemical reactions;

Precursor metabolites, provide the carbon skeletons needed for biosynthesis of important chemical building blocks (monomers)

The Fueling Reactions and Their Role in Metabolism.

Metabolism is the total of all chemical reactions in the cell and is divided into two parts

Catabolism

- Fueling reactions产能反应
- energy-conserving reactions
- provide reducing power (electrons)还原力
- generate precursors前体 for biosynthesis

Anabolism

- the synthesis of complex organic molecules from simpler ones
- requires energy from fueling reactions

The flow of energy and the participation of enzymes make metabolism possible

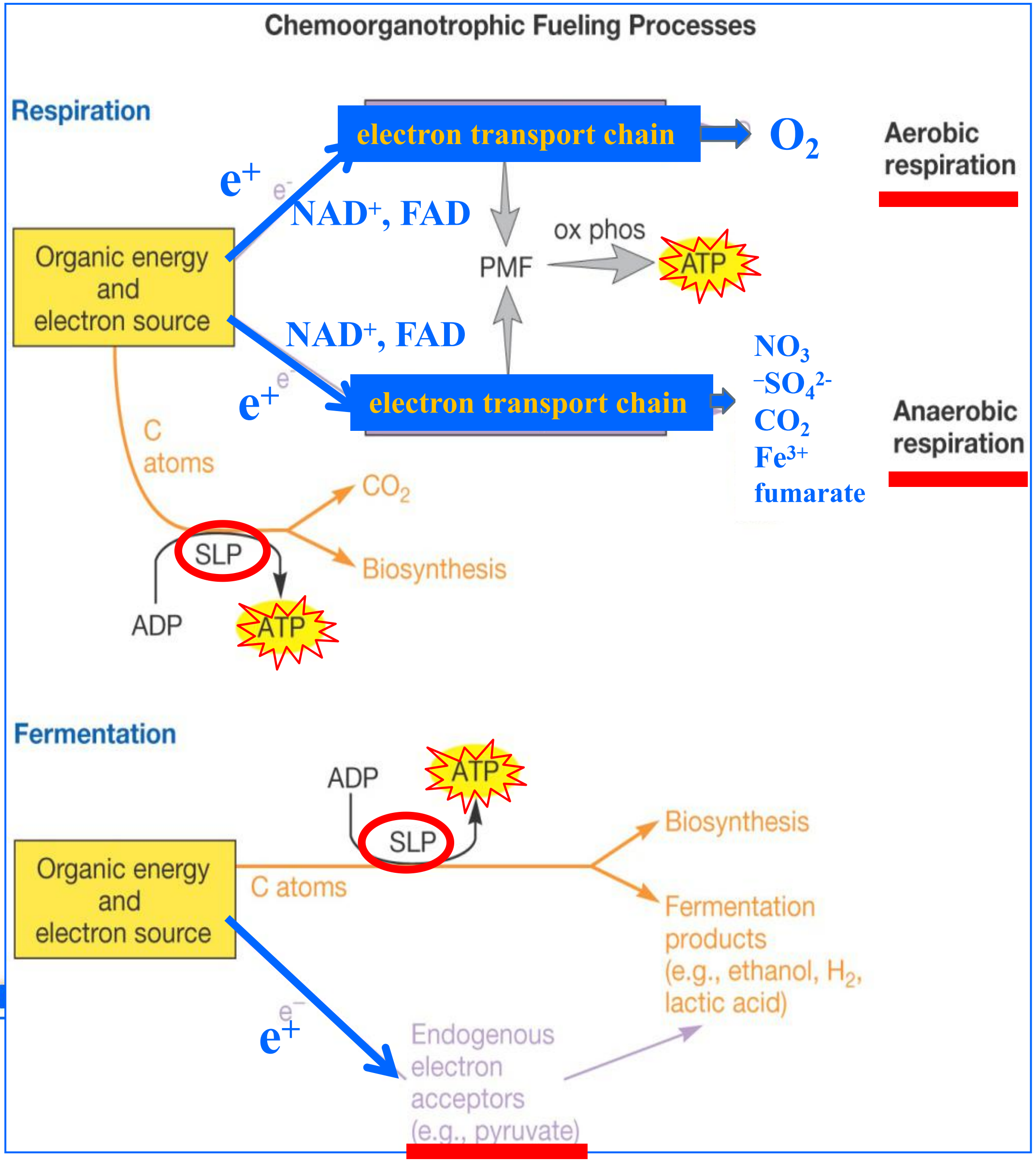
Chemoorganotrophic fueling processes

化能有机营养型的产能代谢-能量来自有机物

- **Respiration**呼吸作用
- **exogenous** 外源的final electron acceptor
- ATP made primarily by Oxidative Phosphorylation through ETC-PMF.

  Aerobic/Anaerobic
- **Fermentation**发酵作用
- **endogeneous**内源的final electron acceptor
- ATP made primarily by Substrate-Level Phosphorylatio

  no ETC involved.

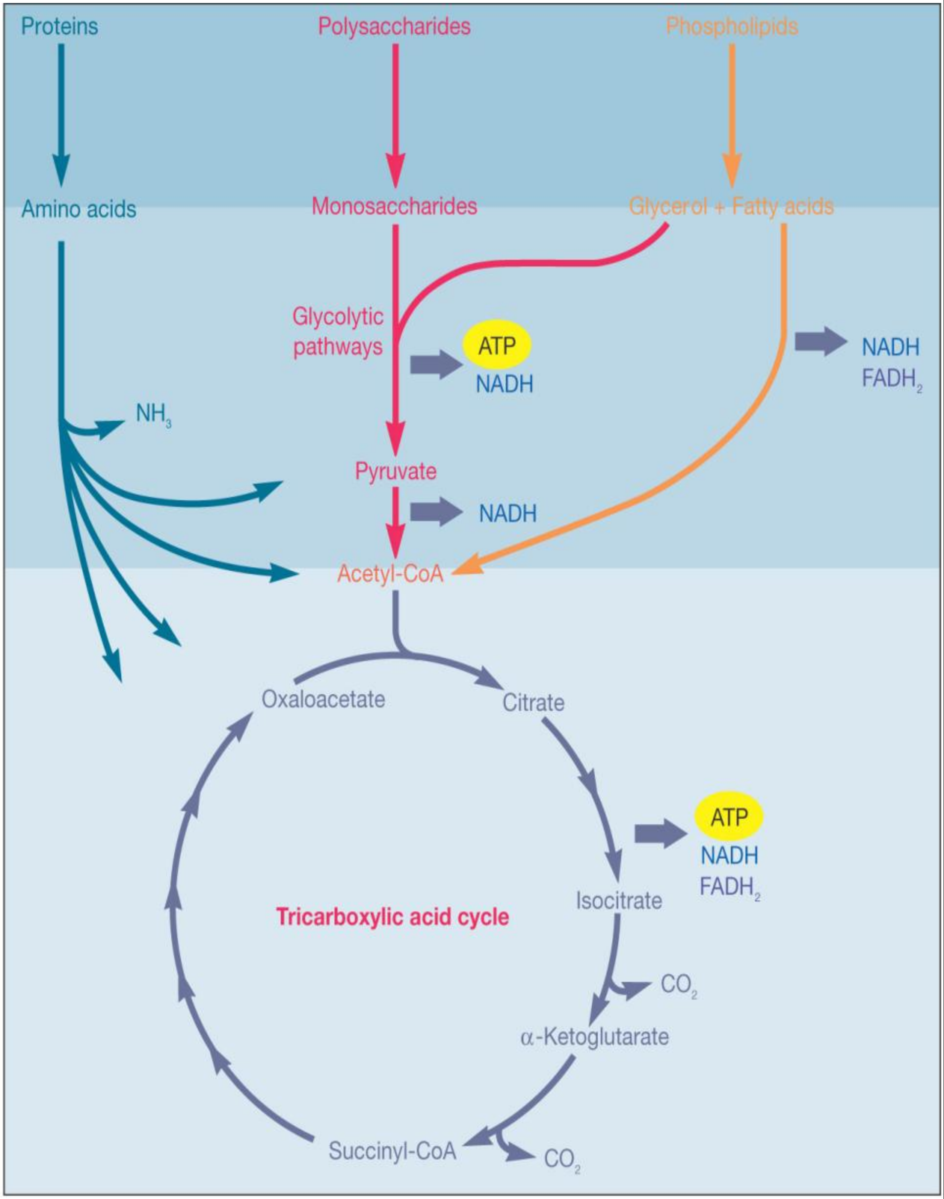


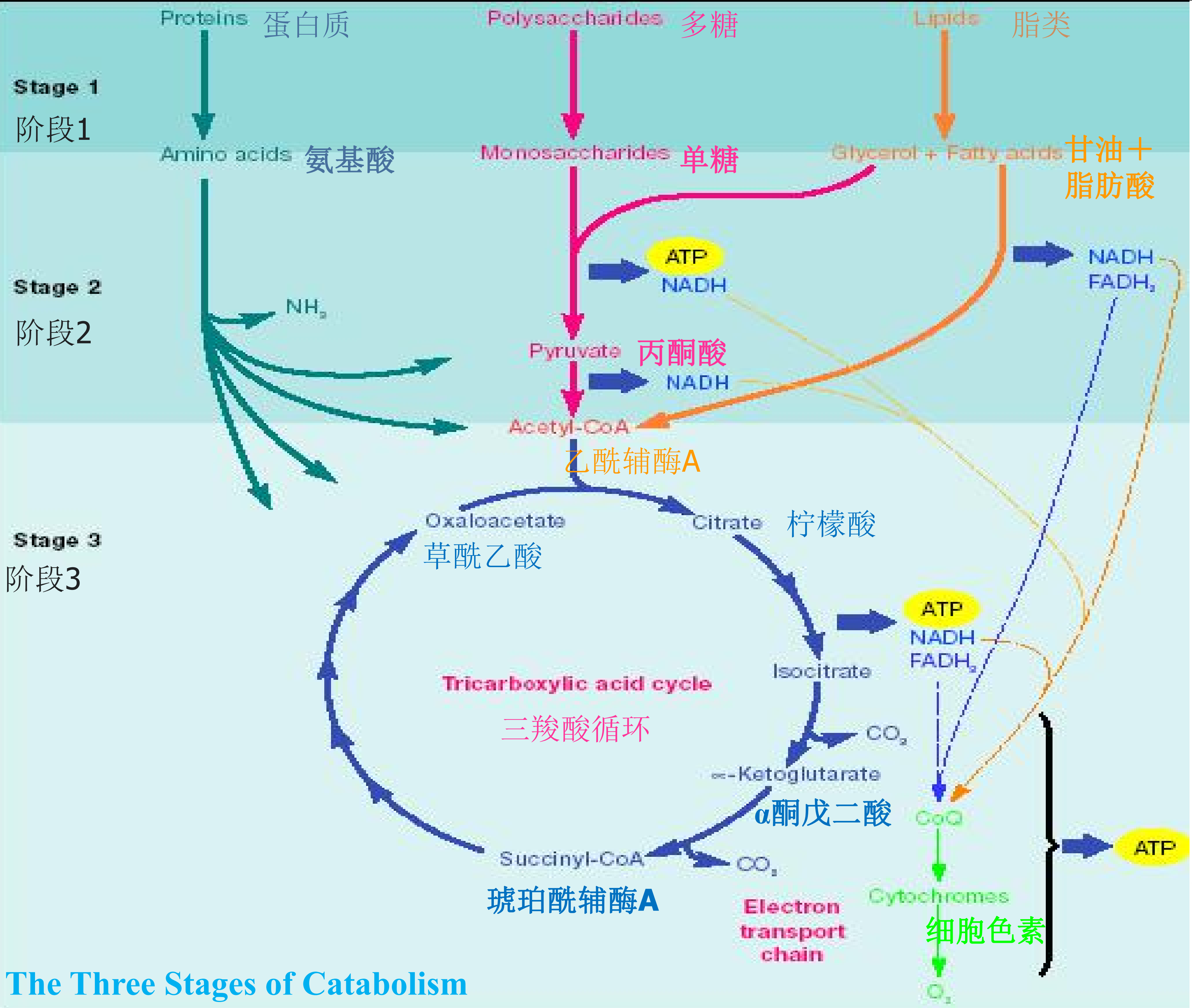
Aerobic respiration-O_2

- process that can completely catabolize an organic energy source to CO_2 using
  - glycolytic pathways (glycolysis)糖酵解
  - TCA cycle三羧酸循环
  - ETC with oxygen as the final electron acceptor
- produces ATP, and high energy electron carriers

Energy produce-Glucose metabolism

- many different organic molecules used as energy sources
- most pathways generate glucose or intermediates of the pathways used in glucose metabolism
- few pathways greatly increase metabolic efficiency
- Glucose metabolism





Proteins 蛋白质

Polysaccharides 多糖

Lipids 脂类

Stage 1

阶段1

Amino acids 氨基酸

Monosaccharides 单糖

Glycerol + Fatty acids 甘油＋脂肪酸

Stage 2

阶段2

ATP

NADH

NADH

$FADH_2$

NH_3

Pyruvate 丙酮酸

NADH

Acetyl-CoA

乙酰辅酶A

Stage 3

阶段3

Oxaloacetate

草酰乙酸

Citrate 柠檬酸

ATP

NADH

$FADH_2$

Isocitrate

Tricarboxylic acid cycle

三羧酸循环

CO_2

α-Ketoglutarate

α酮戊二酸

CoQ

Succinyl-CoA

CO_2

琥珀酰辅酶A

ATP

Electron transport chain

Cytochromes

细胞色素

O_2

The Three Stages of Catabolism

The breakdown of glucose to pyruvate

- three common routes-glycolysis
  - Embden-Meyerhof pathway
  - Pentose phosphate pathway(Hexose monophosphate *pathway)*戊糖磷酸途径
  - Entner-Duodoroff pathway(*agrobacterium,G*$^-$)

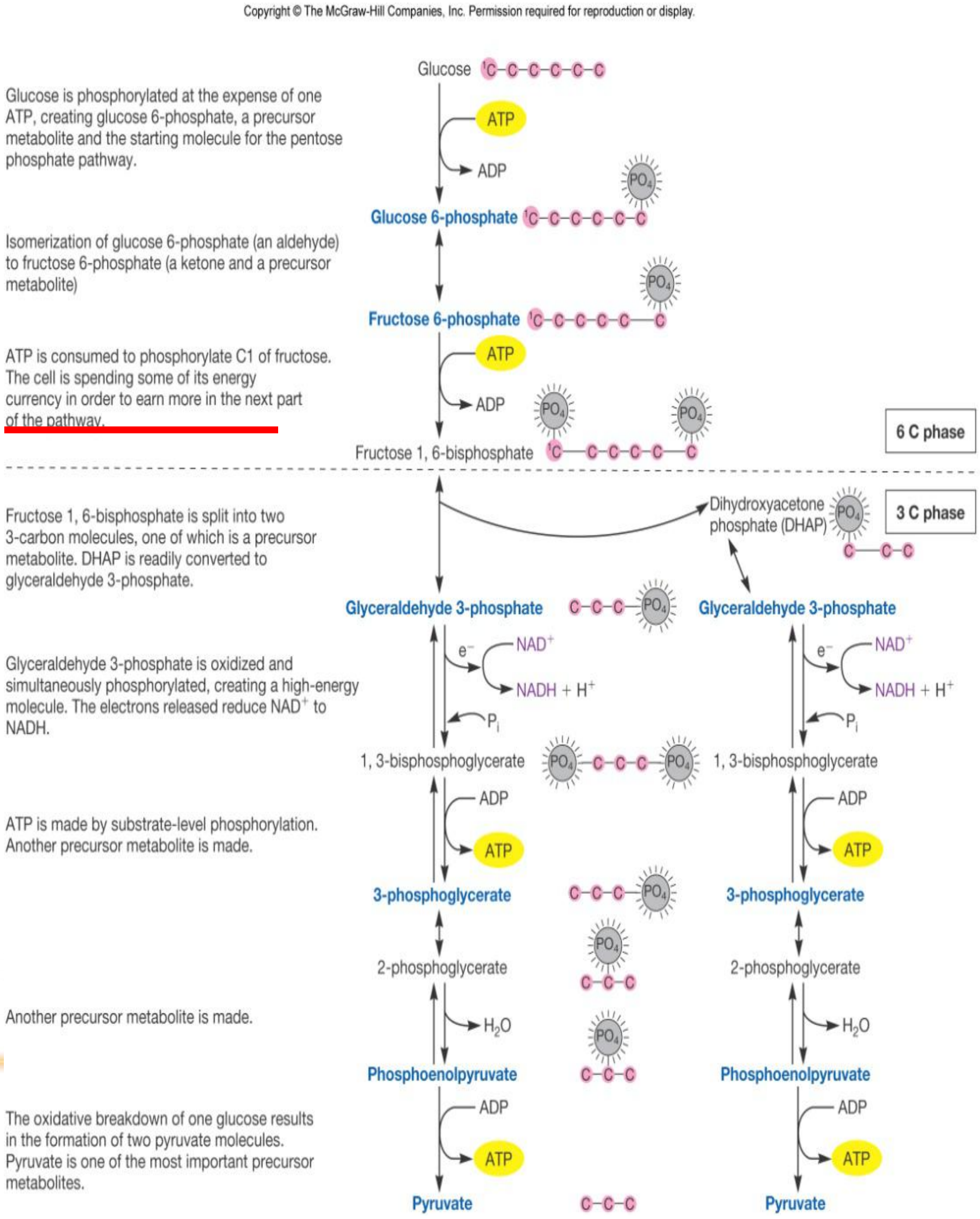
The Embden-Meyerhof Pathway

- **occurs in cytoplasmic matrix of most microorganisms, plants, and animals**
- **the most common pathway for glucose degradation to pyruvate in stage two of aerobic respiration**
- **function in presence or absence of O_2**

addition of phosphates "primes the pump"

oxidation step – generates NADH

high-energy molecules – used to synthesize ATP by substrate-level phosphorylation



Glucose is phosphorylated at the expense of one ATP, creating glucose 6-phosphate, a precursor metabolite and the starting molecule for the pentose phosphate pathway.

Isomerization of glucose 6-phosphate (an aldehyde) to fructose 6-phosphate (a ketone and a precursor metabolite)

ATP is consumed to phosphorylate C1 of fructose. The cell is spending some of its energy currency in order to earn more in the next part of the pathway.

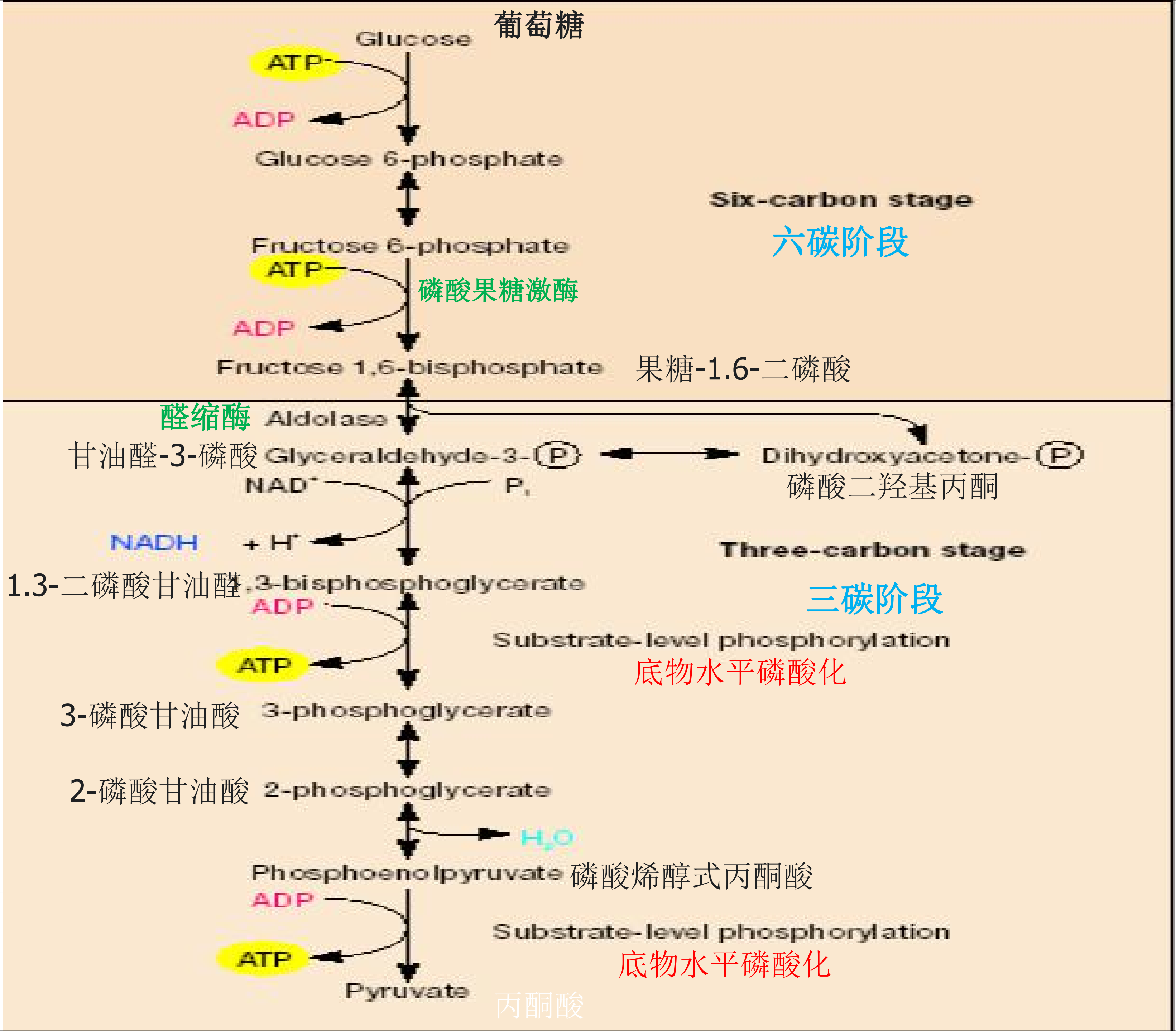
Fructose 1, 6-bisphosphate is split into two 3-carbon molecules, one of which is a precursor metabolite. DHAP is readily converted to glyceraldehyde 3-phosphate.

Glyceraldehyde 3-phosphate is oxidized and simultaneously phosphorylated, creating a high-energy molecule. The electrons released reduce NAD^+ to NADH.

ATP is made by substrate-level phosphorylation. Another precursor metabolite is made.

Another precursor metabolite is made.

The oxidative breakdown of one glucose results in the formation of two pyruvate molecules. Pyruvate is one of the most important precursor metabolites.



葡萄糖

Glucose

ATP

ADP

Glucose 6-phosphate

Six-carbon stage

六碳阶段

Fructose 6-phosphate

ATP

磷酸果糖激酶

ADP

Fructose 1,6-bisphosphate 果糖-1.6-二磷酸

醛缩酶 Aldolase

甘油醛-3-磷酸 Glyceraldehyde-3-Ⓟ ⟷ Dihydroxyacetone-Ⓟ

磷酸二羟基丙酮

NAD$^+$ P$_i$

NADH + H$^+$

Three-carbon stage

1.3-二磷酸甘油醛 1,3-bisphosphoglycerate

三碳阶段

ADP

Substrate-level phosphorylation

底物水平磷酸化

ATP

3-磷酸甘油酸 3-phosphoglycerate

2-磷酸甘油酸 2-phosphoglycerate

H_2O

Phosphoenolpyruvate 磷酸烯醇式丙酮酸

ADP

Substrate-level phosphorylation

底物水平磷酸化

ATP

Pyruvate 丙酮酸

Summary of glycolysis

$$\text{glucose} + 2\text{ADP} + 2\text{P}_i + 2\text{NAD}^+$$

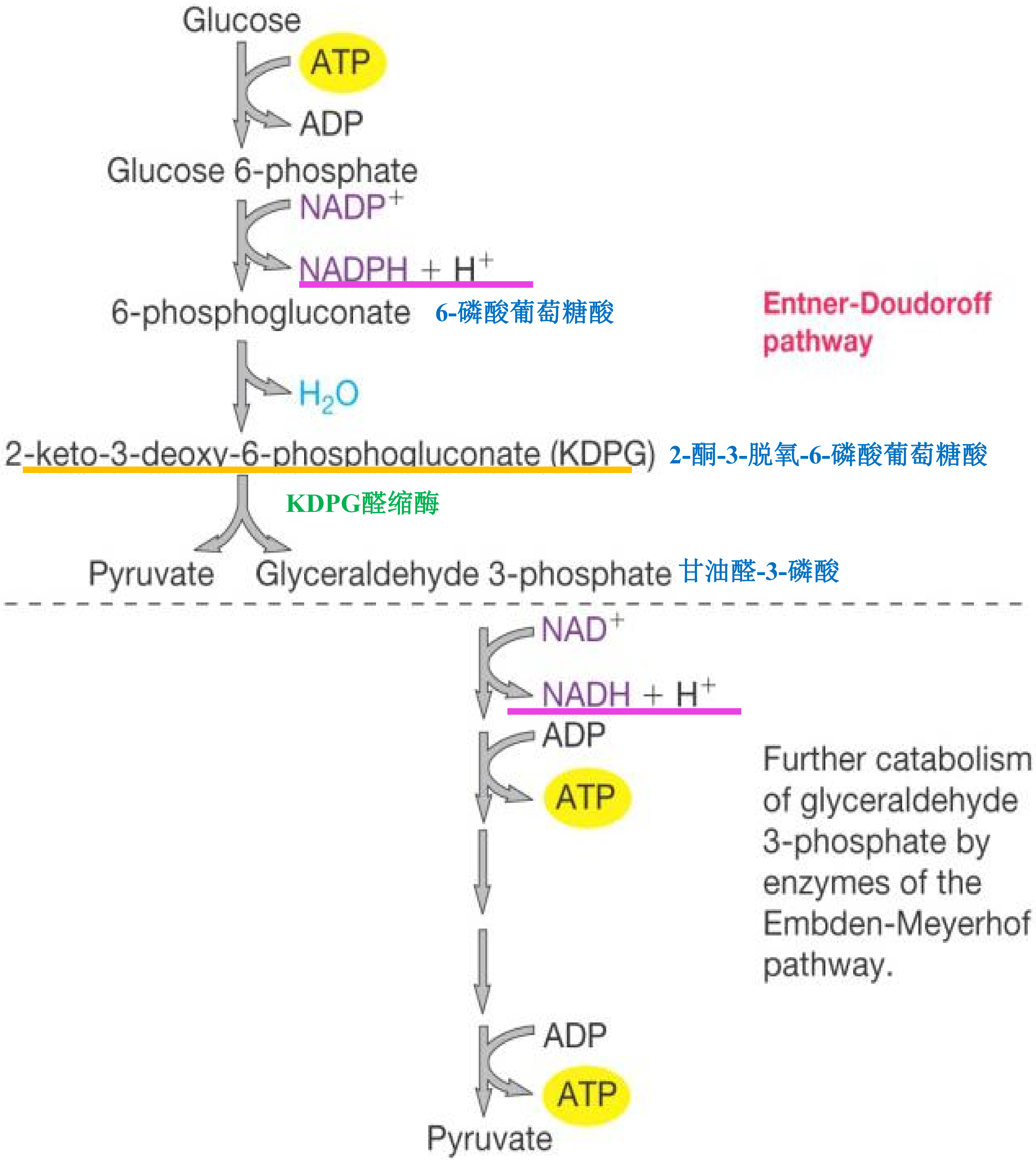
$$\downarrow$$

$$2\ \text{pyruvate} + 2\text{ATP} + 2\text{NADH} + 2\text{H}^+$$

The Entner-Duodoroff pathway*

- used by soil bacteria and a few gram-negative bacteria(G^-)
- replaces the first phase of the Embden-Meyerhof pathway
- It is not used by eukaryotes!

- **yield per glucose molecule:**
  - **1 ATP**
  - **1 NADPH**
  - **1 NADH**



Glucose

ATP

ADP

Glucose 6-phosphate

$NADP^+$

$NADPH + H^+$

6-phosphogluconate 6-磷酸葡萄糖酸

H_2O

2-keto-3-deoxy-6-phosphogluconate (KDPG) 2-酮-3-脱氧-6-磷酸葡萄糖酸

KDPG醛缩酶

Pyruvate

Glyceraldehyde 3-phosphate 甘油醛-3-磷酸

Entner-Doudoroff pathway

NAD^+

$NADH + H^+$

ADP

ATP

ADP

ATP

Pyruvate

Further catabolism of glyceraldehyde 3-phosphate by enzymes of the Embden-Meyerhof pathway.

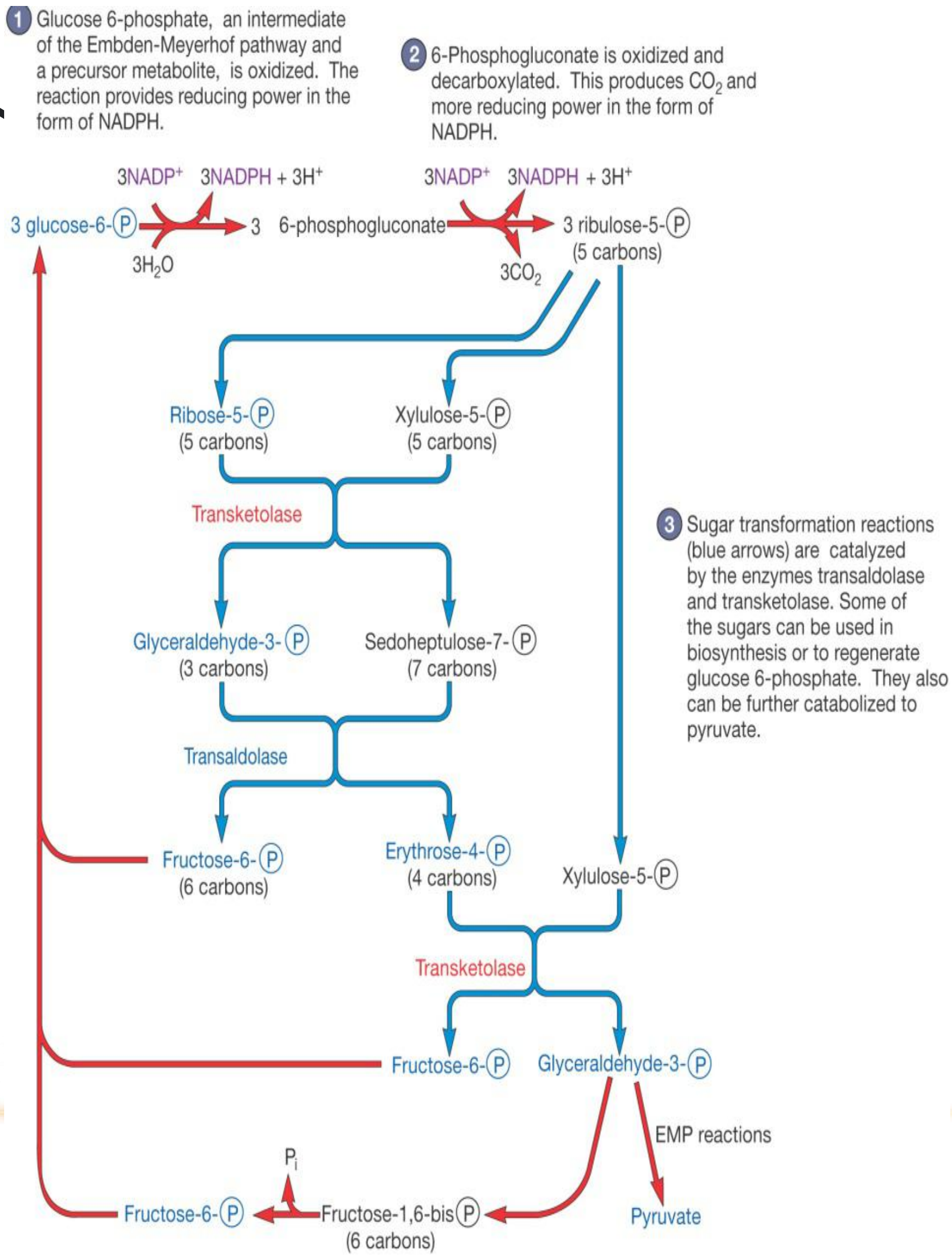
The pentose phosphate pathway

戊糖磷酸途径

- also called hexose monophosphate pathway己糖单磷酸途径
- can operate at same time as glycolytic pathway or Entner-Duodoroff pathway
- can operate aerobically or anaerobically
- an amphibolic pathway两用途径
- Two steps oxidative reaction(6-P-Glucose dehydrogenase and 6-P-Gluconate dehydrogenase，NADPH, CO_2)

oxidation steps

produce NADPH, which is needed for biosynthesis



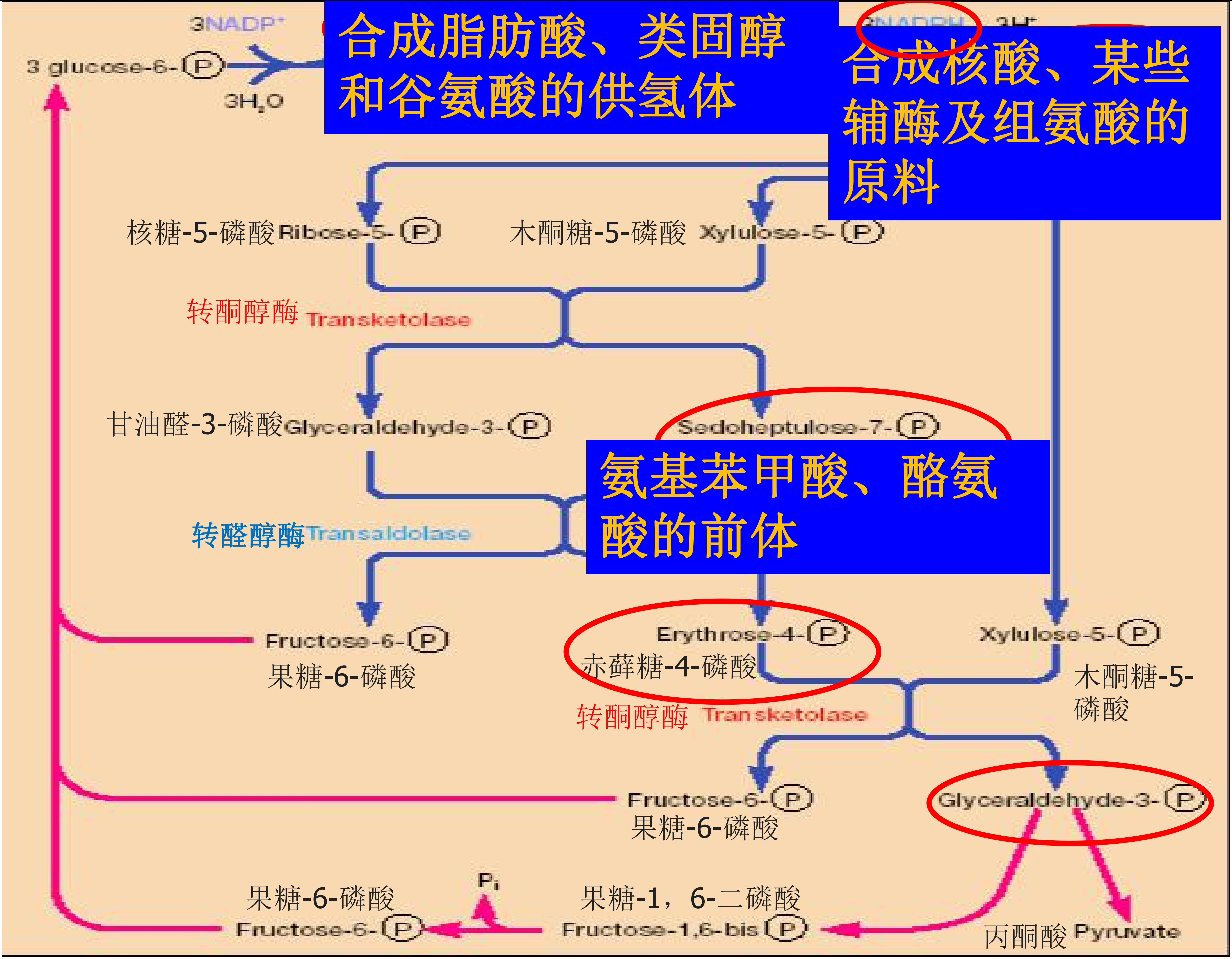
① Glucose 6-phosphate, an intermediate of the Embden-Meyerhof pathway and a precursor metabolite, is oxidized. The reaction provides reducing power in the form of NADPH.

② 6-Phosphogluconate is oxidized and decarboxylated. This produces CO_2 and more reducing power in the form of NADPH.

③ Sugar transformation reactions (blue arrows) are catalyzed by the enzymes transaldolase and transketolase. Some of the sugars can be used in biosynthesis or to regenerate glucose 6-phosphate. They also can be further catabolized to pyruvate.

produce sugars needed for biosynthesis

sugars can also be further degrade



合成脂肪酸、类固醇和谷氨酸的供氢体

合成核酸、某些辅酶及组氨酸的原料

核糖-5-磷酸

木酮糖-5-磷酸

转酮醇酶

甘油醛-3-磷酸

氨基苯甲酸、酪氨酸的前体

转醛醇酶

果糖-6-磷酸

赤藓糖-4-磷酸

木酮糖-5-磷酸

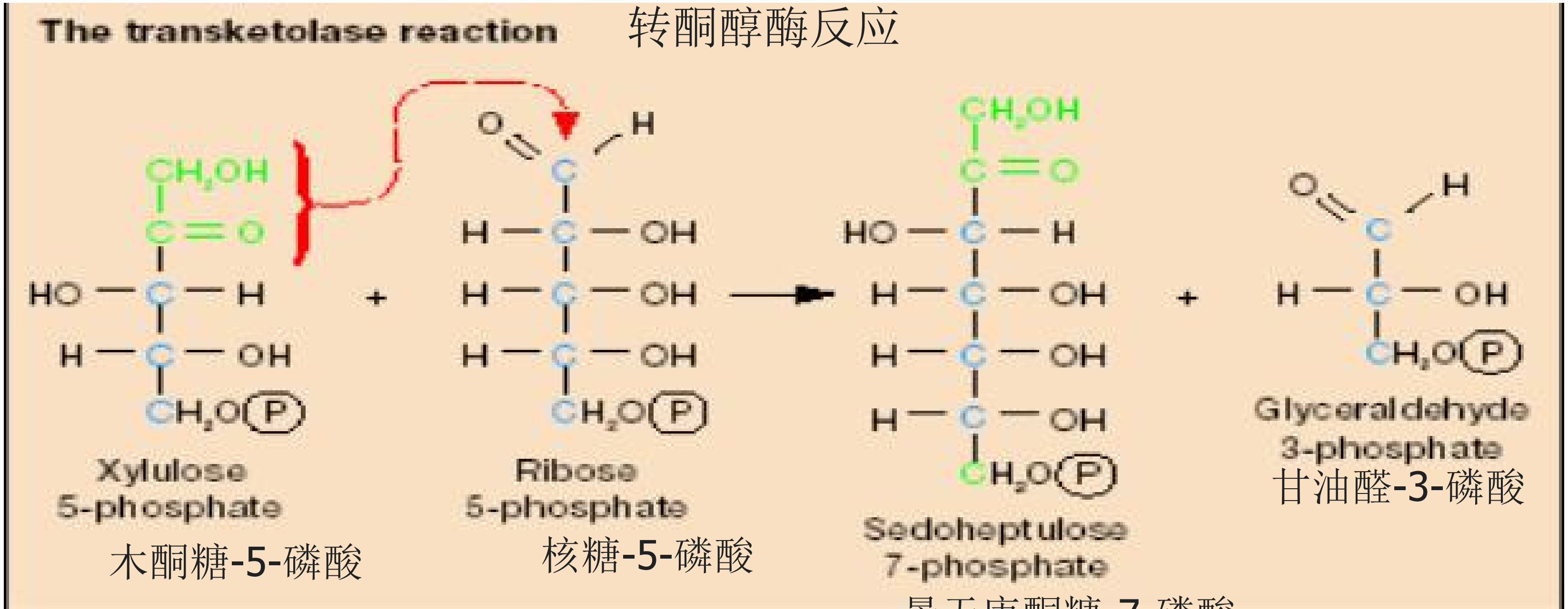
转酮醇酶

果糖-6-磷酸

果糖-6-磷酸

果糖-1，6-二磷酸

丙酮酸



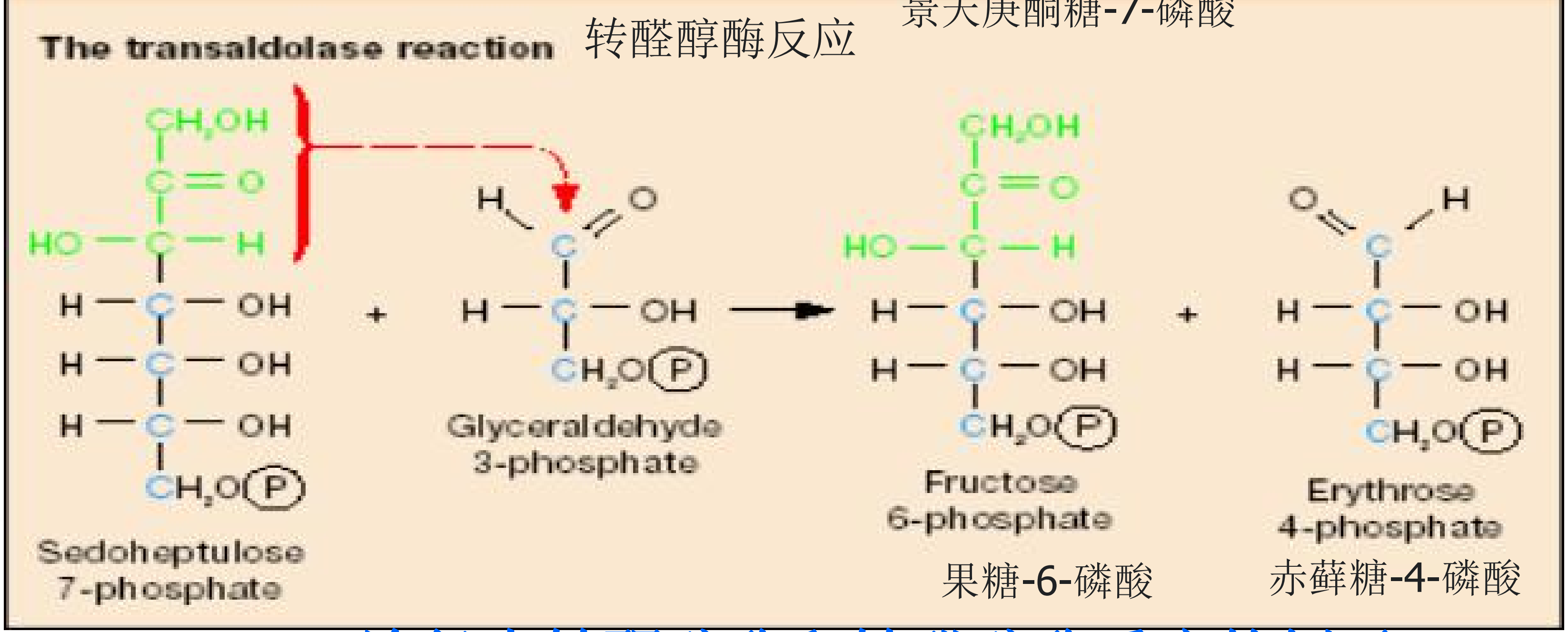
转酮醇酶反应

木酮糖-5-磷酸

核糖-5-磷酸

景天庚酮糖-7-磷酸

甘油醛-3-磷酸



转醛醇酶反应

果糖-6-磷酸

赤藓糖-4-磷酸

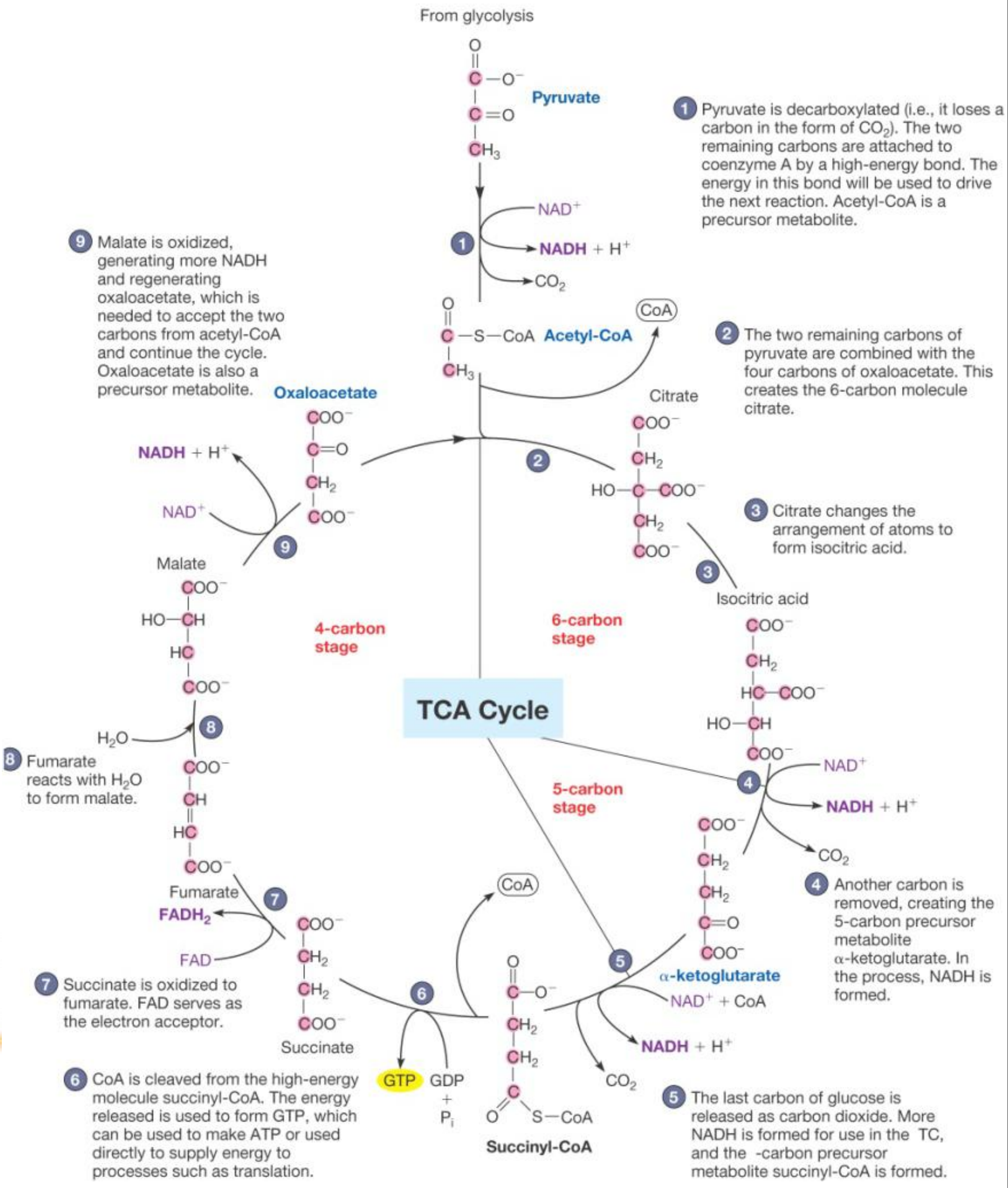
HMP途径中转酮醇酶和转醛醇酶反应的例子

Discussion

Why might it be desirable for a microorganism with the Embden-Meyerhof pathway and the TCA cycle also to have the pentose phosphate pathway?

The tricarboxylic acid cycle

- also called citric acid cycle and Kreb’s cycle
- common in aerobic bacteria, free-living protozoa, most algae, and fungi
- major role is as a source of Carbon Skeletons for use in biosynthesis



① Pyruvate is decarboxylated (i.e., it loses a carbon in the form of CO$_2$). The two remaining carbons are attached to coenzyme A by a high-energy bond. The energy in this bond will be used to drive the next reaction. Acetyl-CoA is a precursor metabolite.

② The two remaining carbons of pyruvate are combined with the four carbons of oxaloacetate. This creates the 6-carbon molecule citrate.

③ Citrate changes the arrangement of atoms to form isocitric acid.

④ Another carbon is removed, creating the 5-carbon precursor metabolite α-ketoglutarate. In the process, NADH is formed.

⑤ The last carbon of glucose is released as carbon dioxide. More NADH is formed for use in the TC, and the -carbon precursor metabolite succinyl-CoA is formed.

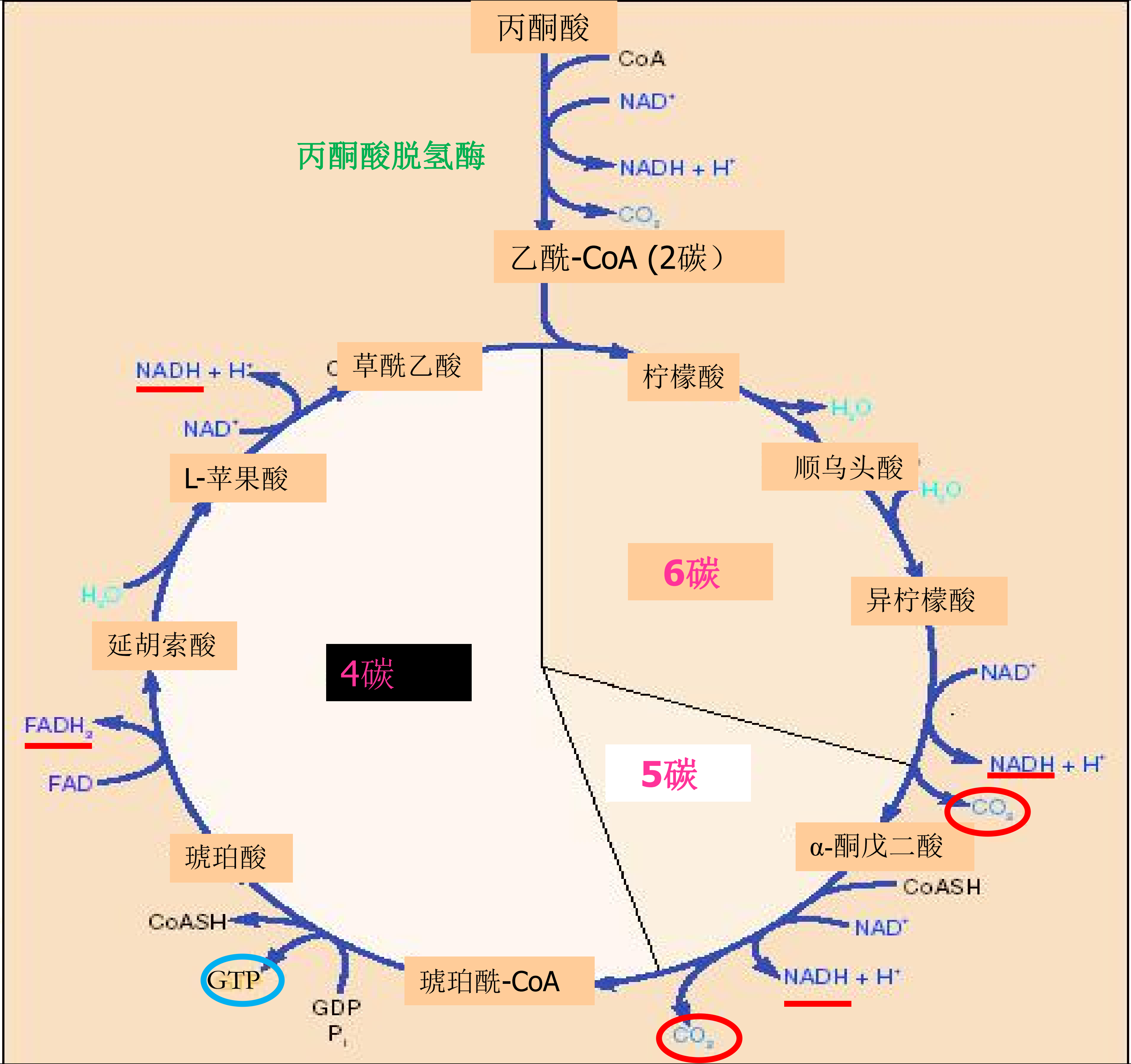
⑥ CoA is cleaved from the high-energy molecule succinyl-CoA. The energy released is used to form GTP, which can be used to make ATP or used directly to supply energy to processes such as translation.

⑦ Succinate is oxidized to fumarate. FAD serves as the electron acceptor.

⑧ Fumarate reacts with H$_2$O to form malate.

⑨ Malate is oxidized, generating more NADH and regenerating oxaloacetate, which is needed to accept the two carbons from acetyl-CoA and continue the cycle. Oxaloacetate is also a precursor metabolite.

考察TCA循环的另一种方式是了解其将乙酰CoA氧化成CO_2的功能。



Summary TCA cycle

- for each acetyl-CoA molecule oxidized, TCA cycle generates:
  - 2 molecules of CO_2
  - 3 molecules of NADH
  - one $FADH_2$
  - one GTP

Electron transport and oxidative phosphorylation

- **only 4 ATP molecules synthesized directly from oxidation of glucose to CO_2**
- **most ATP made when NADH and $FADH_2$ (formed as glucose degraded) are oxidized in ETC!**
- **P/O ratios**

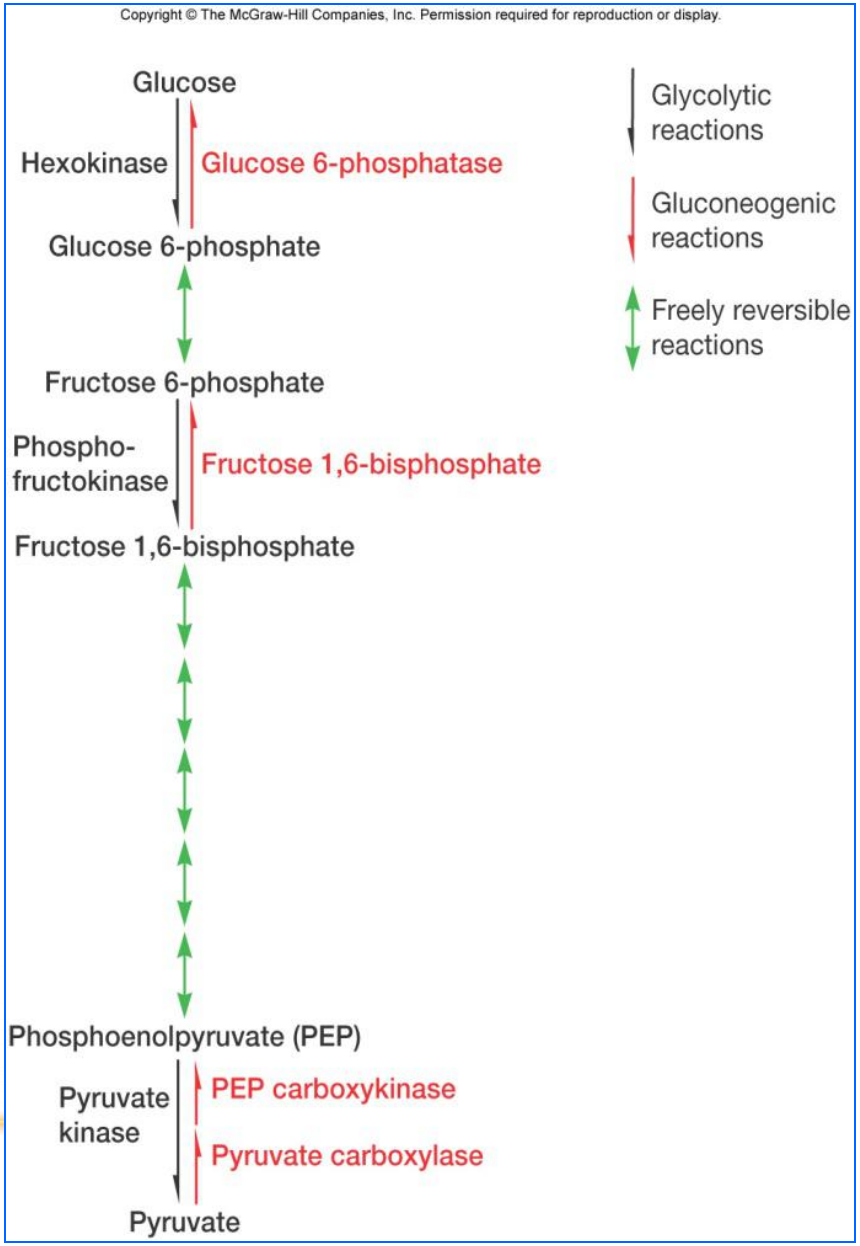
  measure of the number of ATP molecules (phosphorus) generated per oxygen (O) reduced as NADH and $FADH_2$ were oxidized.
- **NADH P/O ratio = 2.5**
- **$FADH_2$ P/O ratio = 1.5**

Discussion

- **Calculate the ATP yield when glucose is catabolized completely to six CO_2 by a eukaryotic microbe. How does this value compare to the ATP yield observed for a bacterium?**

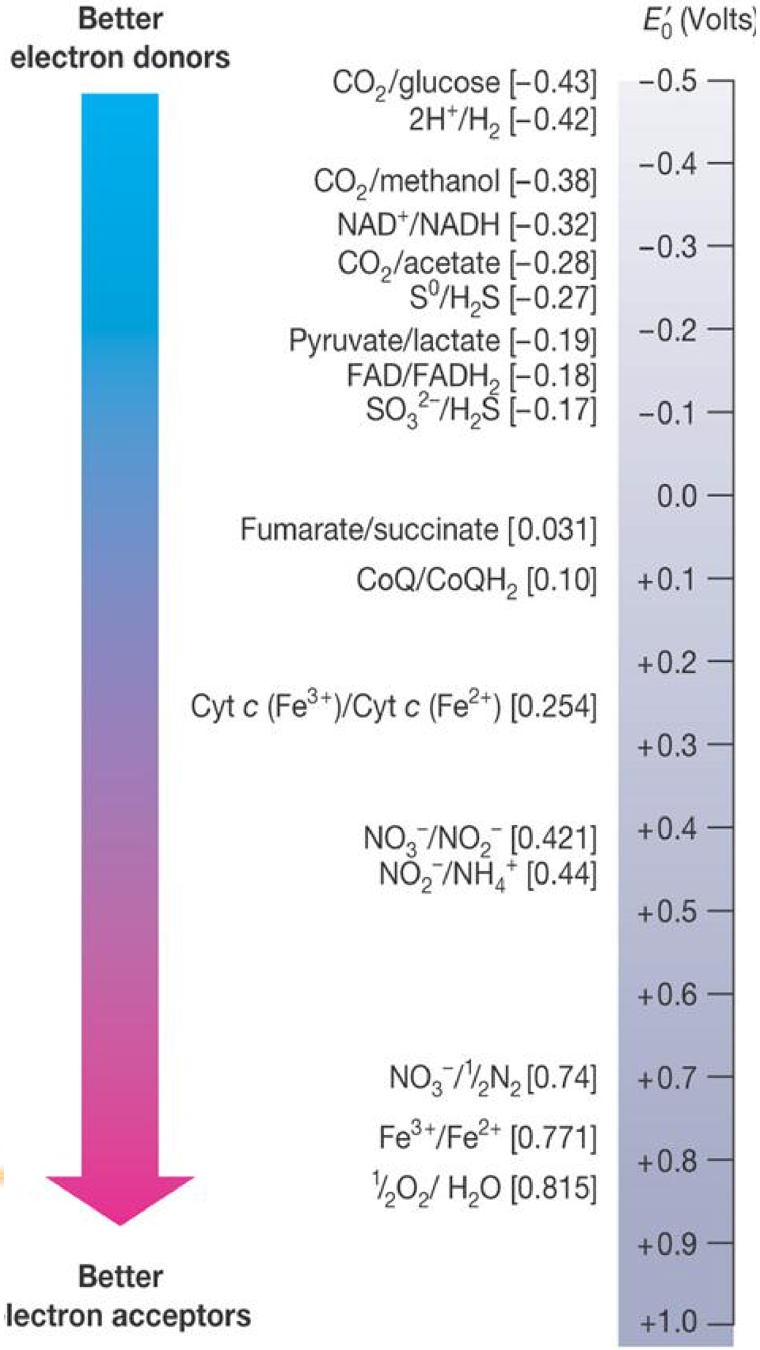
Amphibolic pathways

- function both as catabolic and anabolic pathways
- important ones
  - Embden-Meyerhof pathway(EMP)
  - Pentose phosphate pathway
  - Tricarboxylic acid (TCA) cycle
- independent regulation



Anaerobic respiration

- uses electron carriers other than O_2
- generally yields less energy because E_0 of electron acceptor is less positive than E_0 of O_2
- By many bacteria, archaea and some eukaryotic microbes



Anaerobic respiration

- dissimilatory nitrate reduction硝酸盐异化还原
  - use of nitrate as terminal electron acceptor

$$NO_3^- + 2e^- + 2H^+ \longrightarrow NO_2^- + H_2O$$

- denitrification反硝化作用
  - reduction of nitrate to nitrogen gas

$$2NO_3^- + 10e^- + 12H^+ \longrightarrow N_2 + 6H_2O$$

  - in soil, causes loss of soil fertility

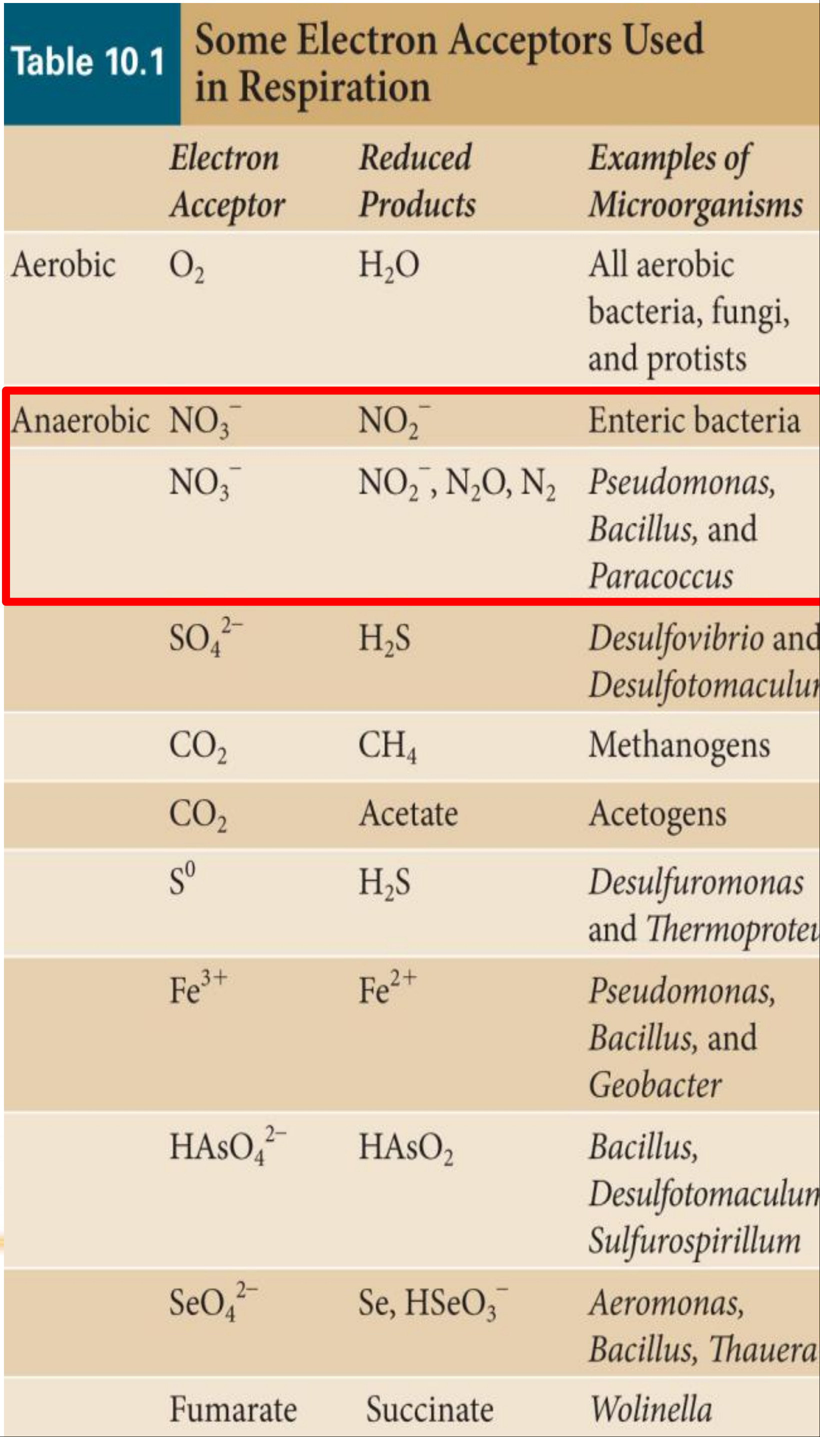
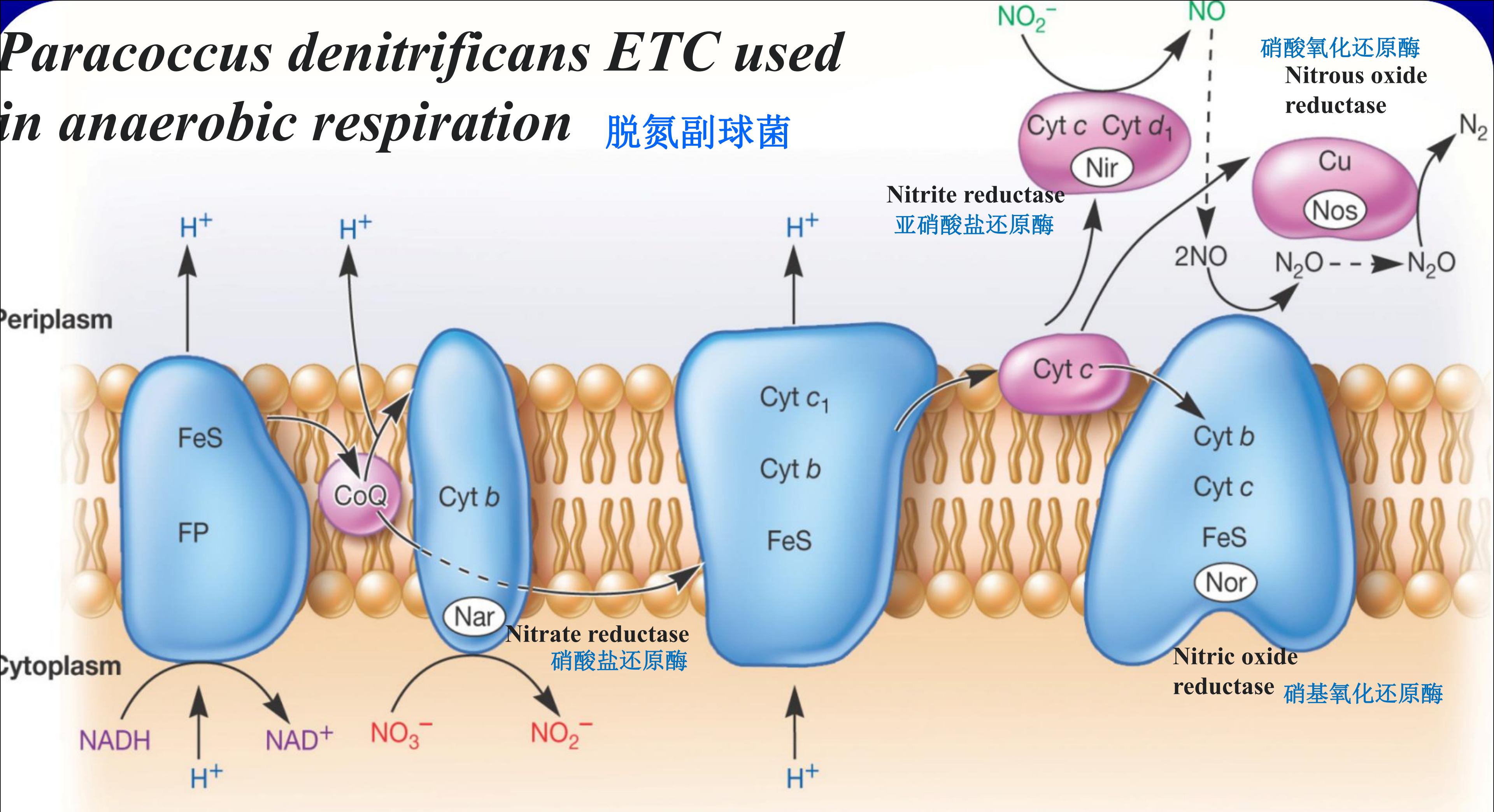


Table 10.1 Some Electron Acceptors Used in Respiration

	Electron Acceptor	*Reduced Products*	*Examples of Microorganisms*
Aerobic	O_2	H_2O	All aerobic bacteria, fungi, and protists
Anaerobic	NO_3^-	NO_2^-	Enteric bacteria
	NO_3^-	NO_2^-, N_2O, N_2	*Pseudomonas*, *Bacillus*, and *Paracoccus*
	SO_4^{2-}	H_2S	*Desulfovibrio* and *Desulfotomaculu*
	CO_2	CH_4	Methanogens
	CO_2	Acetate	Acetogens
	S^0	H_2S	*Desulfuromonas* and *Thermoprote*
	Fe^{3+}	Fe^{2+}	*Pseudomonas*, *Bacillus*, and *Geobacter*
	$HAsO_4^{2-}$	$HAsO_2$	*Bacillus*, *Desulfotomaculu* *Sulfurospirillum*
	SeO_4^{2-}	Se, $HSeO_3^-$	*Aeromonas*, *Bacillus*, *Thauera*
	Fumarate	Succinate	*Wolinella*

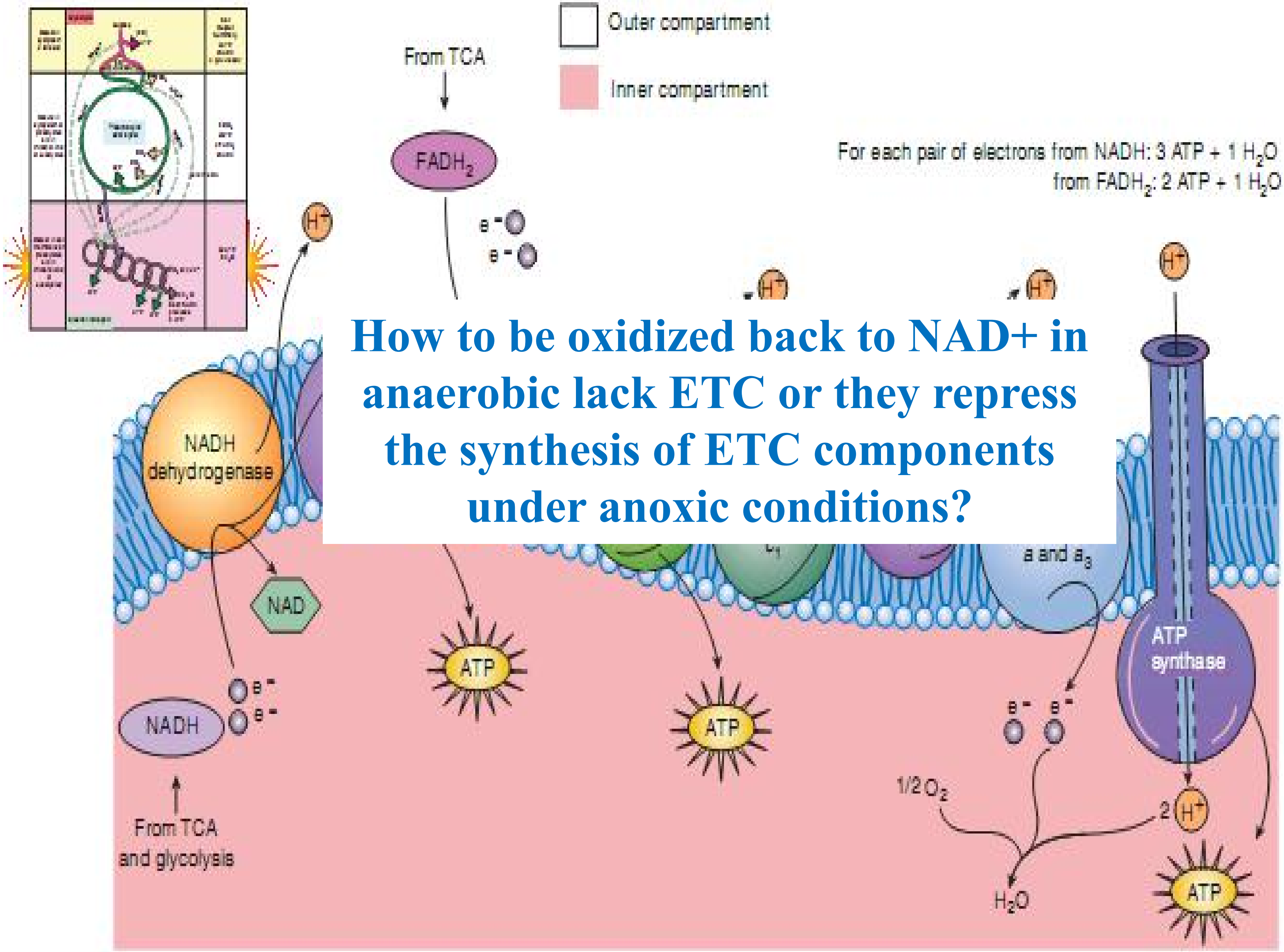
Paracoccus denitrificans ETC used in anaerobic respiration 脱氮副球菌



$$NO_3^- \longrightarrow NO_2^- \longrightarrow NO \longrightarrow N_2O \longrightarrow N_2$$

Denitrification causes loss of soil fertility, but has important role in ecosystem.

Why?



Outer compartment

Inner compartment

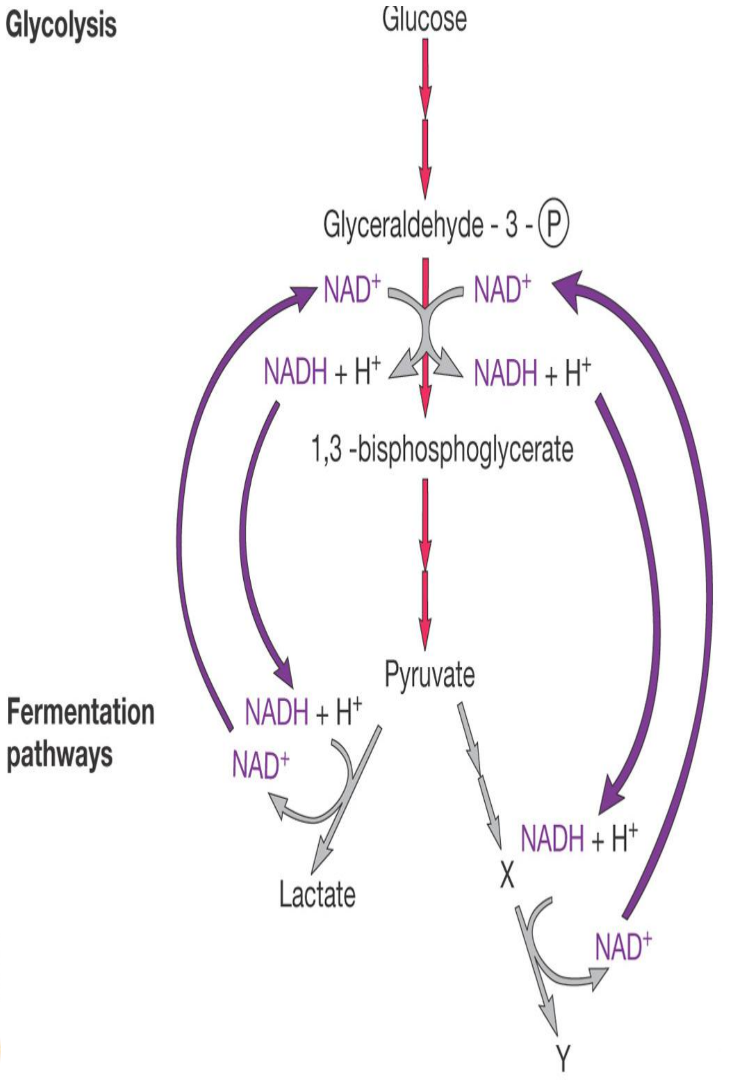
For each pair of electrons from NADH: 3 ATP + 1 H_2O
from $FADH_2$: 2 ATP + 1 H_2O

How to be oxidized back to NAD+ in anaerobic lack ETC or they repress the synthesis of ETC components under anoxic conditions?

*Note that the NADH ═ ═ ═ transfers H$^+$ and e$^-$ from the first 2 pathways to the 3rd.

Fermentation

- NADH is oxidized to NAD+
- electron acceptor is either pyruvate or
- Oxygen is not needed
- ETC not operate, ATP formed by substrate-level phosphorylation
- Substrate only partially oxidized



Some common fermentation

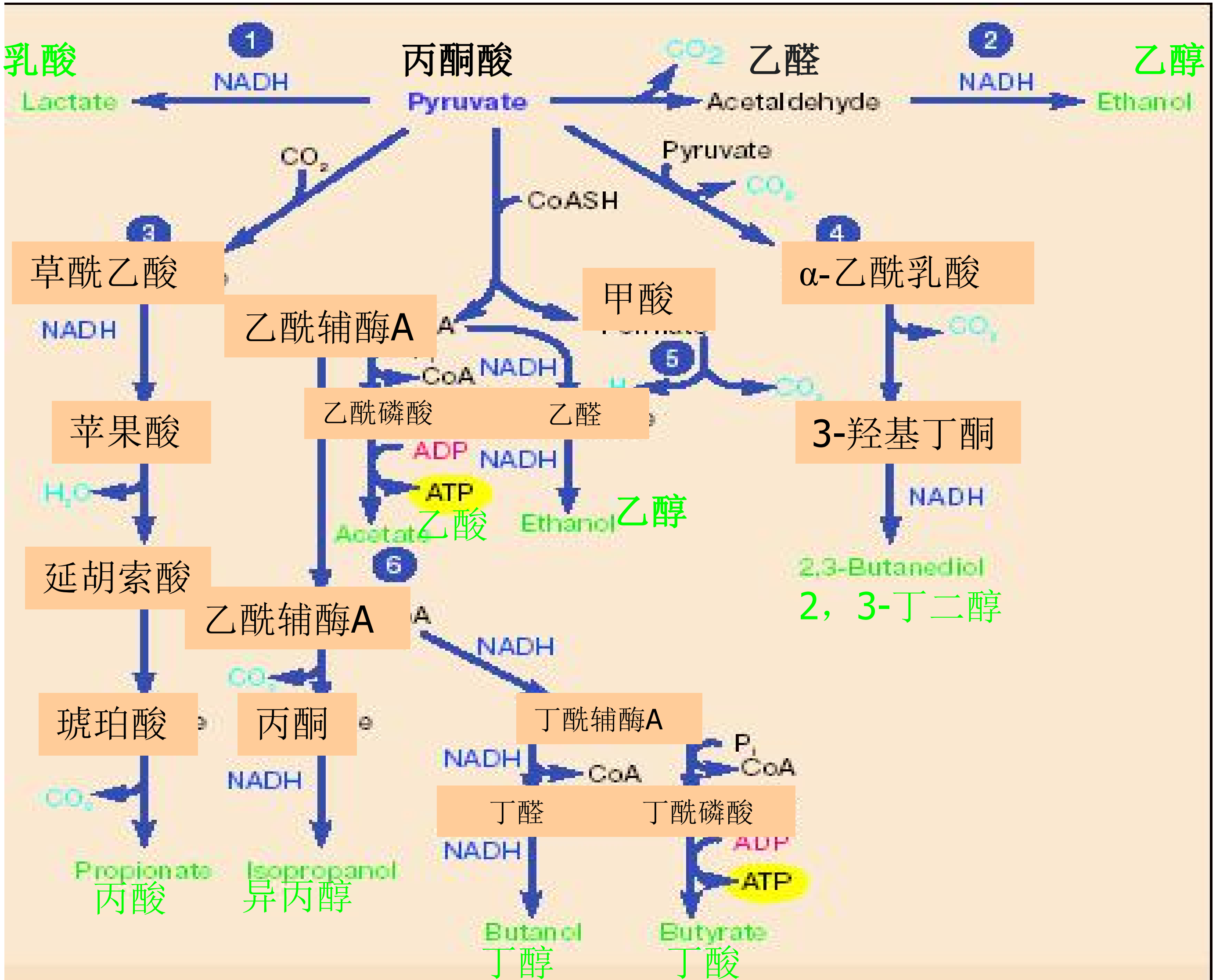
- Homolactic fermentation: Pyr → lactate同型乳酸发酵
- Heterolactic fermentation:pyr → alcohol(yogurt)
- Alcohol fermentation: Glucose → alcohol+CO_2
- Mixed acid fermentation: formic, acetic, lactic and succinic acid(e)+alcohol
- Butanediol fermentation: enterobactriaceae
- Stickland reaction: *Clostridium sporogenes*生孢梭菌

H donor：Ala; Leu, Ile, Val, Phe, Ser, His, trp

H acceptor：Gly, Pro, Ori, OH-Pro, Arg, trp.

发酵类型

一些常见的微生物发酵作用

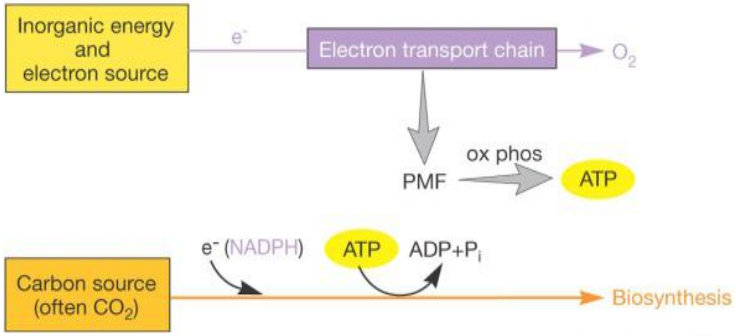


1. Lactic acid bacteria (*Streptococcus, Lactobacillus*), *Bacillus* 乳酸细菌，芽孢杆菌
2. Yeast, *Zymomonas* 酵母，发酵单孢菌
3. Propionic acid bacteria (*Propionibacterium*) 丙酸细菌（丙酸杆菌）
4. *Enterobacter, Serratia, Bacillus* 肠杆菌，赛氏杆菌，芽孢杆菌
5. Enteric bacteria (*Escherichia, Enterobacter, Salmonella, Proteus*) 肠道杆菌
6. *Clostridium* 梭菌

How about of the chemolithotrophy?

Chemolithotrophic fueling processes

- Electrons source - an inorganic molecule
  - transferred to terminal electron acceptor (usually O_2) by ETC
- ATP synthesized by oxidative phosphorylation
- Carbon source-CO_2



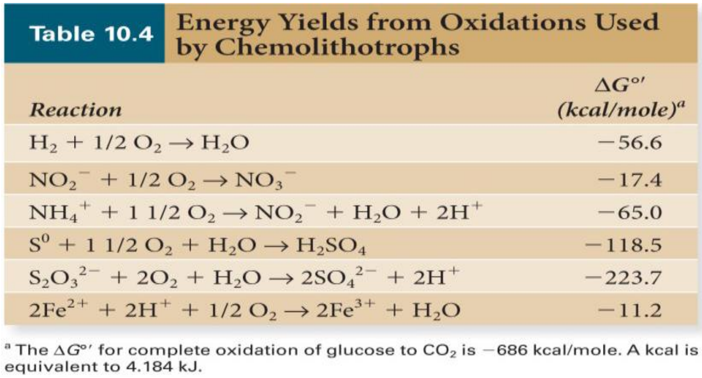


Table 10.4 Energy Yields from Oxidations Used by Chemolithotrophs

Reaction	$\Delta G^{\circ\prime}$ *(kcal/mole)*[a]
$H_2 + 1/2\ O_2 \rightarrow H_2O$	−56.6
$NO_2^- + 1/2\ O_2 \rightarrow NO_3^-$	−17.4
$NH_4^+ + 1\ 1/2\ O_2 \rightarrow NO_2^- + H_2O + 2H^+$	−65.0
$S^0 + 1\ 1/2\ O_2 + H_2O \rightarrow H_2SO_4$	−118.5
$S_2O_3^{2-} + 2O_2 + H_2O \rightarrow 2SO_4^{2-} + 2H^+$	−223.7
$2Fe^{2+} + 2H^+ + 1/2\ O_2 \rightarrow 2Fe^{3+} + H_2O$	−11.2

[a] The $\Delta G^{\circ\prime}$ for complete oxidation of glucose to CO_2 is −686 kcal/mole. A kcal is equivalent to 4.184 kJ.

Much less energy is available from oxidation of inorganic molecules than glucose oxidation due to more positive redox potentials.

$P/O \approx 1.0$

Three major groups of chemolithotrophs

- oxidize hydrogen (several bacteria and archaea)

$$H_2 \rightarrow 2H^+ + 2e^-$$

- sulfur-oxidizing microbes
  - hydrogen sulfide (H_2S), sulfur (S^0), thiosulfate ($S_2O_3^{2-}$)硫代亚硫酸盐
- oxidize ammonia氨 to nitrate nitrifying bacteria

硝化细菌

bacterial and archaeal species

- have ecological importance

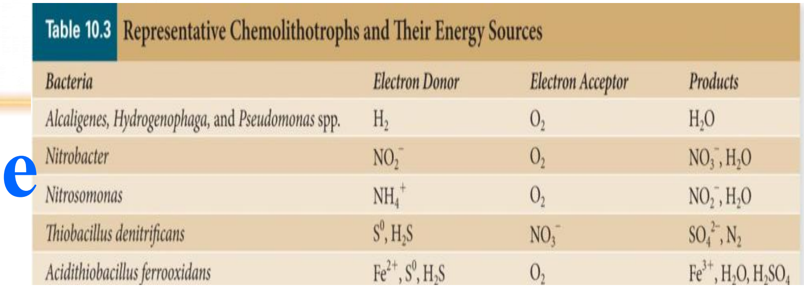


Table 10.3 Representative Chemolithotrophs and Their Energy Sources

Bacteria	*Electron Donor*	*Electron Acceptor*	*Products*
Alcaligenes, Hydrogenophaga, and *Pseudomonas* spp.	H_2	O_2	H_2O
Nitrobacter	NO_2^-	O_2	NO_3^-, H_2O
Nitrosomonas	NH_4^+	O_2	NO_2^-, H_2O
Thiobacillus denitrificans	S^0, H_2S	NO_3^-	SO_4^{2-}, N_2
Acidithiobacillus ferrooxidans	Fe^{2+}, S^0, H_2S	O_2	Fe^{3+}, H_2O, H_2SO_4

Sulfur-oxidizing bacteria

ATP can be synthesized by both oxidative phosphorylation and substrate-level phosphorylation

(a) Direct oxidation of sulfite

$$SO_3^{2-} \xrightarrow{\text{sulfite oxidase}} SO_4^{2-} + 2e^-$$

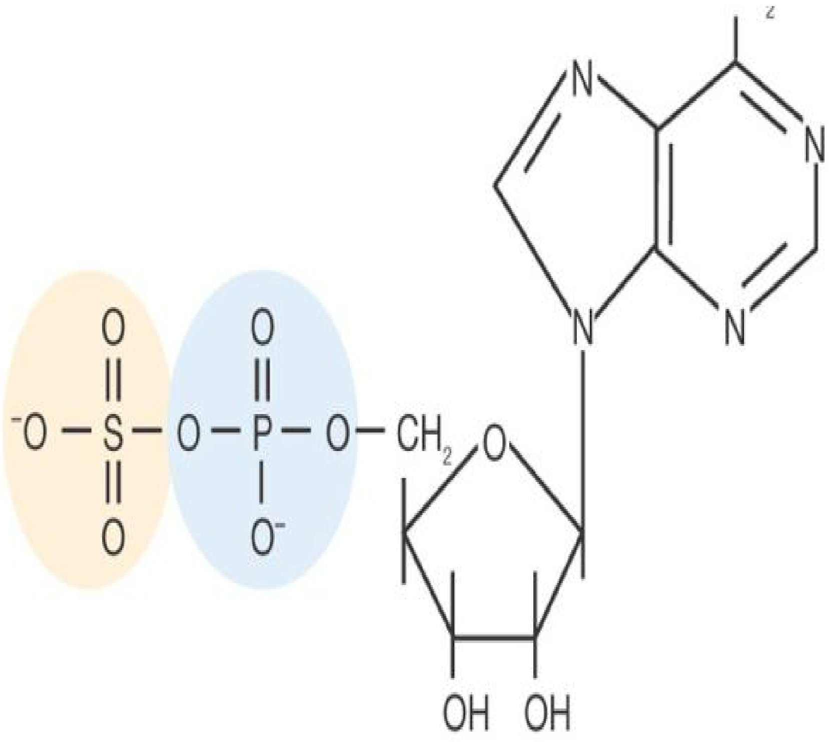
(b) Formation of adenosine 5′-phosphosulfate 腺苷酰硫酸的形成

$$2SO_3^{2-} + 2AMP \longrightarrow 2APS + 4e^-$$

$$2APS + 2P_i \longrightarrow 2ADP + 2SO_4^{2-}$$

$$2ADP \longrightarrow AMP + ATP$$

$$2SO_3^{2-} + AMP + 2P_i \longrightarrow 2SO_4^{2-} + ATP + 4e^-$$



(c) Adenosine 5′-phosphosulfate

Nitrifying bacteria example

oxidize ammonia to nitrate
requires 2 different genera

Aerobic: $NH_4^+ + O_2 \rightarrow NO_2^-$

$NO_2^- + O_2 \rightarrow NO_3^-$

Nitrosomonas

Nitrobacte

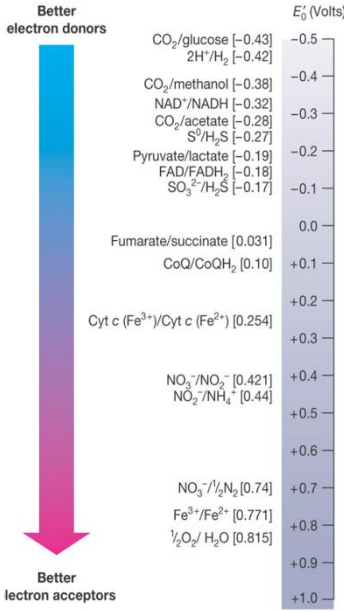
Planctomycetes 浮霉状菌

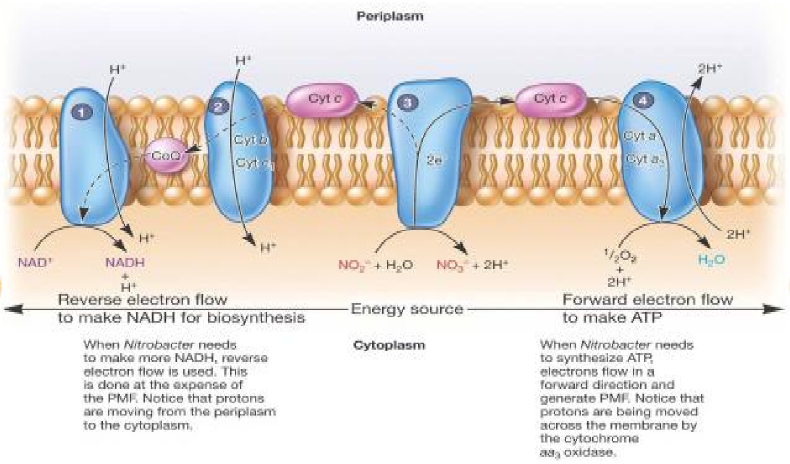
Anaerobic： $NO_2^- + NH_4^+ \rightarrow N_2 + H_2O$

Anaerobic ammonicoxidation-anammoxosome

*Reverse electron flow by chemolithotrophs

- Calvin cycle requires NAD(P)H as electron source for fixing CO_2
  - many energy sources used by chemolithotrophs have E_0 more positive than $NAD^+(P)/NAD(P)H$
  - use reverse electron flow to generate NAD(P)H





When *Nitrobacter* needs to make more NADH, reverse electron flow is used. This is done at the expense of the PMF. Notice that protons are moving from the periplasm to the cytoplasm.

When *Nitrobacter* needs to synthesize ATP, electrons flow in a forward direction and generate PMF. Notice that protons are being moved across the membrane by the cytochrome aa_3 oxidase.

*Metabolic flexibility of chemolithotrophs

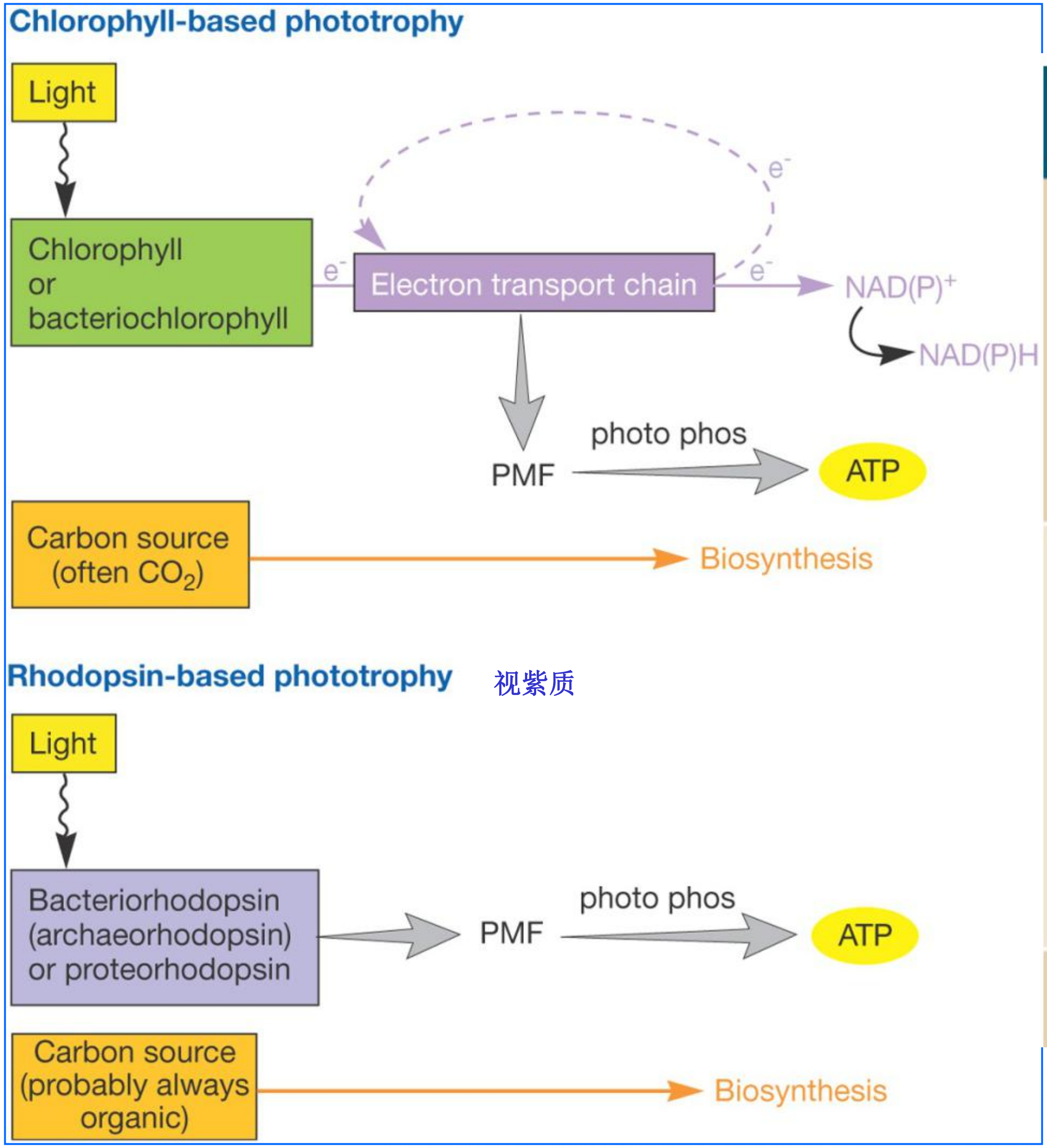
- **many switch from chemolithotrophic metabolism to chemoorganotrophic metabolism**
- **many switch from autotrophic metabolism (via Calvin cycle) to heterotrophic metabolism**

How about

the fueling reactions of <u>phototrophs</u>?

Phototrophy

- photosynthesis
  - energy from light trapped and converted to chemical energy
  - a two-part process
    - light reactions in which light energy is trapped and converted to chemical energy
    - dark reactions in which the energy produced in the light reactions is used to reduce CO_2 and synthesize cell constituents(see 12.3)



Chlorophyll-based phototrophy

Light

Chlorophyll or bacteriochlorophyll

e^-

Electron transport chain

e^-

e^-

$NAD(P)^+$

NAD(P)H

PMF

photo phos

ATP

Carbon source (often CO_2)

Biosynthesis

Rhodopsin-based phototrophy 视紫质

Light

Bacteriorhodopsin (archaeorhodopsin) or proteorhodopsin

PMF

photo phos

ATP

Carbon source (probably always organic)

Biosynthesis

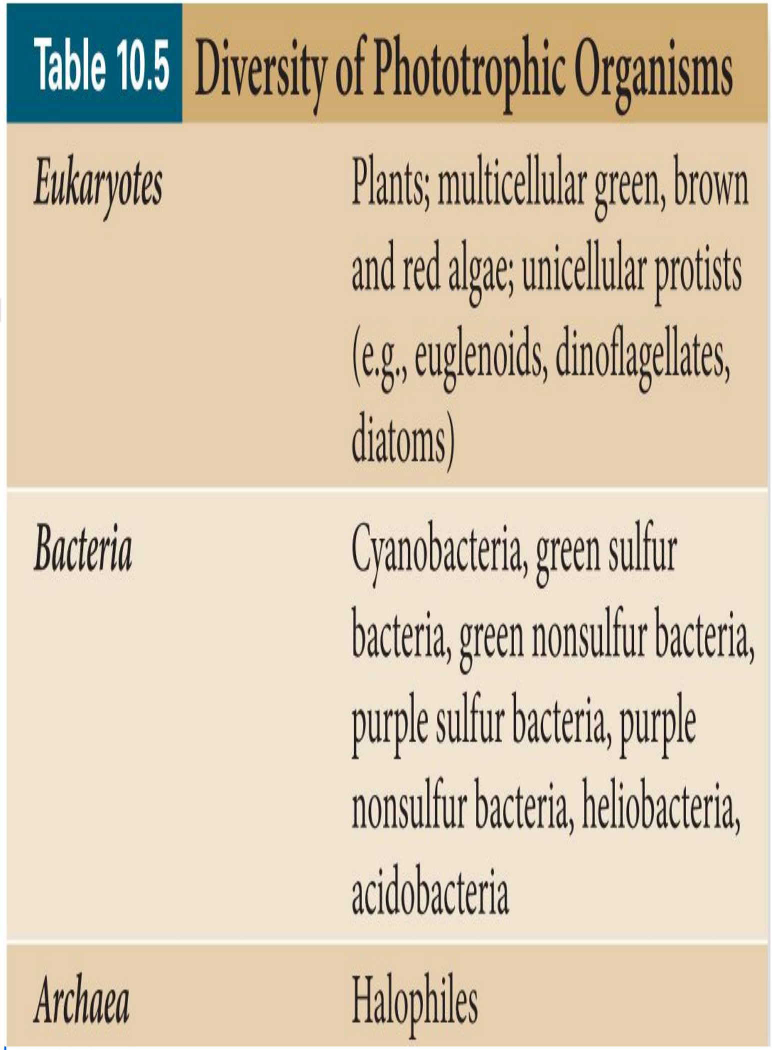


Table 10.5 Diversity of Phototrophic Organisms

Eukaryotes	Plants; multicellular green, brown and red algae; unicellular protists (e.g., euglenoids, dinoflagellates, diatoms)
Bacteria	Cyanobacteria, green sulfur bacteria, green nonsulfur bacteria, purple sulfur bacteria, purple nonsulfur bacteria, heliobacteria, acidobacteria
Archaea	Halophiles

Over half the photosynthesis on Earth is carried out by microorganisms!

Oxygenic photosynthesis生氧光合作用

- **photosynthetic eukaryotes and cyanobacteria蓝细菌**
- **oxygen is generated and released into the environment**
- **most important pigments are chlorophylls叶绿素**

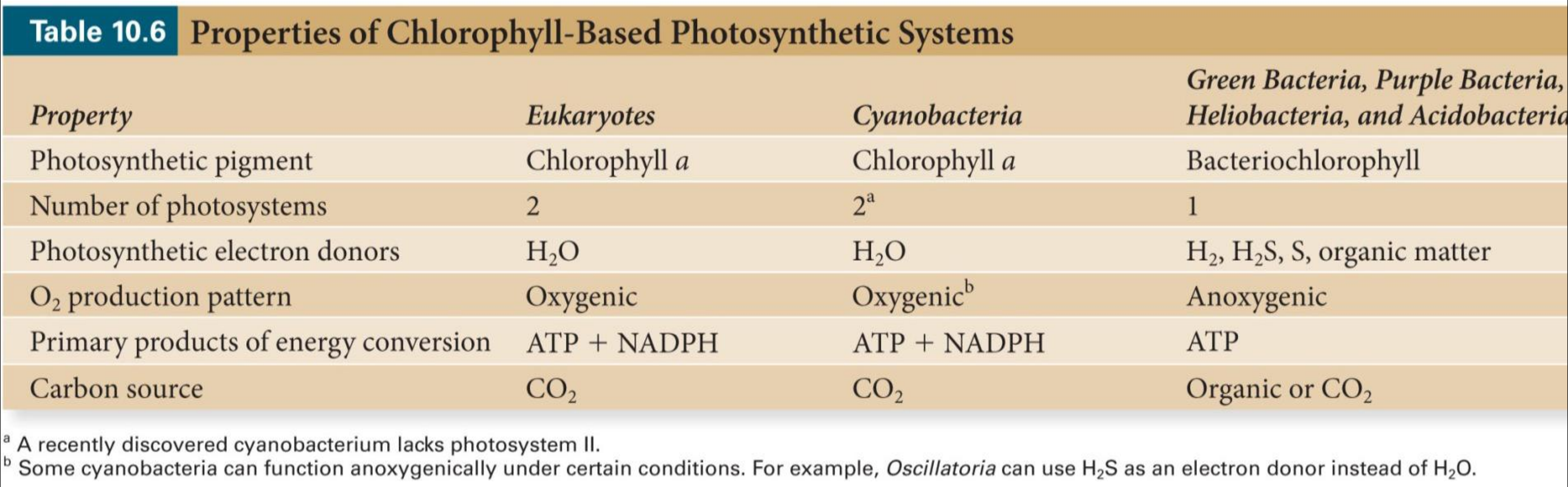


Table 10.6 Properties of Chlorophyll-Based Photosynthetic Systems

Property	*Eukaryotes*	*Cyanobacteria*	*Green Bacteria, Purple Bacteria, Heliobacteria, and Acidobacteri*
Photosynthetic pigment	Chlorophyll *a*	Chlorophyll *a*	Bacteriochlorophyll
Number of photosystems	2	2[a]	1
Photosynthetic electron donors	H_2O	H_2O	H_2, H_2S, S, organic matter
O_2 production pattern	Oxygenic	Oxygenic[b]	Anoxygenic
Primary products of energy conversion	ATP + NADPH	ATP + NADPH	ATP
Carbon source	CO_2	CO_2	Organic or CO_2

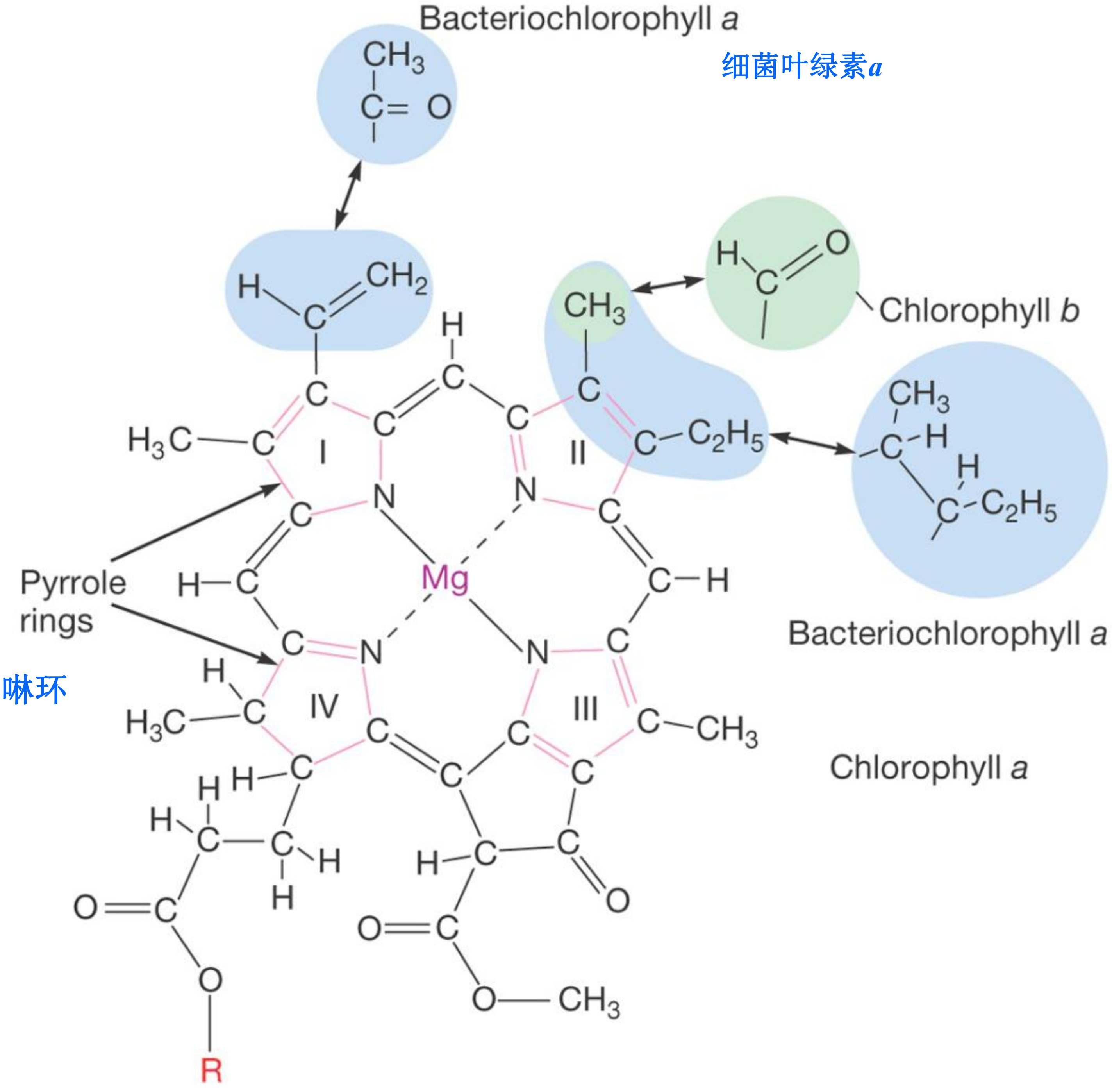
[a] A recently discovered cyanobacterium lacks photosystem II.

[b] Some cyanobacteria can function anoxygenically under certain conditions. For example, *Oscillatoria* can use H_2S as an electron donor instead of H_2O.

Oxygenic photosynthesis 生氧光合作用

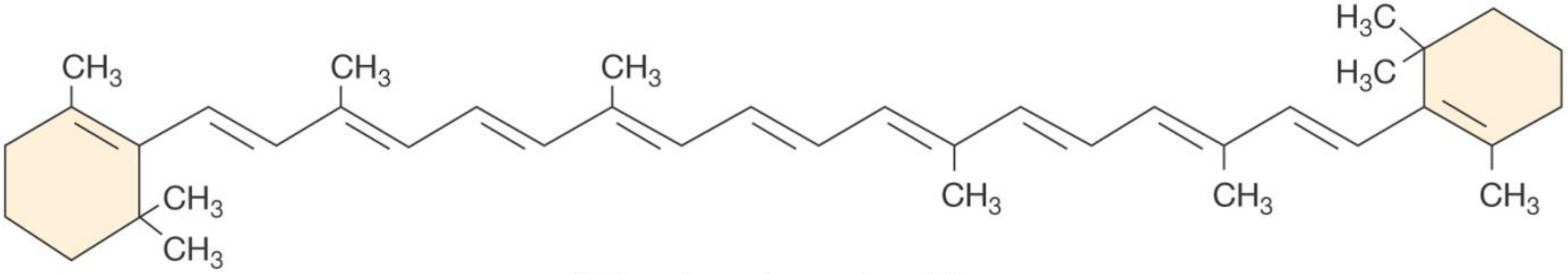
- Chlorophylls 叶绿素
  - major light-absorbing pigments
  - different chlorophylls have different absorption peaks
- accessory pigments 辅助色素
  - transfer light energy to chlorophylls
  - e.g., carotenoids（类胡萝卜素 ）and

    phycobiliproteins藻胆（色素）蛋白
  - accessory pigments absorb different wavelengths of light than chlorophylls

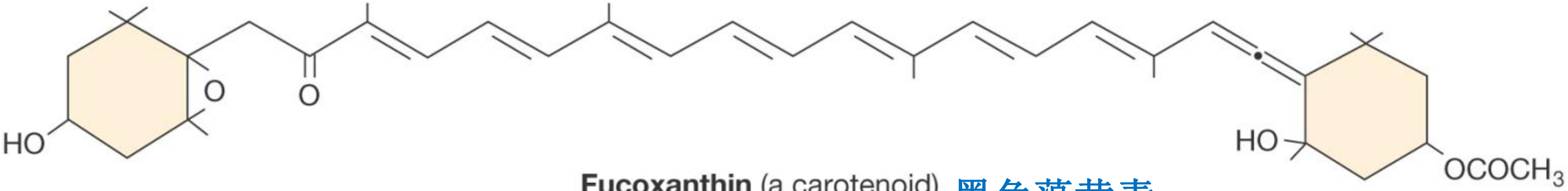

Bacteriochlorophyll *a*
CH3
C= O
H
C
CH2
H
C
CH3
C
C–C2H5
H
C
O
Chlorophyll *b*
CH3
C-H
H
C-C2H5
Bacteriochlorophyll *a*
H3C–C
I
II
III
IV
N
Mg
Pyrrole rings
H–C
C–H
C–CH3
Chlorophyll a
H3C–C
H–C
H–C
O
O=C
O–CH3
O=C
O
R

细菌叶绿素*a*

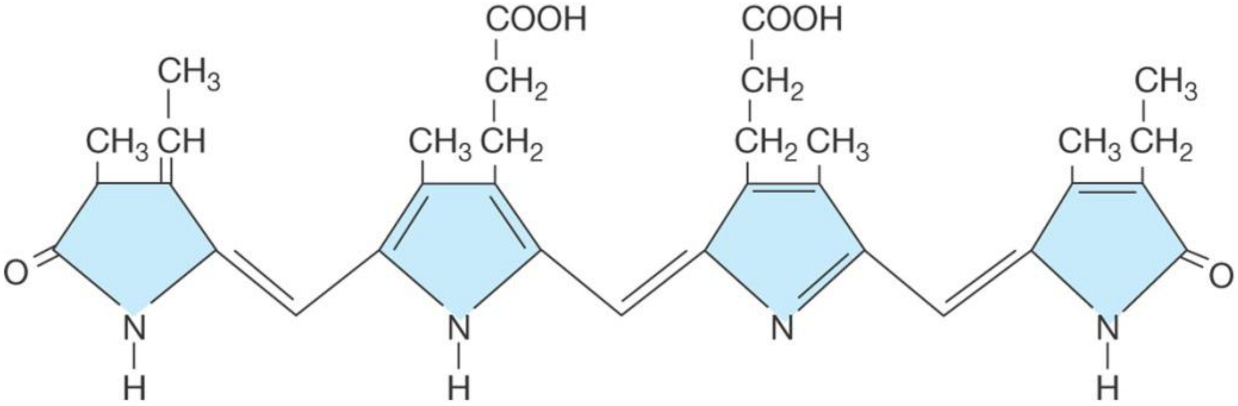
卟啉环



β-Carotene (a carotenoid) β-胡萝卜素



Fucoxanthin (a carotenoid) 墨角藻黄素



Phycocyanobilin 藻蓝素

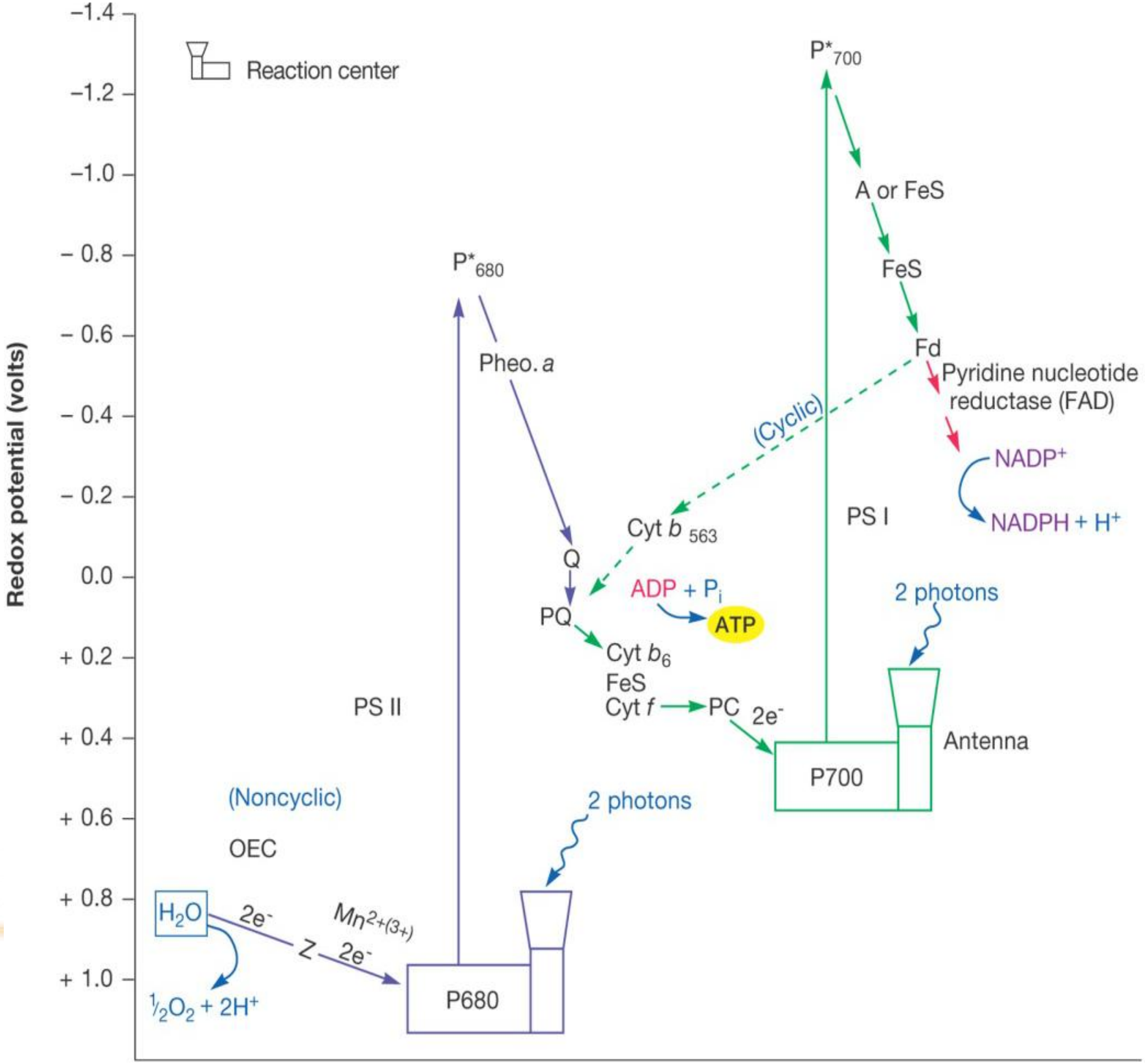
Organization of pigments

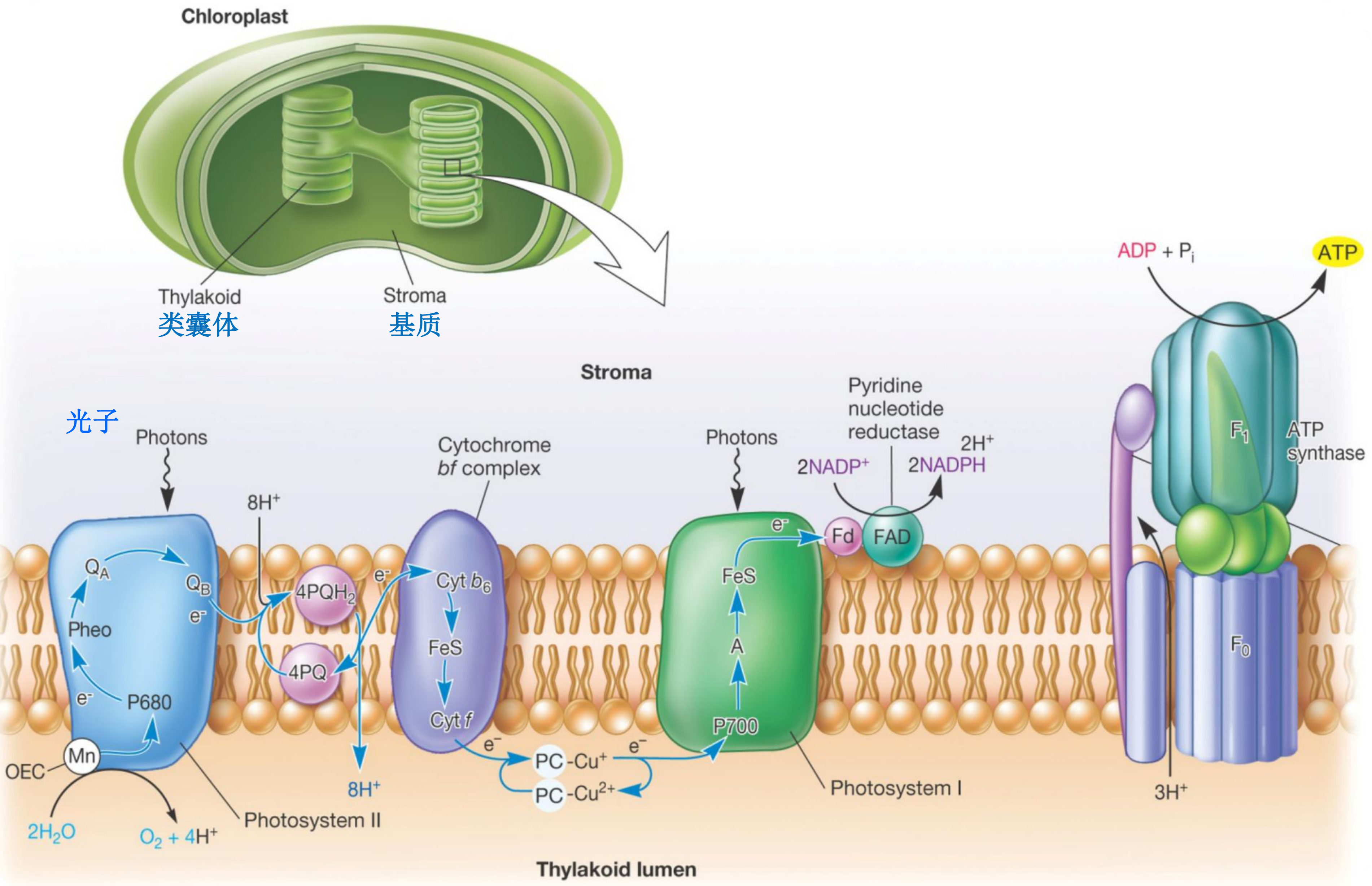
- Antennas天线色素
  - highly organized arrays of chlorophylls and accessory pigments
  - captured light transferred to special reaction-center chlorophyll
    - directly involved in photosynthetic electron transport
- photosystems
  - antenna and its associated reaction-center chlorophyll
  - PS-P700 光合系统I/ PSII-P680光合系统II
- electron flow → PMF → ATP

Oxygenic photosynthesis

Cyclic electron flow – ATP made (cyclic photophosPhorylation环式光合磷酸化)

Noncyclic electron flow – ATP + NADPH made (noncyclic photophosphorylation

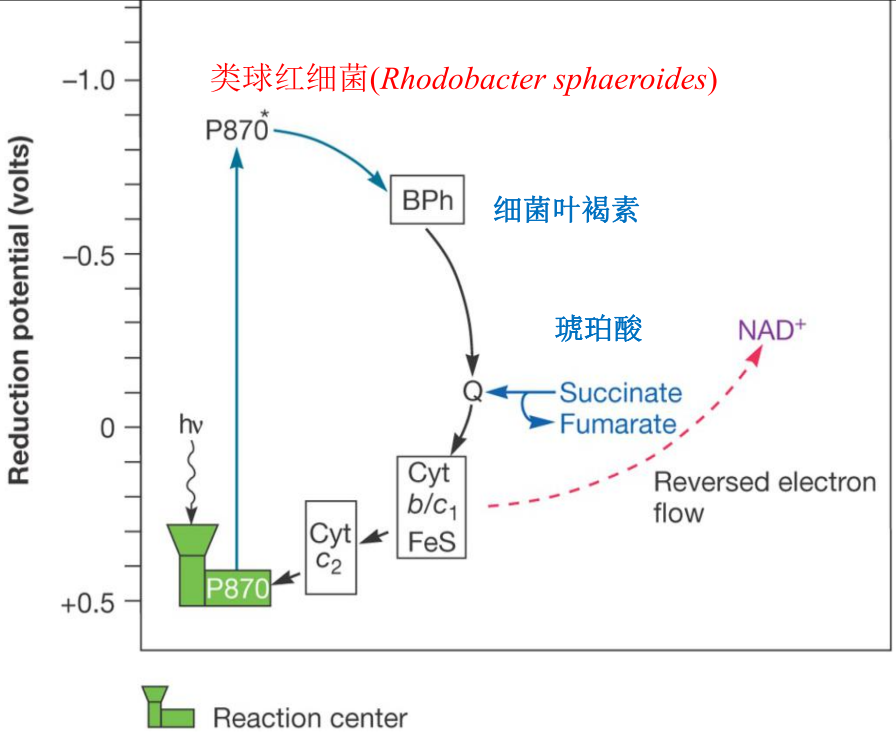


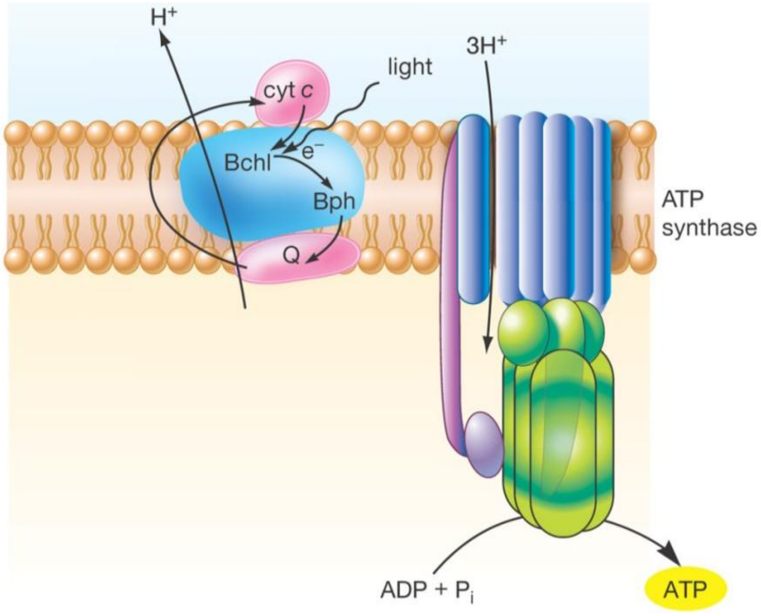

Chloroplast
Thylakoid
类囊体
Stroma
基质
Stroma
光子
Photons
$8H^+$
Cytochrome *bf* complex
Photons
Pyridine nucleotide reductase
$2H^+$
$2NADP^+$
$2NADPH$
$ADP + P_i$
ATP
F_1
ATP synthase
Q_A
Q_B
e^-
Pheo
e^-
P680
Mn
OEC
$4PQH_2$
$4PQ$
e^-
Cyt b_6
FeS
Cyt *f*
e^-
FeS
A
P700
e^-
Fd
FAD
F_0
e^-
$PC\text{-}Cu^+$
e^-
$PC\text{-}Cu^{2+}$
$8H^+$
$3H^+$
$2H_2O$
$O_2 + 4H^+$
Photosystem II
Photosystem I
Thylakoid lumen

Anoxygenic photosynthesis

非产氧光合作用

- H_2O not used as an electron source; therefore O_2 is not produced
- only one photosystem involved(anaerobe)
- uses bacteriochlorophylls细菌叶绿素 and mechanisms to generate reducing power
- carried out by phototrophic green bacteria, phototrophic purple bacteria, and heliobacteria

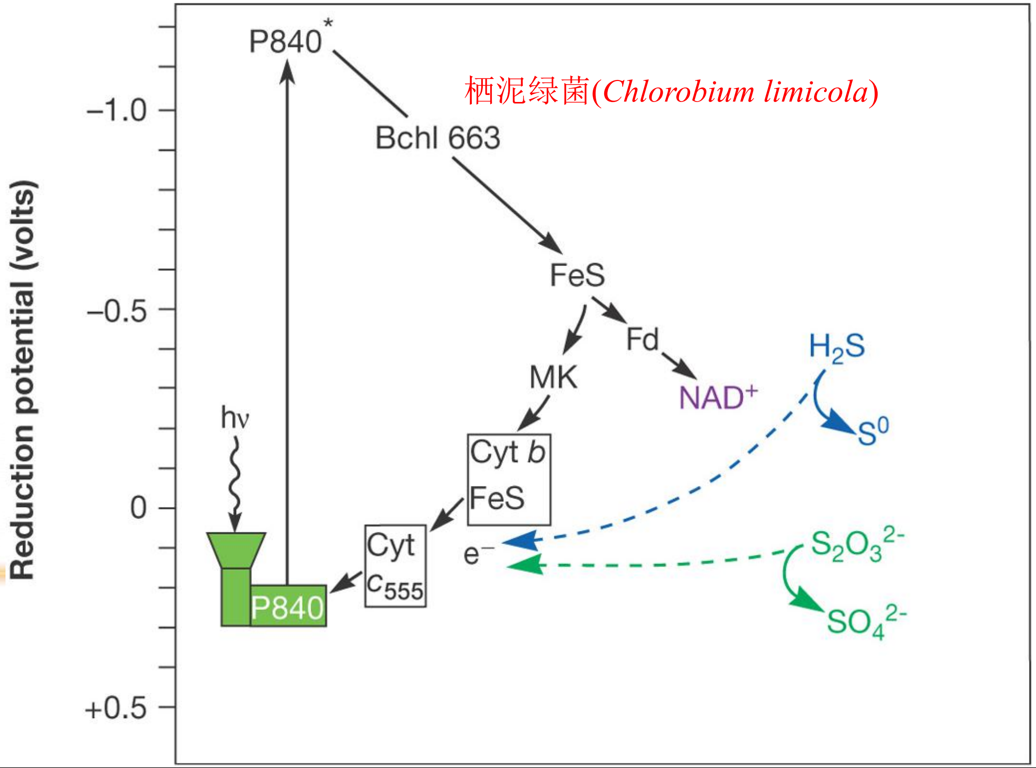




How to produce reducing power?

1. **Hydrogenase**
2. **Reverse electron**
3. **Electron draw off**

(noncylic-)



Bacteriorhodopsin细菌视紫红质-based phototrophy(Halophilie)

- some archaea use a type of phototrophy that involves bacteriorhodopsin, a membrane protein which functions as a light-driven proton pump光驱动质子泵
- a proton motive force is generated
- an electron transport chain is not involved

- **Summary**
    - **Catabolism is a fueling process which included in respiration and fermentation. A big difference of R and F is energy production and electron acceptor.**
    - **three common routes-glycolysis**
        - **Embden-Meyerhof pathway**
        - **pentose phosphate pathway**
        - **Entner-Duodoroff pathway(*agrobacterium*,G^-)**
    - **TCA cycle oxidizes acetyl-CoA to CO2 and forms one GTP or ATP, three NADH, and one FADH2 per acetyl-CoA. It also generates several precursor metabolites.**

Discussion

1.Why might it be desirable for a microorganism with the Embden-Meyerhof pathway and the TCA cycle also to have the pentose phosphate pathway?

2. Calculate the ATP yield when glucose is catabolized completely to six CO_2 by a eukaryotic microbe. How does this value compare to the ATP yield observed for a bacterium?

3. What is denitrification? Why do farmers dislike this process? but it has important role in ecosystem. Why?

4. When bacteria carry out fermentation, only a few reactions of the TCA cycle operate. What purpose do you think these reactions might serve? Why are some parts of the cycle shut down?

5. Why can hydrogen-oxidizing bacteria and archaea donate electrons to NAD^+, whereas sulfur- and ammonia-oxidizing bacteria and archaea cannot? How do they get NADH?

6. Compare and contrast anoxygenic phototrophy and oxygenic photosynthesis. How do these two types of phototrophy differ from rhodopsin-based phototrophy?