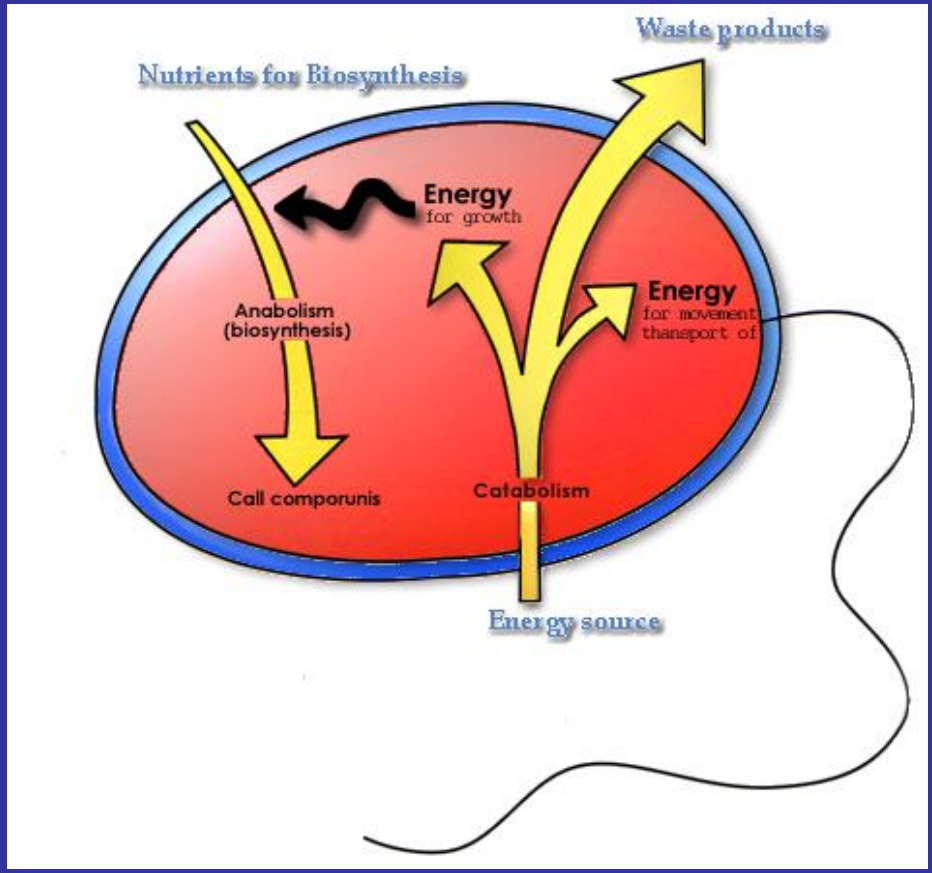
Chapter 6

Microbial Nutrition and Metabolism



Chapter outline

6.1 Nutrient requirements
6.2 Nutritional types of microorganisms
6.3 Uptake of nutrients by the cell
6.3 Culture Media
6.4 An Overview of Metabolism
6.5 Fermentation: The Embden-Meyerhof Pathway
6.6 Respiration and Electron Transport
6.7 The Balance Sheet of Aerobic Respiration and Energy Storage
6.8 An Overview of Alternate Modes of Energy Generation
6.9 Biosynthesis of Monomers
6.10 Nitrogen fixation

Concepts

- Microorganisms require about 10 elements in large quantities, in part because they are used to construct carbohydrates, lipids, proteins, and nucleic acids. Several other elements are needed in very small amount and are parts of enzymes and cofactors.
- All microorganisms can be placed in one of a few nutritional categories on the bases of their requirements for carbon, energy and hydrogen atoms or electrons.
- Nutrient molecules frequently cannot cross selectively permeable plasma membranes through passive diffusion. They must be transported by one of three major mechanisms involving the use of membrane carrier proteins.

6.1 Nutrient requirements

Concepts:

Microorganisms require about ten elements in large quantities, because they are used to construct carbohydrates, lipids, proteins, and nucleic acids. Several other elements are needed in very small amounts and are parts of enzymes and cofactors.

Macronutrients

- 95% or more of cell dry weight is made up of a few major elements: carbon, oxygen, hydrogen, nitrogen, sulfur, phosphorus, potassium, calcium, magnesium and iron.
- The first six (C, H, O, N, P and S) are components of carbohydrates, lipids, proteins and nucleic acids

Trace Elements

Microbes require very small amounts of other mineral elements, such as iron, copper, molybdenum, and zinc; these are referred to as trace elements. Most are essential for activity of certain enzymes, usually as cofactors.

Growth Factors

(1)Amino acids

(2) Purines and pyrimidines,

(3) Vitamins

Amino acids for protein synthesis

Purines and pyrimidines for nucleic acid synthesis.

Vitamins are small organic molecules that usually make up all or part enzyme cofactors, and only very small amounts are required for growth.

6.2 Nutritional types of microorganisms

Major nutritional type	Sources of energy, hydrogen/electrons, and carbon	Representative microorganisms
Photoautotroph (Photolithotroph)	Light energy, inorganic hydrogen/electron(H/e^-) donor, CO_2 carbon source	Algae, Purple and green bacteria, Cyanobacteria
Photoheterotroph (Photoorganotroph)	Light energy, inorganic H/e^- donor, Organic carbon source	Purple nonsulfur bacteria, Green sulfur bacteria
Chemoautotroph (Chemolithotroph)	Chemical energy source (inorganic), Inorganic H/e^- donor, CO_2 carbon source	Sulfur-oxdizing bacteria, Hydrogen bacteria, Nitrifying bacteria
Chemoheterotroph (Chenoorganotroph)	Chemical energy source (organic), Organic H/e^- donor, Organic carbon source	Most bacteria, fungi, protozoa

Photoautotroph

Algae, Cyanobacteria

$$CO_2 + H_2O \xrightarrow{\text{Light + Chlorophyll}} (CH_2O) + O_2$$

Purple and green bacteria

$$CO_2 + 2H_2S \xrightarrow{\text{Light + bacteriochlorophyll}} (CH_2O) + H_2O + 2S$$

Photoheterotroph

Purple nonsulfur bacteria (Rhodospirillum)

$$CO_2 + 2CH_3CHOHCH_3 \xrightarrow{\text{Light + bacteriochlorophyll}} (CH_2O) + H_2O + 2CH_3COCH_3$$

Properties of microbial photosynthetic systems

Property	Cyanobacteria	Green and purple bacteria	Purple nonsulfur bacteria
Photo - pigment	Chlorophyll	Bcteriochlorophyll	Bcteriochlorophyll
O_2 production	Yes	**No**	No
Electron donors	H_2O	H_2, H_2S, S	H_2, H_2S, S
Carbon source	CO_2	CO_2	Organic / CO_2
Primary products of energy conversion	ATP + NADPH	ATP	ATP

Chemoautotroph

Bacteria	Electron donor	Electron acceptor	Products
Alcaligens and Pseudomonas sp.	H_2	O_2	H_2O
Nitrobacter	NO_2^-	O_2	NO_3^- , H_2O
Nitrosomonas	NH_4^+	O_2	NO_2^- , H_2O
Desulfovibrio	H_2	SO_4^{2-}	H_2O. H_2S
Thiobacillus denitrificans	S^0. H_2S	NO_3^-	SO_4^{2-} , N_2
Thiobacillus ferrooxidans	Fe^{2+}	O_2	Fe^{3+} , H_2O

Nitrifying bacteria

$$2\ NH_4^+ + 3\ O_2 \longrightarrow 2\ NO_2^- + 2\ H_2O + 4\ H^+ + 132\ Kcal$$

6.3 Uptake of nutrients

Nutrient molecules frequently cannot cross selectively permeable plasma membranes through passive diffusion and must be transported by one of three major mechanisms involving the use of membrane carrier proteins.

1. **Phagocytosis** – **Protozoa**

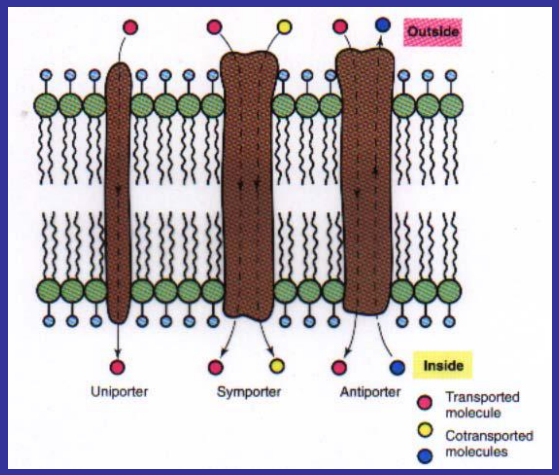
2. **Permeability absorption** – **Most microorganisms**

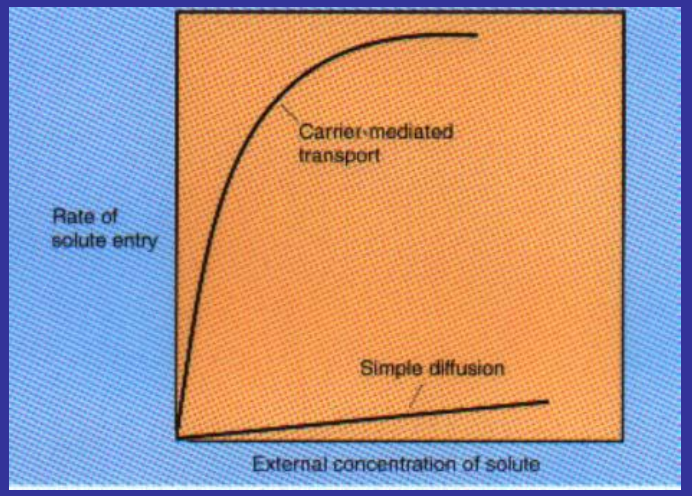
- Passive transport　simple diffusion
- Facilitated diffusion
- Active transport
- Group translocation

Passive diffusion

Passive diffusion is the process in which molecules move from a region of higher concentration to one of lower concentration as a result of random thermal agitation. A few substances, such as glycerol, can cross the plasma membrane by **passive diffusion.**

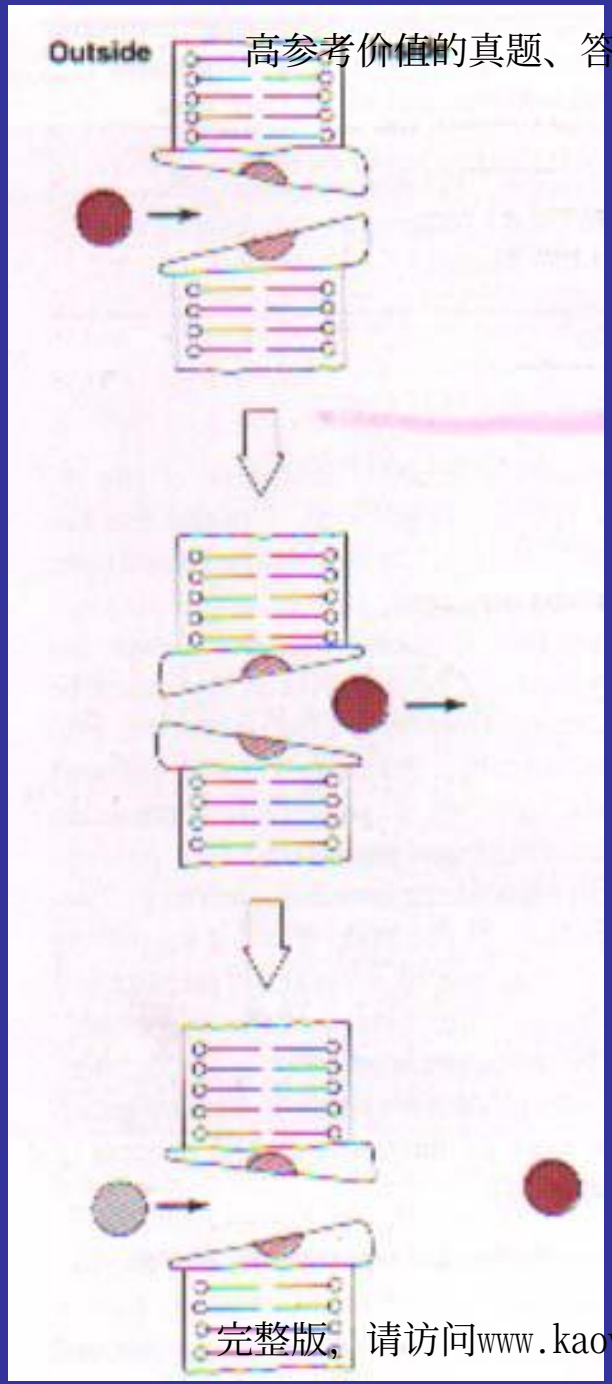
Facilitated diffusion





The rate of diffusion across selectively permeable membranes is greatly increased by the use of carrier proteins, sometimes called **permeases,** which are embedded in the plasina membrane. Since the diffusion process is aided by a carrier, it is called **facilitated diffusion.** The rate of facilitated diffusion increases with the concentratioti gradient much more rapidly and at lower concentrations of the diffusing molecule than that of passive diffusion.

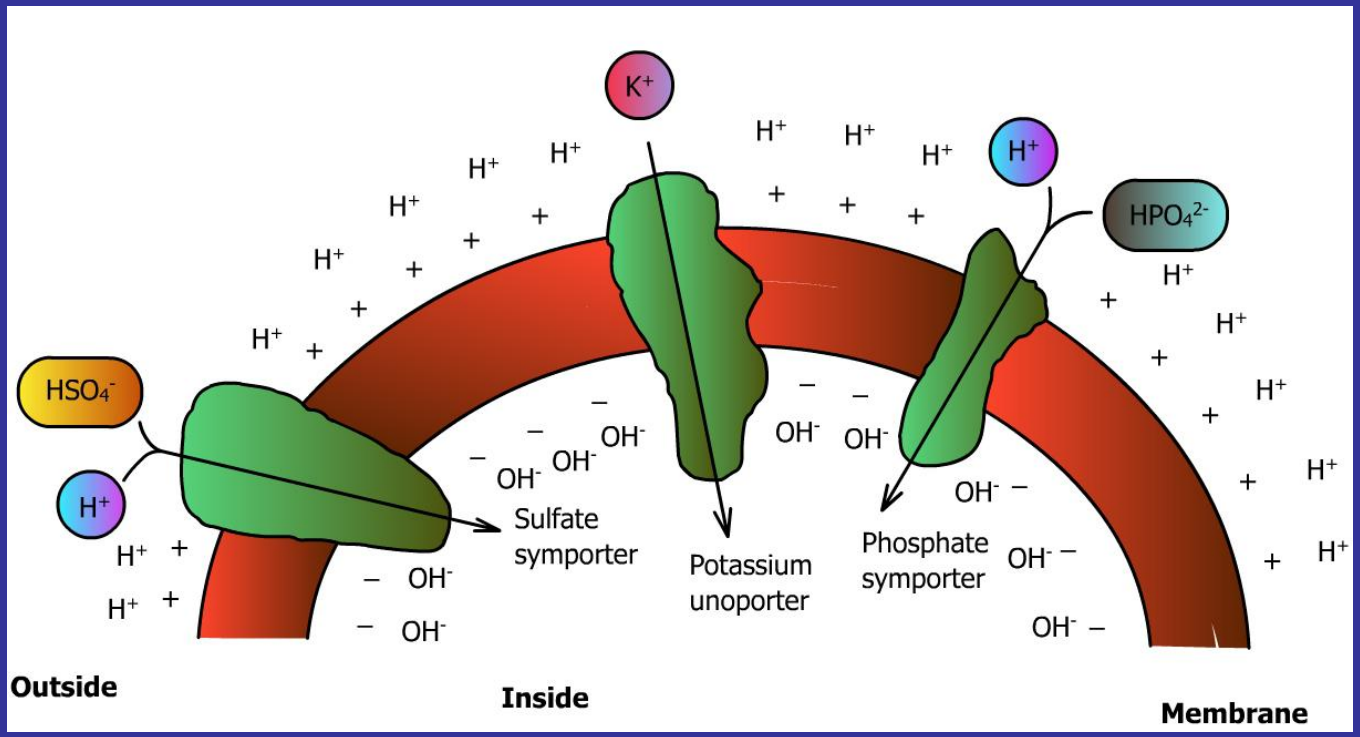
A model of facilitated diffusion



The membrane carrier can change conformation after binding an external molecule and subsequently release the molecule on the cell interior. It then returns to the outward oriented position and is ready to bind another solute molecule.

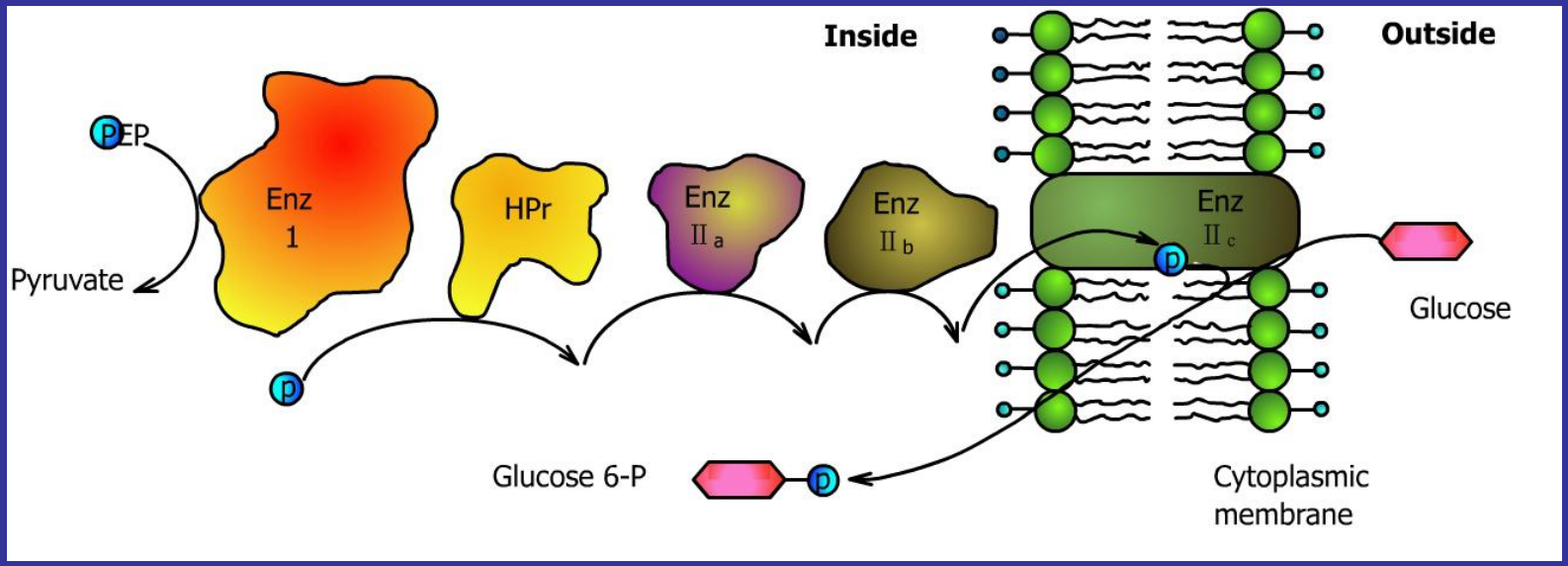
Because there is no energy input, molecules will continue to enter only as long as their concentration is greater on the outside.

Active transport



Active transport is the transport of solute molecules to higher concentrations, or against a concentration gradient, with the use of metabolic energy input.

Group translocation

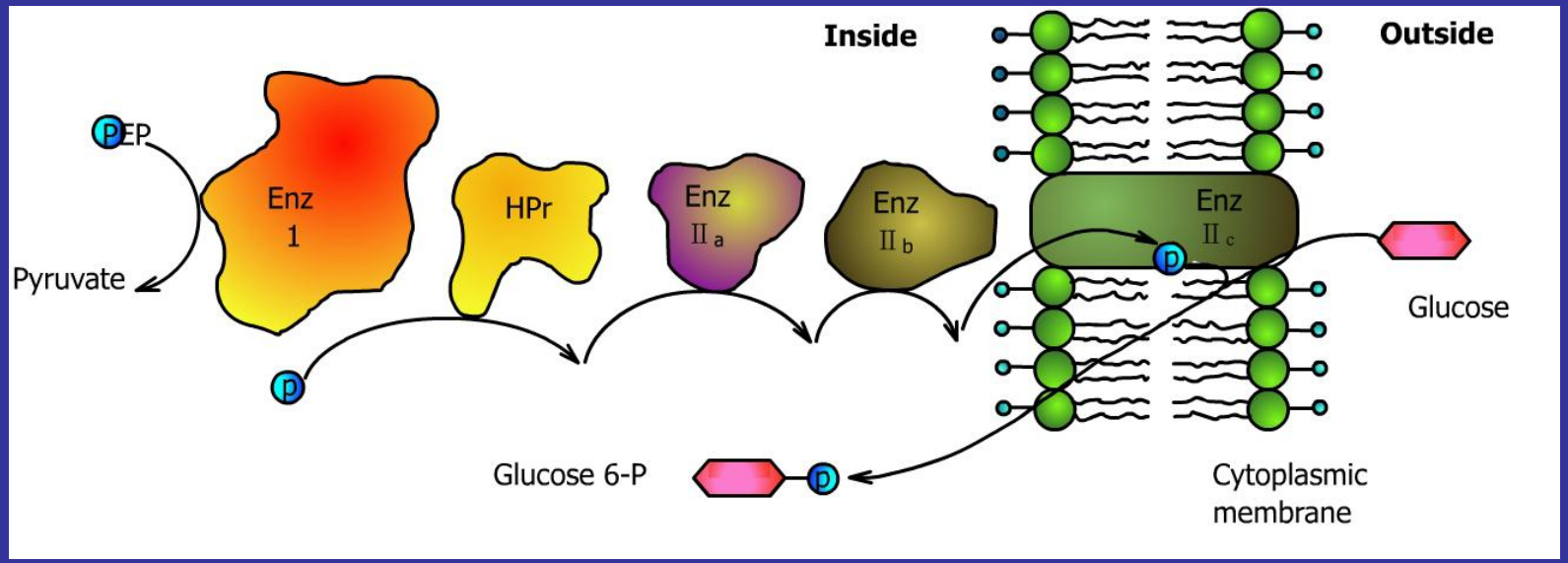


Group translocation

The best-known group translocation system is the *phosphoenolpyruvate: sugar phosphotransferase system (PTS),* which transports a variety of sugars into procaryotic cells while Simultaneously phosphorylating them using phosphoenolpyruvate (PEP) as the phosphate donor.

PEP + sugar (outside) ⟶ pyruvate + sugar-P (inside)

The phosphoenolpyruvate: sugar phosphotransferase system of *E. coli*. The following components are involved in the system: phosphoenolpyruvate, *PEP;* enzyme 1, *E I;* the low molecular weight heat-stable protein, *HPr;* enzyme 11, *E II,*- and enzyme III*, E III*.



Simple comparison of transport systems

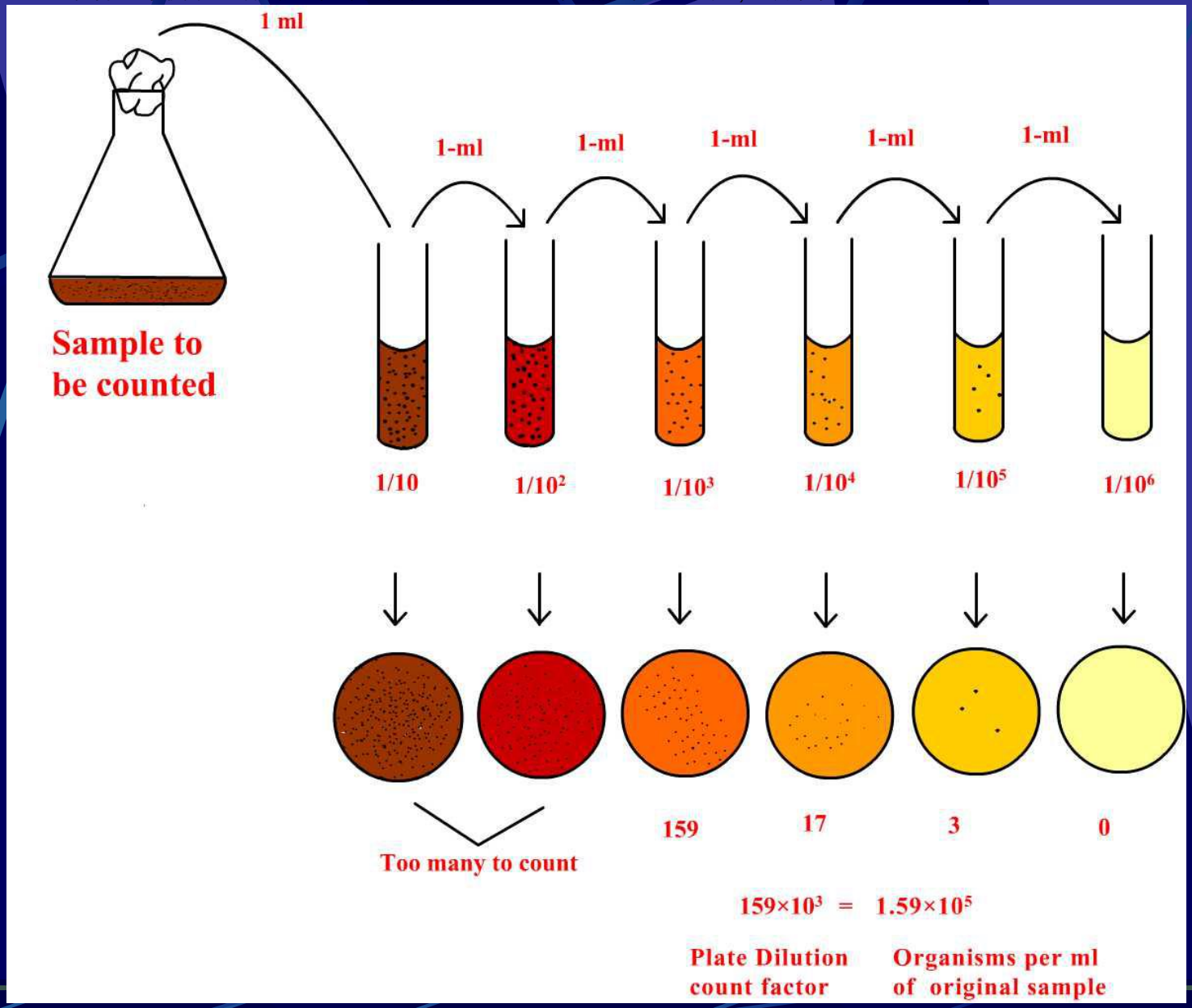
Items	Passive diffusion	Facilitated diffusion	Active transport	Group translocation
carrier proteins	Non	Yes	Yes	Yes
transport speed	Slow	Rapid	Rapid	Rapid
against gradient	Non	Non	Yes	Yes
transport molecules	No specificity	Specificity	Specificity	Specificity
metabolic energy	No need	Need	Need	Need
Solutes molecules	Not changed	Changed	Changed	Changed

Culture media

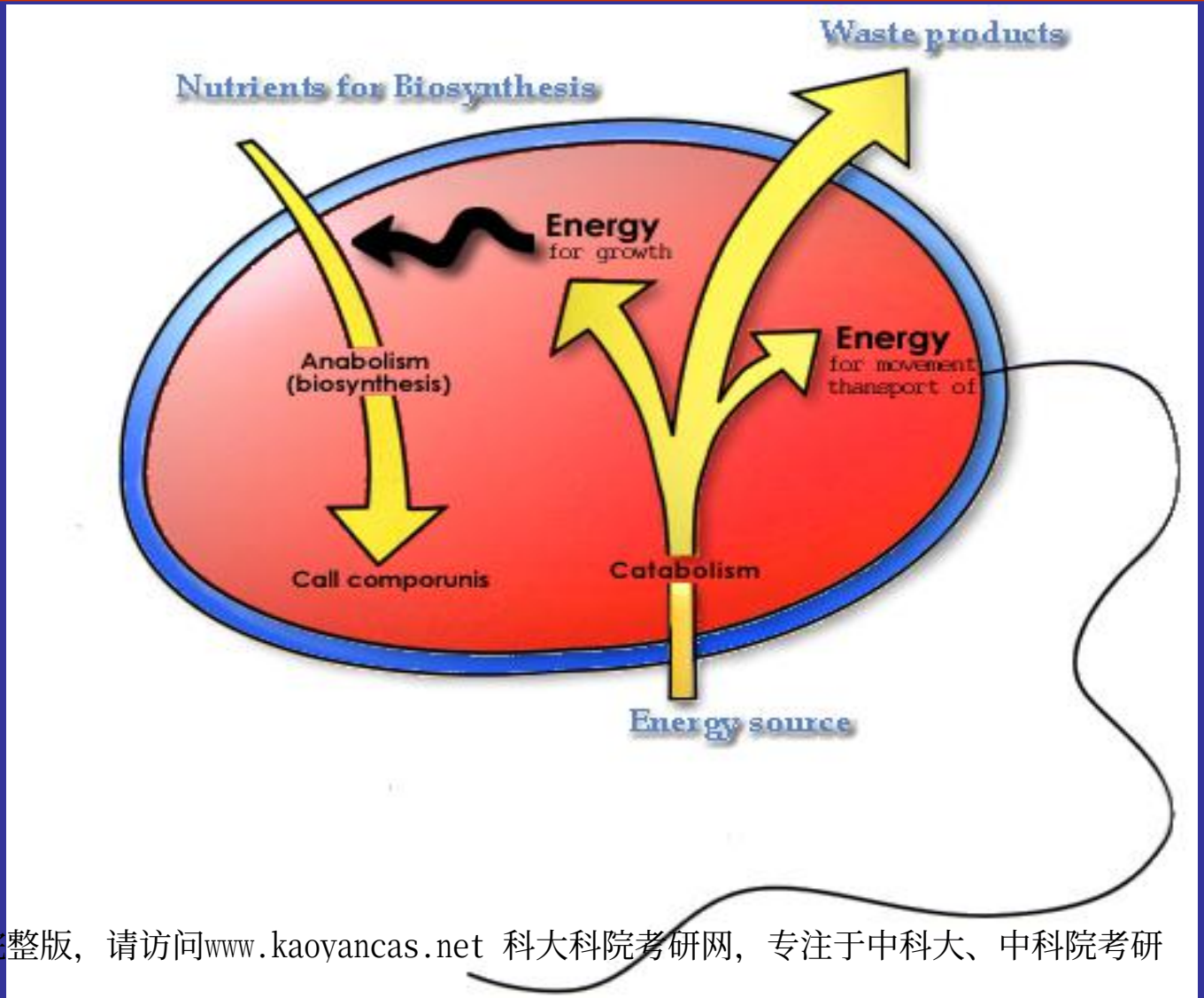
Culture media are needed to grow microorganisms in the laboratory and to carry out specialized procedures like microbial identification, water and food analysis, and the isolation of particular microorganisms. A wide variety of media is available for these and other purposes.

Pure cultures

Pure cultures can be obtained through the use of spread plates, streak plates, or pour plates and are required for the careful study of an individual microbial species.



6.4 An Overview of Metabolism

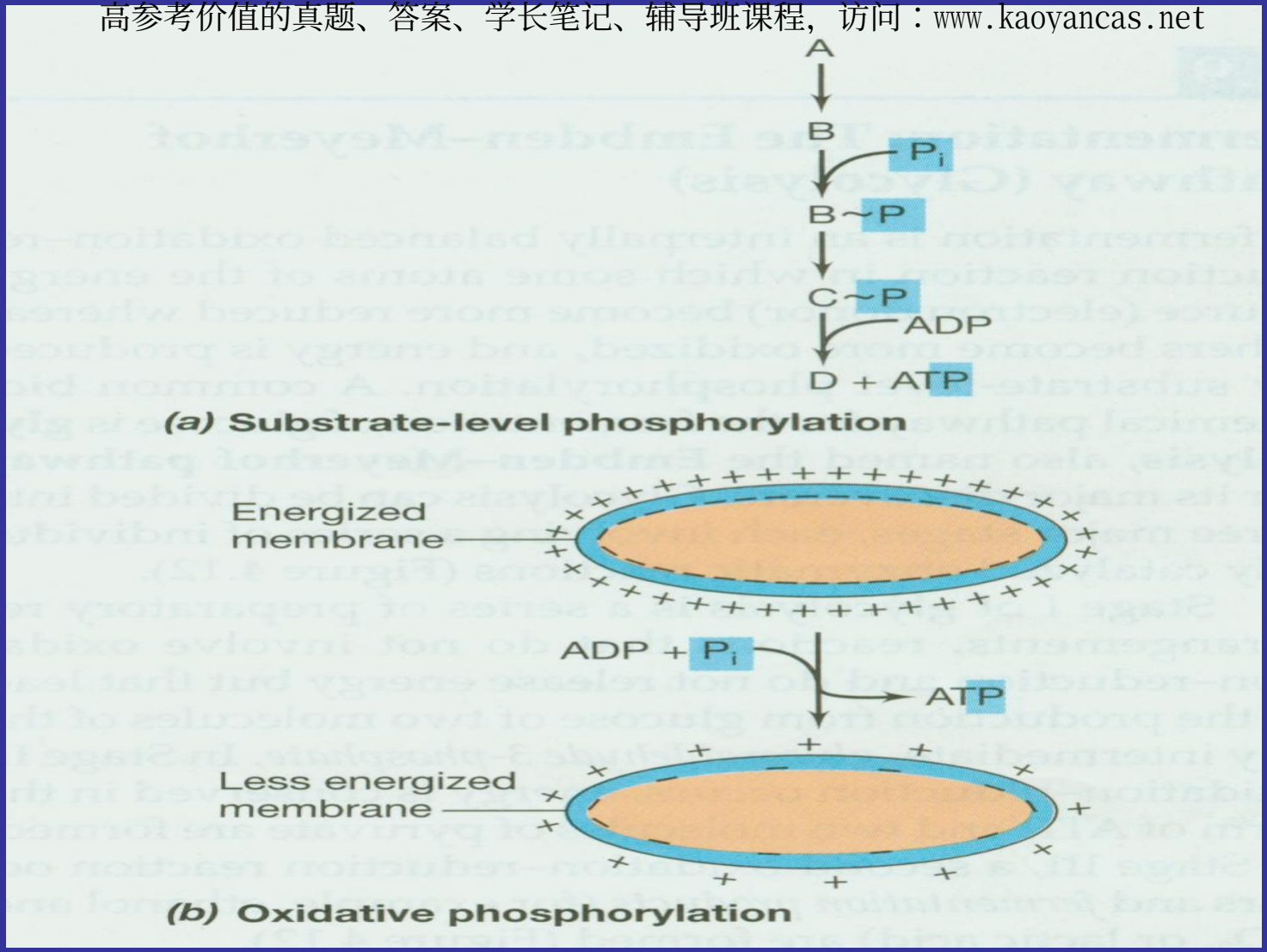


Metabolism is the total of all chemical reactions occurring in the cell. A simplified view of cell metabolism depicts how catabolic degradative reactions supply energy needed for cell functions and how anabolic reactions bring about the synthesis of cell components from nutrients.

Note that in anabolism, nutrients from the environment or those generated from catabolic reactions are converted to cell components, whereas in catabolism, energy sources from the environment are converted to waste products

6.5 Fermentation : The Embden-Meyerhof Pathway

A fermentation is an internally balanced oxidation-reduction reaction in which some atoms of the energy source (electron donor) become more reduced whereas others become more oxidized, and energy is produced by substrate-level phosphorylation.



Energy conservation in fermentation and respiration

Embden-Meyerhof pathway

Glycolysis:

A common biochemical pathway for the fermentation of glucose is glycolysis, also named the Embden-Meyerhof pathway for its major discoverers. Can be divided into three major stages.

Stages I and II: Preparatory and Redox Reactions

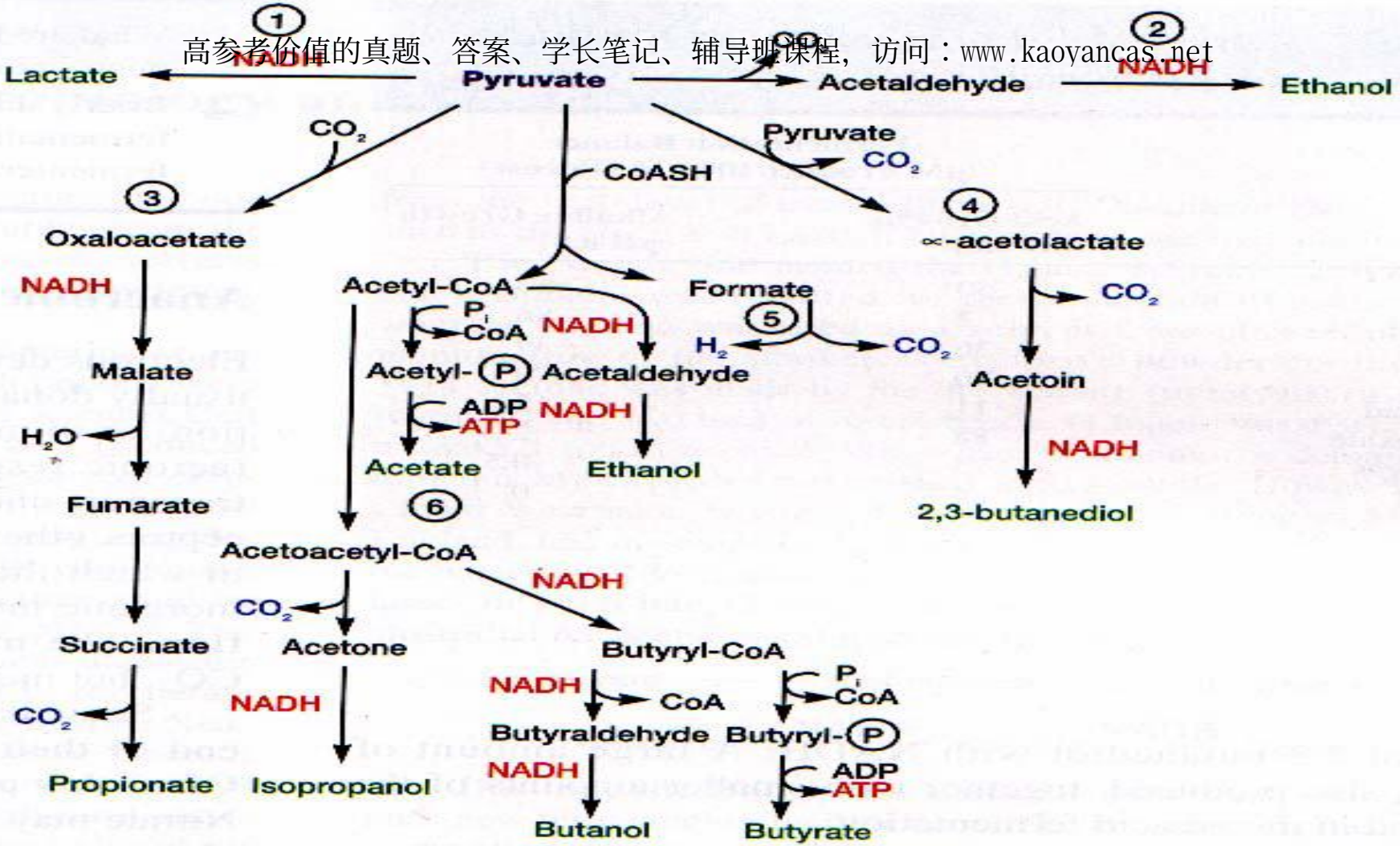
Stage I : A series of preparatory rearrangements: reactions that do not involve oxidation-reduction and do not release energy but that lead to the production from glucose of two molecules of the key intermediate, glyceraldehyde 3-phosphate.

Stage II: Oxidation-reduction occurs, energy is conserved in the form of ATP, and two molecules of pyruvate are formed.

Stage III: Production of Fermentation Products

Stage III:

A second oxidation-reduction reaction occurs and fermentation products (for example, ethanol and CO_2, or lactic acid) are formed.



1. Lactic acid bacteria (*Streptococcus, Lactobacillus*), *Bacillus*
2. Yeast, *Zymomonas*
3. Propionic acid bacteria (*Propionibacterium*)
4. *Enterobacter, Serratia, Bacillus*
5. Enteric bacteria (*Escherichia, Enterobacter, Klebsiella, Proteus*)
6. *Clostridium*

Glucose Fermentation: Net and Practical Results

The ultimate result of glycolysis is the consumption of glucose, the net synthesis of two ATPs, and the production of fermentation products.

6.6 Respiration and Electron Transport

Respiration : in which molecular oxygen or some other oxidant serves as the terminal electron acceptor

The discussion of respiration deals with both the carbon and electron transformations:

- (1) the biochemical pathways involved in the transformation of organic carbon to CO_2
- (2) the way electrons are transferred from the organic compound to the terminal electron acceptor, driving ATP synthesis at the expense of the proton motive force.

Electron Transport

Electron transport systems are composed of membrane associated electron carriers. These systems have two basic functions:

(1) to accept electrons from an electron donor and transfer them to an electron acceptor

(2) to conserve some of the energy released during electron transfer for synthesis of ATP.

Types of oxidation-reduction enzymes involved in electron transport

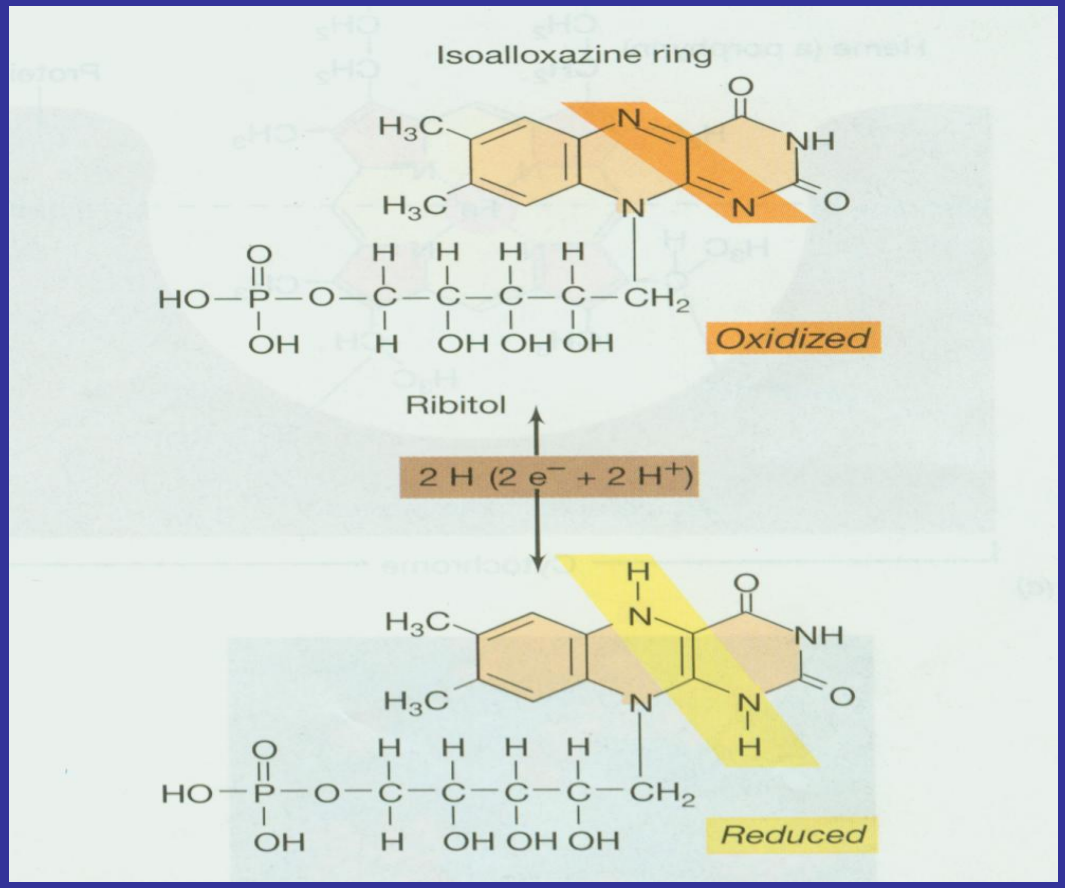
(1) NADH dehydrogenases

(2) Riboflavin-containing electron carriers, generally called flavoproteins

(3) iron-sulfur proteins

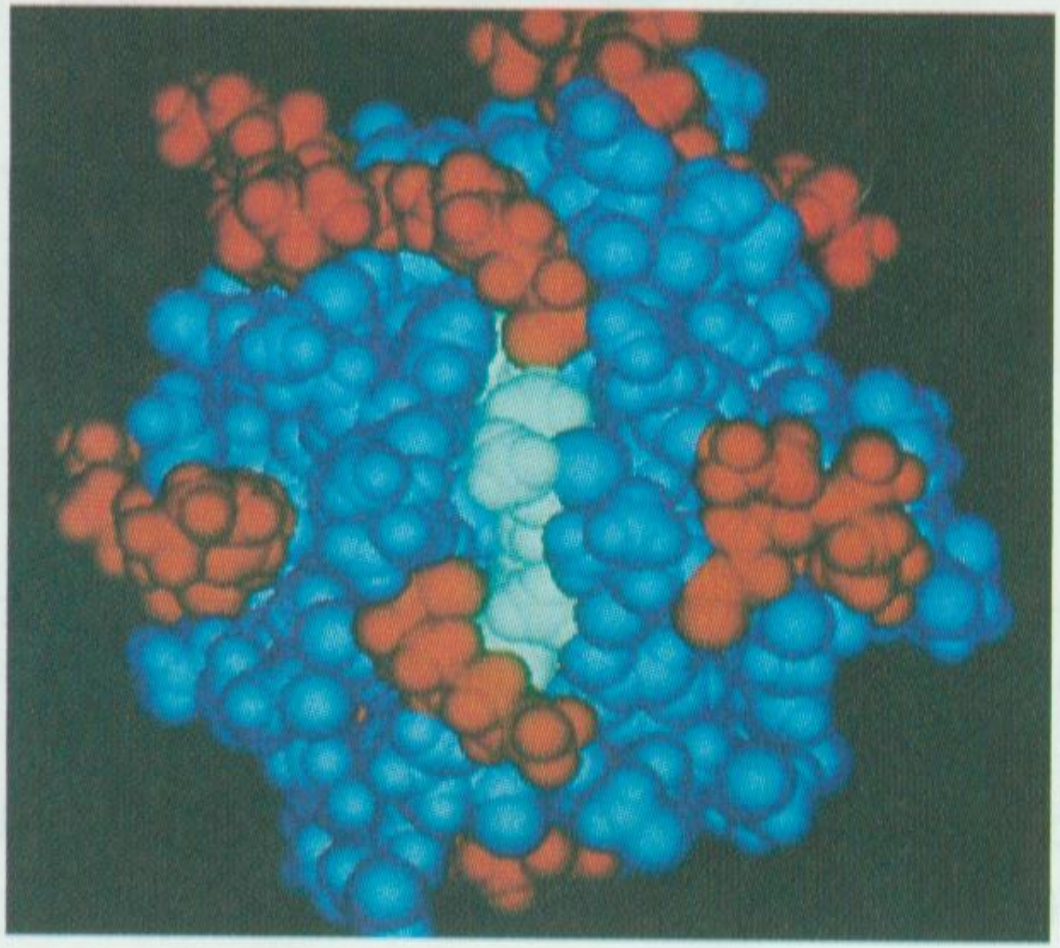
(4) Cytochromes

In addition, one class of nonprotein electron carriers is known, the lipid-soluble quinones.



Flavin mononucleotide (FMN) (riboflavin phosphate, a hydrogen atom carrier). The site of oxidation-reduction is the same in FMN and flavin-adeninedinucleotide (FAD).

Computer-generated model of cytochrome c.



6.7 The Balance Sheet of Aerobic Respiration and Energy Storage

- **ATP and Cell Yield**
- **Energy Storage**

ATP and Cell Yield

The amount of ATP produced by an organism has a direct effect on cell yield. cell yield is directly proportional to the amount of ATP produced has been confirmed from experimental studies on the growth yields of various microorganisms and implies that the energy costs for assembly of macromolecules are much the same for all microorganisms.

Energy Storage

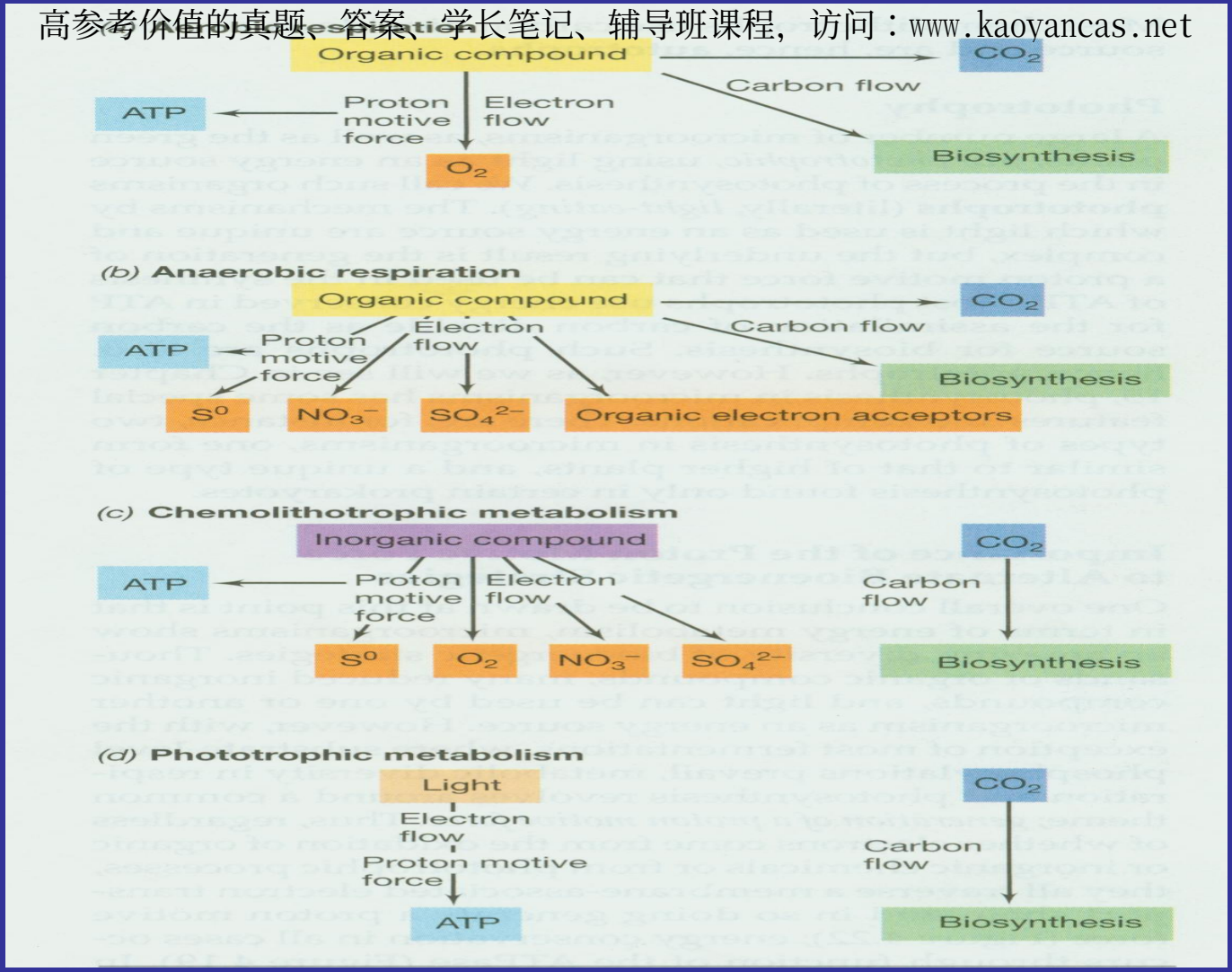
Most microorganisms produce insoluble polymers that can later be oxidized for the production of ATP.

Polymer formation is important to the cell for two reasons. First, potential energy is stored in a stable form, and second, insoluble polymers have little effect on the internal osmotic pressure of cells.

Storage polymers make possible the storage of energy in a readily accessible form that does not interfere with other cellular processes.

6.8 An Overview of Alternate Modes of Energy Generation

- Anaerobic Respiration
- Chemolithotrophy
- Phototrophy
- Importance of the Proton Motive Force to Alternate Bioenergetic Strategies

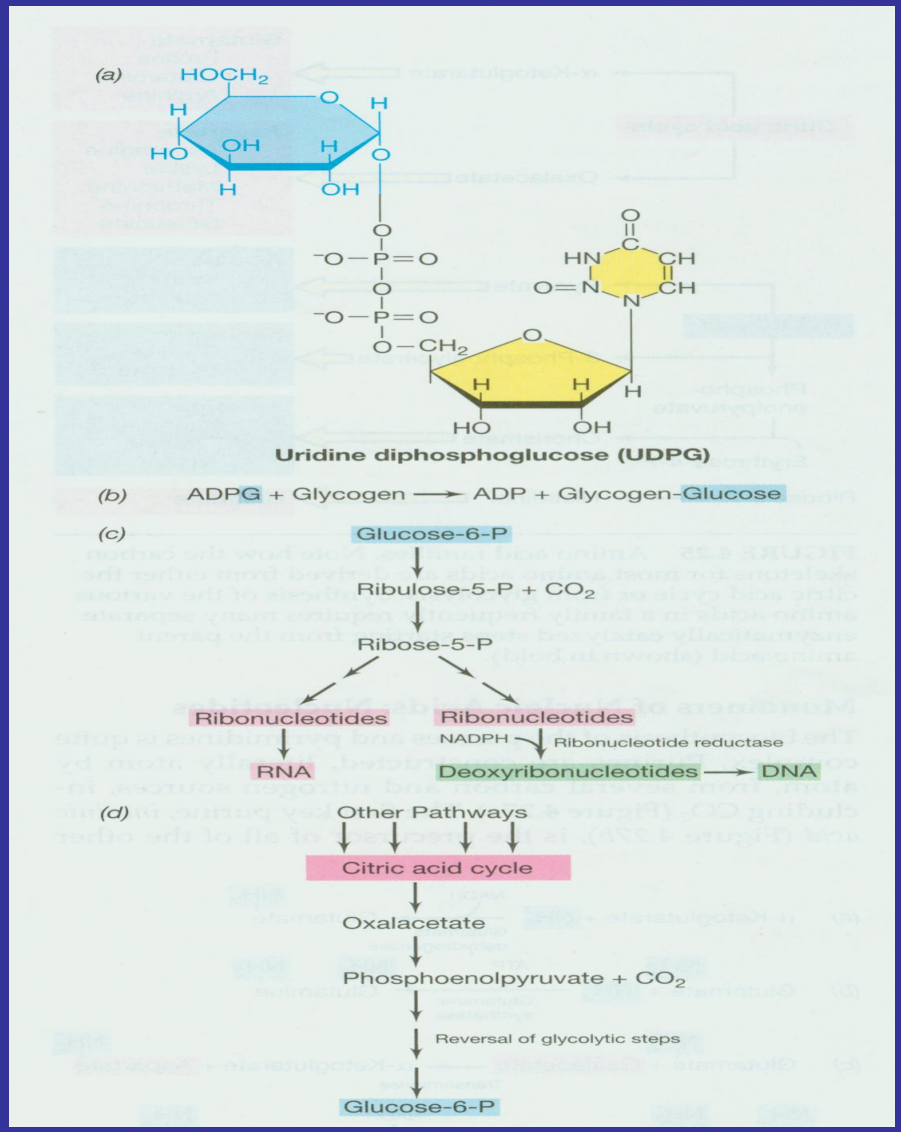


Energetics and carbon flow in (a) aerobic respiration, (b) anaerobic respiration, (c) chemolithotrophic metabolism, and (d) phototrophic; metabolism

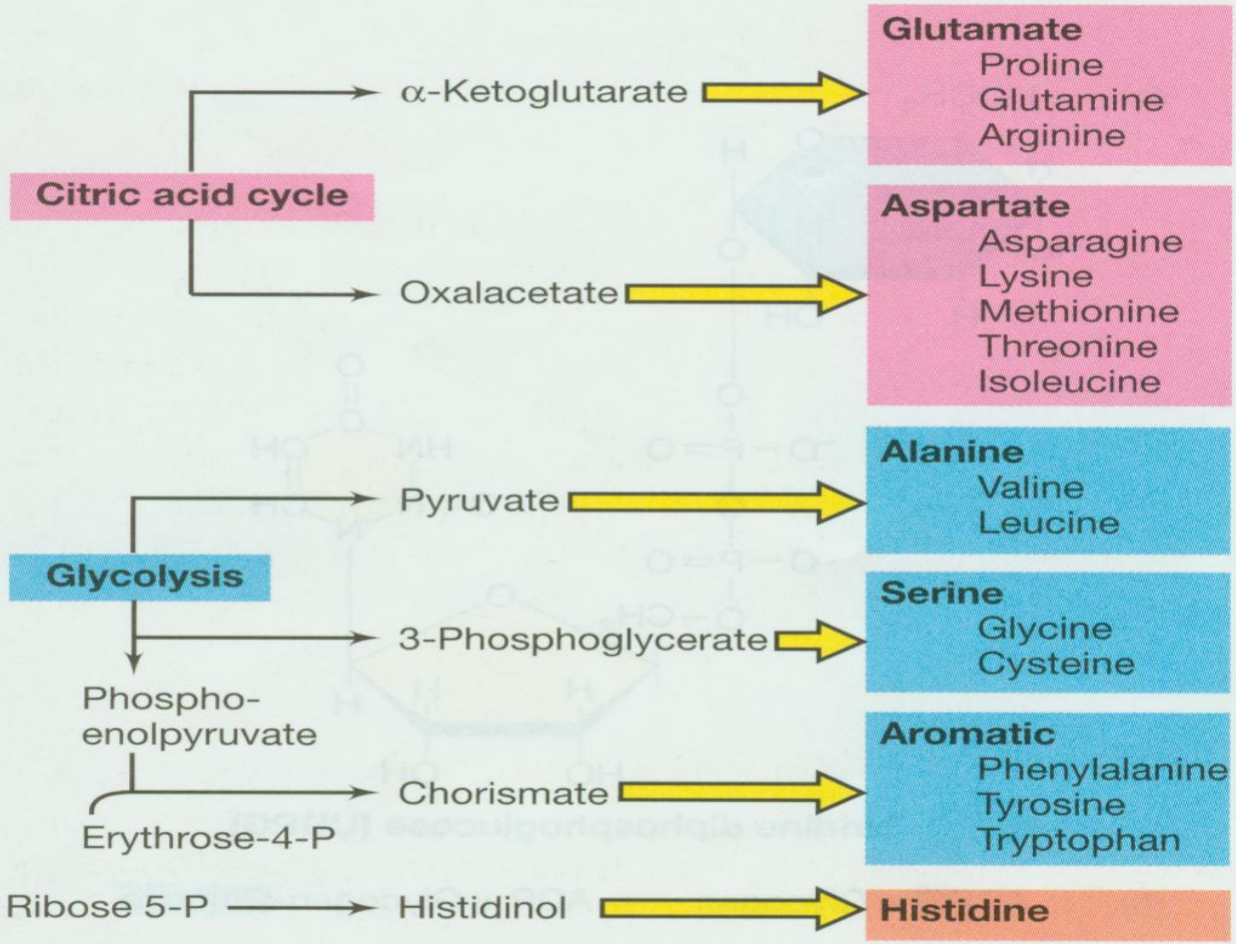
6.9 Biosynthesis of Monomers

- Monomers of Polysaccharides: Sugars
- Monomers of Proteins: Amino Acids
- Monomers of Nucleic Acids: Nucleotides
- Monomers of Lipids: Fatty Acids
- Biosynthesis of Peptidoglycan

Sugar metabolism

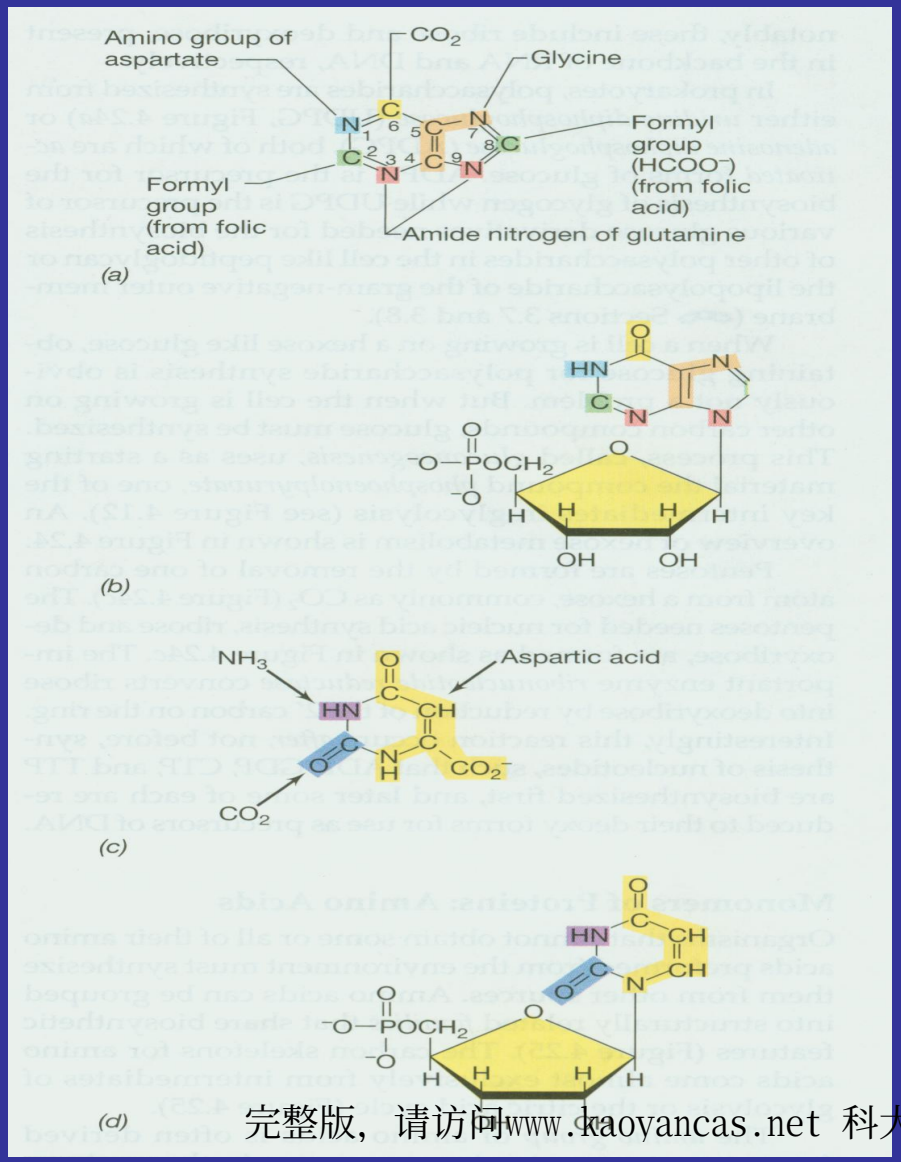


1. Polysaccharides are synthesized from activated forms of hexoses such as UDPG, whose structure is shown here.
2. Glycogen is biosynthesized from adenosine-phosphoglucose by the sequential addition of glucose.
3. Pentoses for nucleic acid synthesis are formed by decarboxylation of hexoses like glucose-6-phosphate.
4. Gluconeogenesis



Synthesis of the various amino acids in a family frequently requires many separate enzymatically catalyzed steps starting from the parent amino acid

Biosynthesis of purines and pyrimidines



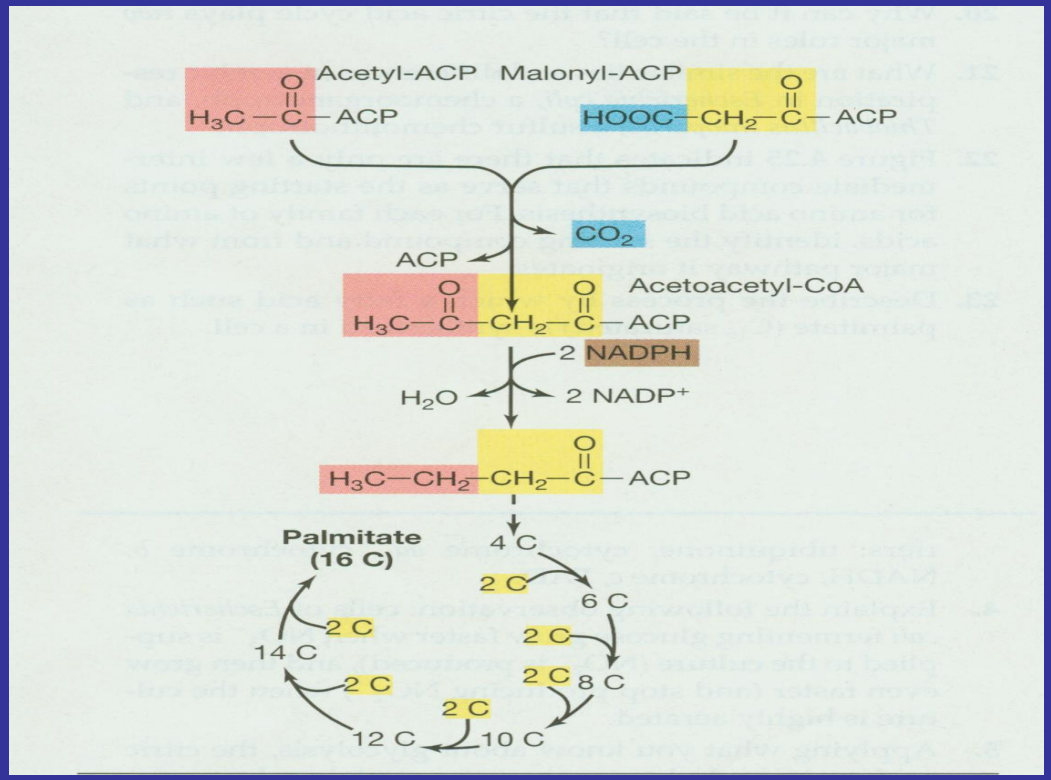
(a) The precursors of the purine skeleton

(b) Inosinic acid,the precursor of all purine nucleotides.

(c) The precursors of the pyrimidine skeleton, orotic acid.

(d) Uridylate, the precursor of all pyrimidine nucleotides. Uridylate is formed from orotate following a decarboxylation and the addition of ribose-5-phosphate.

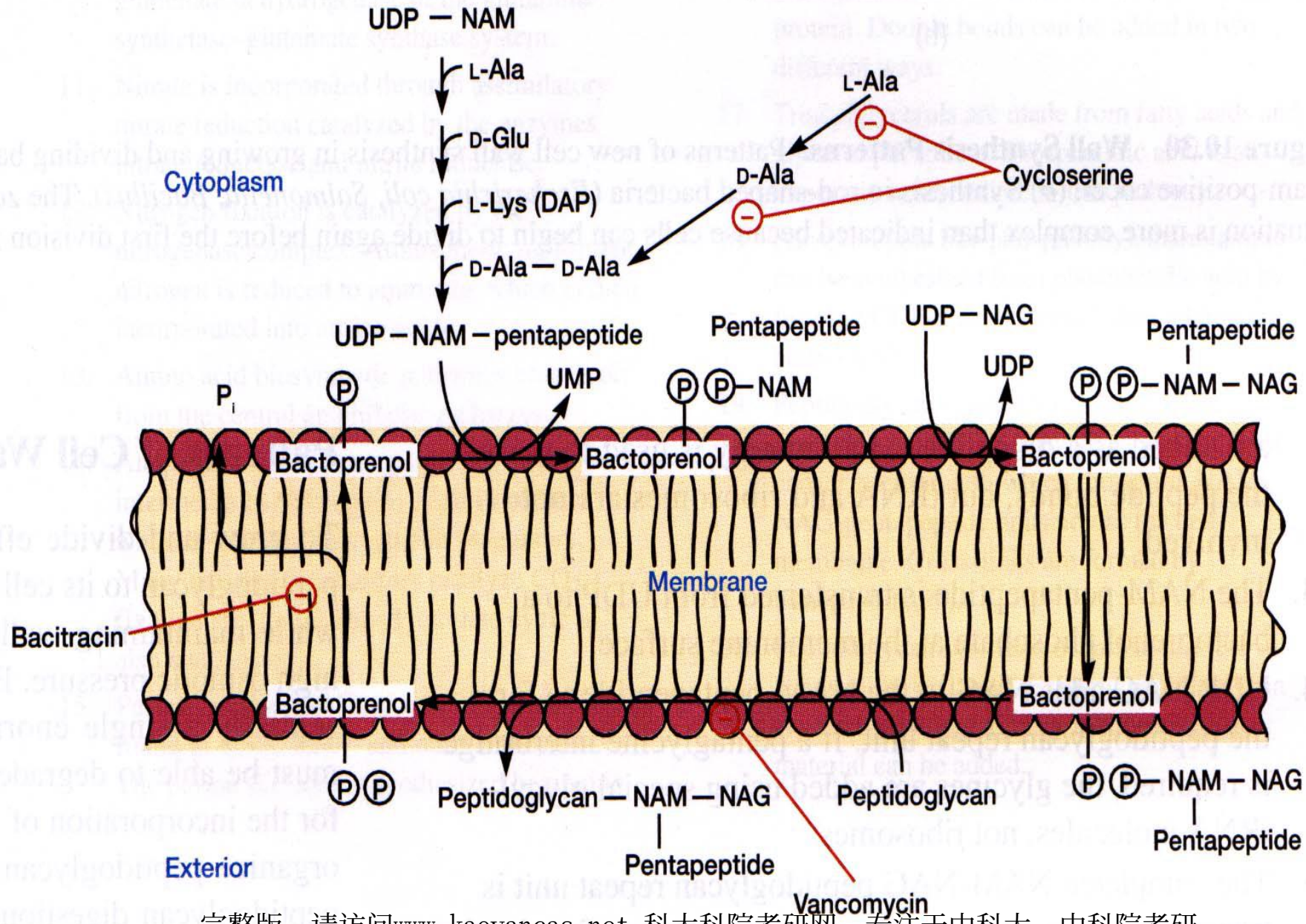
The biosynthesis of fatty acids

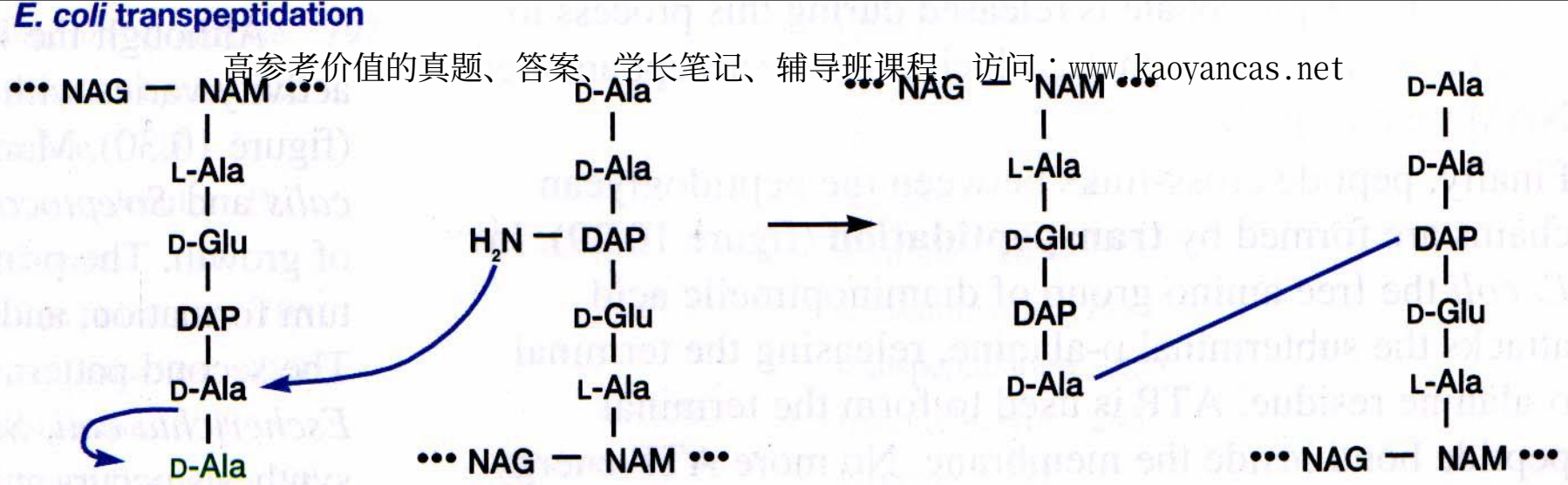


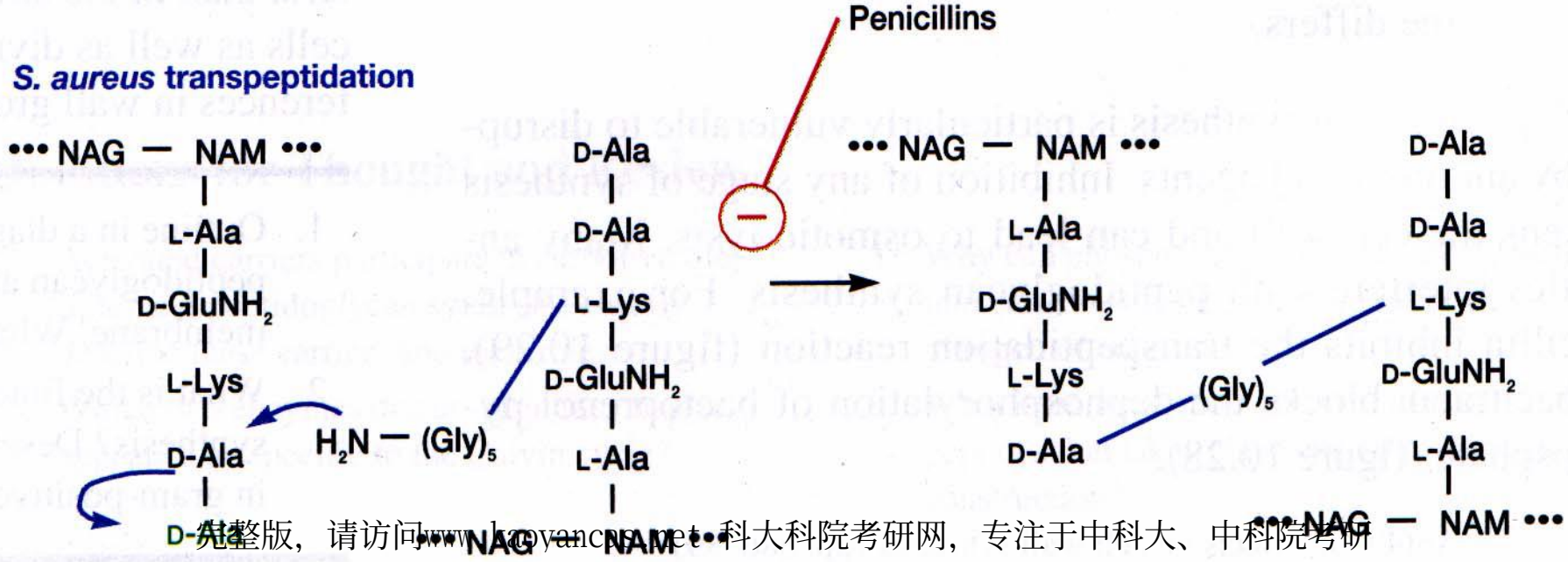
Shown is the biosynthesis of the C16 fatty arid, plamitate. The condensa tion of acetyl-ACP and malonyl-ACP forms acetoacetylCoA. liach successive addition of an acetyl unit comes from malonyl-CoA.

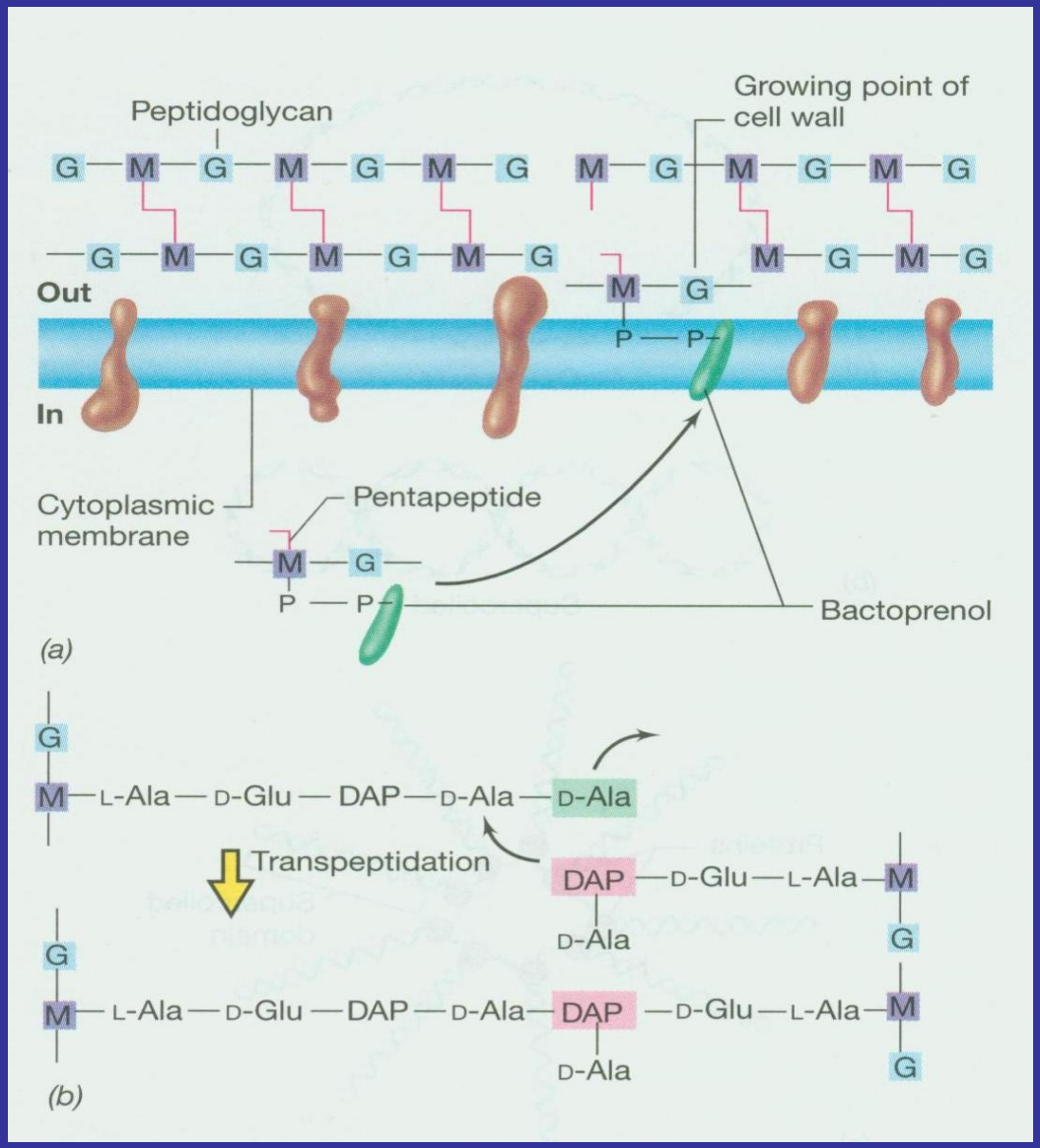
Biosynthesis of Peptidoglycan

Most bacterial cell walls contain a large, complex peptidoglycan molecule consisting of long polysaccharide chains made of alternating NAM and NAG residues. NAM is N-acetylmuramic acid and NAG is N-acetylglucosamine. The pentapeptide contains L-lysine in ***S.****aureus* peptidoglycan, and diaminopimelic acid (DAP) in ***E****.coli*. Inhibition by bacitracin, cycloserine, and vancomycin.









Peptidoglycan synthesis:

(a)Transport of peptidoglycan precursors across the cytoplasmic membrane to the growing point of the cell wall.

(b)The transpeptidation reaction that leads to the final cross-linking of two peptidoglycan chains. Penicillin inhibits this reaction.

6.10 Nitrogen fixation

The utilization of nitrogen gas (N_2) as a source of nitrogen is called ***nitrogen fixation*** and is a property of only certain prokaryotes. From *the table* below it can be seen that a variety of prokaryotes, both anaerobic and aerobic, fix nitrogen. There are some bacteria, called *symbiotic,*that fix nitrogen only in association with certain plants. As far as is currently known,no eukaryotic organisms fix nitrogen.

Some nitrogen-fixing organisms

Free-living aerobes

Chemo-organotrophs	**phototrophs**	**Chemo-lithotrophs**
Azotobacter spp.	*Cyanobacteria*	*Alcaligenes*
Azomonas	(various,but not all)	*Thiobacillus*
Beijerinckia		
Bacillus polymyxa		

- N_2 fixation occurs only under anoxic condition

Some nitrogen-fixing organisms

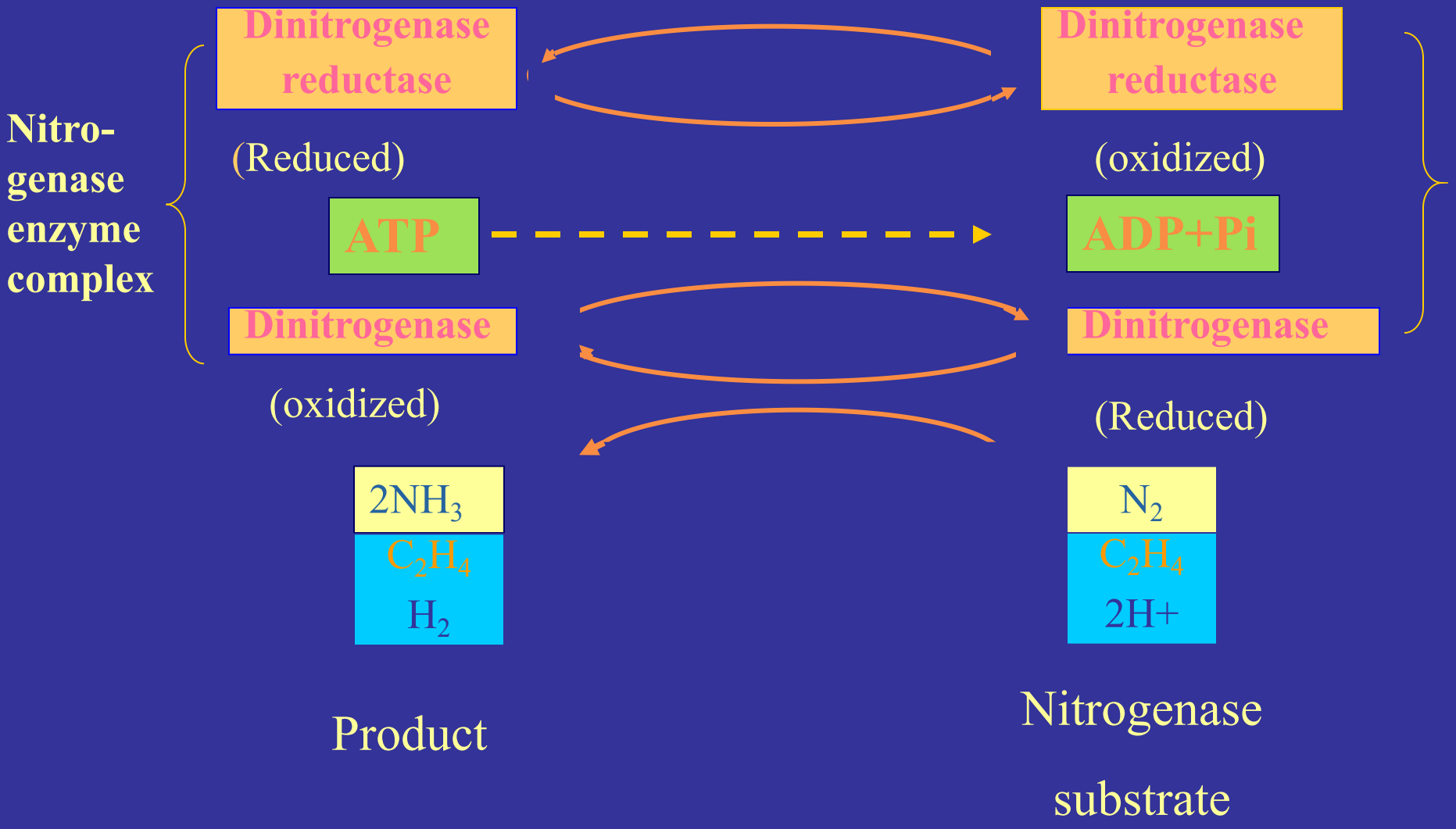
Free-living anaerobes

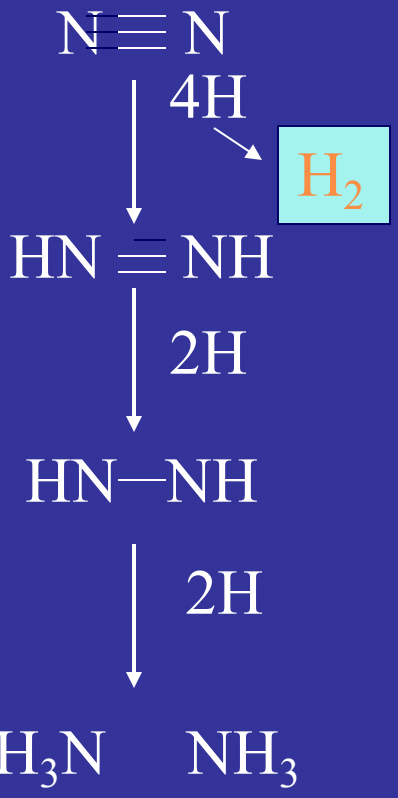
Chemo-organotrophs	**phototrophs**	**Chemo-lithotrophs**
Bacteria:	Bacteria:	Archaea:
Clostridium spp.	*Chlorobium*	*Methanosarcina*
Desulfovibio	*Rhodospirillum*	*Methanoccous*
Desulfotomacullum		

- N_2 fixation occurs only under anoxic condition

One of the most interesting and important nitrogen-fixation bacteria is certain type ,such as *Rhizobium* *Bradyrhizobium*、 *Sinorhizobium* or *Azorhzobium*, they can build up symbiosis relationship with leguminous plant.

Steps in nitrogen fixation: reduction of N_2 to NH_3. Electrons are supplied from dinitrogenase reductase to dinitrogenase one at a time, and each electron supplied is associated with the hydrolysis of two ATPs.





Overall reaction

$$8H^+ + 8e^- + N_2 \longrightarrow 2NH_3 + H_2$$

$$16\text{-}24\ ATP \longrightarrow 16\text{-}24ADP + 16\text{-}24Pi$$

REVIEW QUESTIONS

1. Define the terms chemoorganotroph, chemolithotroph, photoautotroph, and photoheterotroph.
2. Why are carbon and nitrogen macronutrients while cobalt is a micronutrient?
3. Where in glycolysis is NADH produced? Where is NADH consumed?

4. What is an electron carrier? Give three examples of electron carriers and indicate their oxidized and reduced forms.

5. Knowing the function of the electron transport chain, can you imagine an organism that could live if it completely lacked the components (for example, cytochromes) needed for an electron transport chain? (Hint: Focus your answer on the mechanism of ATPase.)