เอกสารประกอบการสอน
วิชาหลักชีววิทยา 1
(Principles of Biology I)
รหัสวิชา 104101

เรื่อง
เอกภาพของสิ่งมีชีวิต
(The Unity of Life)

โดย
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The Unity of Life

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The Unity of Life

1. Fundamentals concept of biology
2. Basic chemistry of life
3. Cells: basic unit of life
4. Energy and life: Biochemical reaction and enzyme
5. Cellular respiration
6. Photosynthesis

Fundamental Concepts of Biology

- Biology
- Properties of Life
- The kingdoms of life
- How Science Is Done
- Theory of Evolution

Biology

- The science of life
- The study of living things

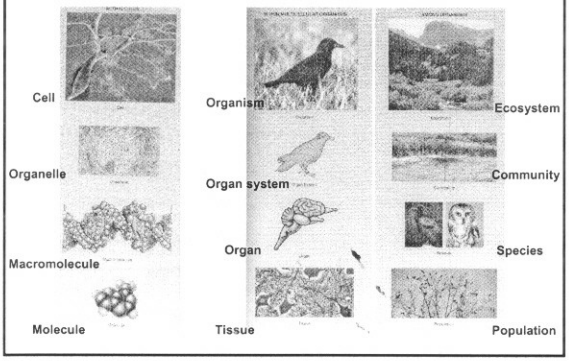
Properties of Life

1. Order
2. Sensitivity
3. Growth and Development
4. Reproduction
5. Energy utilization
6. Homeostasis
7. Evolutionary adaptation

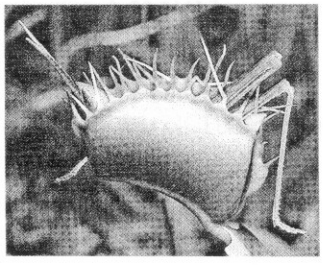
Order

Hierarchical organization of living things

Hierarchical organization of living things

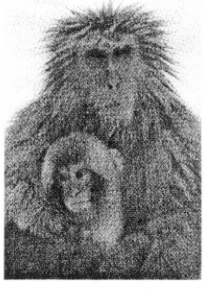


Sensitivity

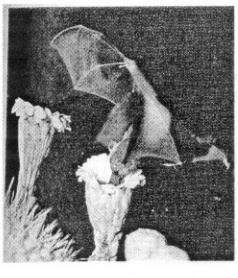


Growth and Development

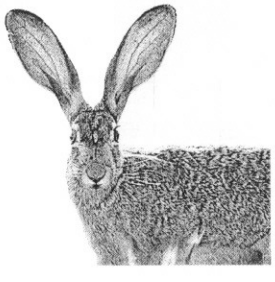
Reproduction



Energy utilization



Homeostasis



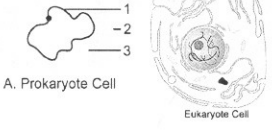
Evolutionary Adaptation

Cells

are an organism's basic units of structure and function.

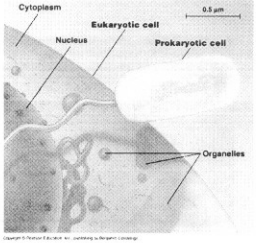
Two major cell types

1. Prokaryotic cells
2. Eukaryotic cells



A. Prokaryote Cell

Eukaryote Cell

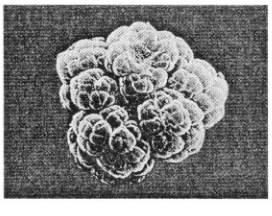


The kingdoms of life

1. Archaebacteria
2. Eubacteria
3. Protista
4. Fungi
5. Plantae
6. Animalia

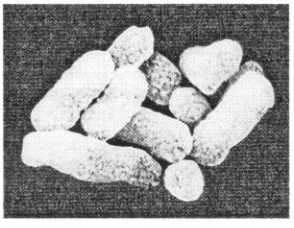
Archaebacteria

- Prokaryote
- ไม่มี peptidoglycan เป็นส่วนประกอบของผนังเซล



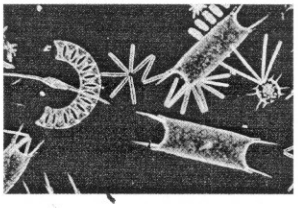
Eubacteria

- Prokaryote
- มี peptidoglycan เป็นส่วนประกอบของผนังเซล



Protista

- Eukaryote
- เป็นพวก Cell เดียว ยกเว้นพวก algae
- สังเคราะห์ด้วยแสงได้
- อาศัยสิ่งมีชีวิตชนิดอื่น



Fungi

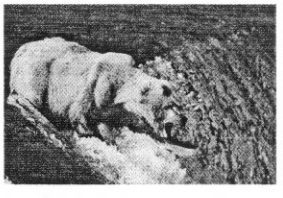
- Eukaryote
- เป็นพวกหลายเซลล์ ยกเว้นพวก yeast
- มี chitin เป็นส่วนประกอบ
- เคลื่อนที่ไม่ได้

Plantae

- Eukaryote
- เป็นพวกหลายเซลล์
- สังเคราะห์ด้วยแสงได้
- เคลื่อนที่ไม่ได้

Animalia

- Eukaryote
- เป็นพวกหลายเซลล์ ยกเว้นพวก yeast
- มี chitin เป็นส่วนประกอบ
- ต้องใช้พลังงานจากสิ่งมีชีวิตอื่น



Domains of life

1. Archaea
   - Archaebacteria
2. Bacteria
   - Eubacteria
3. Eukarya
   - Protista
   - Fungi
   - Plantae
   - Amimalia

Features of Domains of Life

Domain / Feature	Archaea	Bacteria	Eukarya
Amino acid that initiates protein synthesis	Methionine	Formyl methionine	Methionine
Introns	Present in genes	Absent	Present
Membrane bounded organelles	Absent	Absent	Present

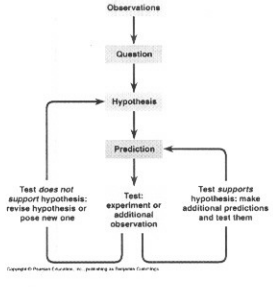
Features of Domains of Life

Domain / Feature	Archaea	Bacteria	Eukarya
Nuclear envelope	Absent	Absent	Present
Number of different RNA polymerases	Several	one	Several
Peptidoglycan in cell wall	Absent	Present	Absent

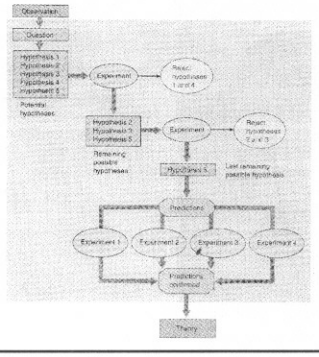
Importance of Biology

- Expanding population
- Life threatening diseases, cancer, AIDS, avian flu
- Suitable management of world's resources
- Improvement of our quality of lives

How Science Is Done



How Science Is Done



Theory

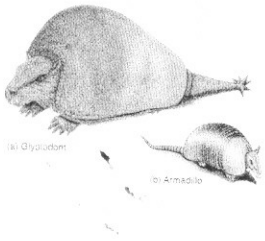
- In general public,
  - –Theory implies a lack of knowledge or a guess.
- In scientist's sense,
  - –Theories are solid ground of science that of which we are most certain.

Theory of Evolution

- It proposes that one type of organism can gradually evolve into another.
- Charles Robert Darwin, an English naturalist (1809-1882)
- Expedition around the coasts of South America with the Beagle (1831-1836)

Darwin's Evidence

- Fossil armadillo (Glyptodont)



Darwin's Evidence

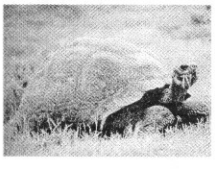
- There are progessive changes in characteristics in rock strata layers (fossils).
- Lands in similar climates, such as Australia, South Africa, California, and Chile, have unrelated plants and animals.

Darwin's Evidence

- The plants and animals of each continent are distinctive.

Darwin's Evidence

- Endemic species in oceanic islands
- Galapagos tortoises



Darwin's Evidence

- Species on oceanic islands show strong affinities to those on the nearest mainland
- Galapagos finches

Basic Chemistry of Life

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โครงสร้างของเนื้อหา (Outline)

- Composition of Matter
- Atoms and Structure of Atoms
- Isotope
- Chemical bonds
- Biological Macromolecules
  - Carbohydrate
  - Lipid
  - Protein
  - Nucleic acid

วัตถุประสงค์

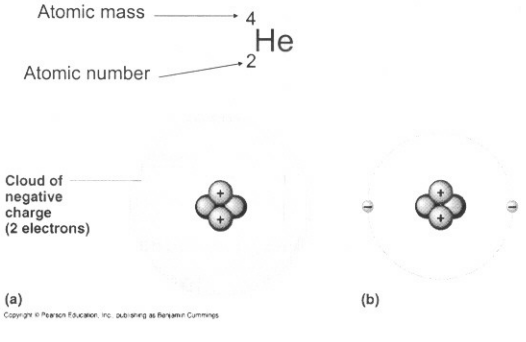
- สามารถจดจำธาตุสำคัญที่เป็นองค์ประกอบของสิ่งมีชีวิต
- รู้จักความหมายของคำต่าง ๆ ที่ใช้อธิบายคุณสมบัติของธาตุและสารประกอบ
- รู้จัก functional group ต่าง ๆ ที่เป็นส่วนประกอบของสารประกอบอินทรีย์
- เข้าใจถึงความแตกต่างของโครงสร้างทางเคมีและหน้าที่ของสารประกอบอินทรีย์แต่ละชนิด

Composition of Matter

- Organic material
- Inorganic material
- 92 natural elements
- 25 elements: B C Ca Cl Co Cr Cu F Fe H I K Mg Mn Mo N Na O P S Se Si Sn V Zn
- 4 elements: C H N O

Structure of Atoms

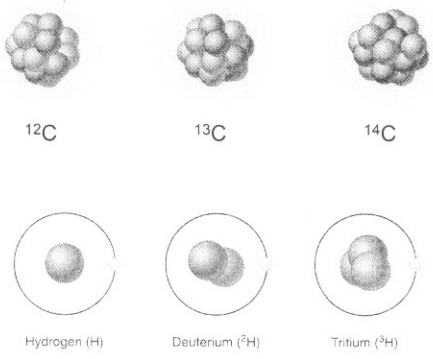
- Atom
  - Proton
  - Neutron
  - Electron
- Atomic mass (dalton)
- Dalton = 1.7×10^{-24} 1 gram
- 6.02×10^{23} dalton = 1 gram
- 1 proton = 1.009 dalton
- 1 electron = 1/1840 dalton



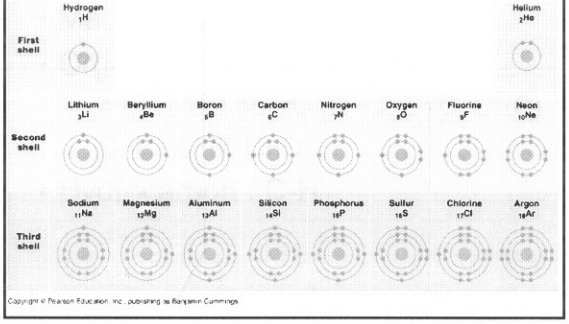
Isotope

- An element: the same number of protons
- More neutron = different atomic forms = isotopes of element
- Example: $^{12}_{6}C$ $^{13}_{6}C$ $^{14}_{6}C$
- Half life: ^{14}C = 5600 years
- Many useful applications

Radioisotope

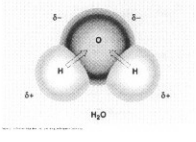


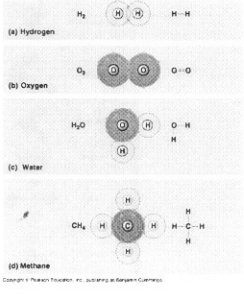
Electron Configuration and Chemical Properties



Chemical bonds hold molecule together

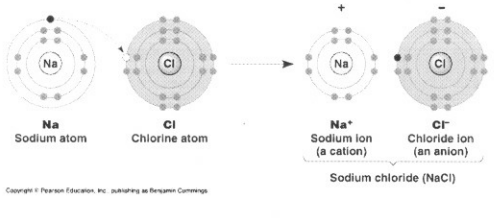
- Covalent bond: electronegativity
  - Polar covalent bond
  - Nonpolar covalent bond





Chemical bonds hold molecule together

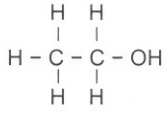
- Ionic bond
  - Cation
  - Anion



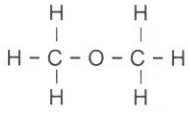
Isomers

- Same molecular formula
- Three types
  - –Structural isomer
  - –Stereoisomer (geometric isomers)
  - –Enantiomer

Structural isomer

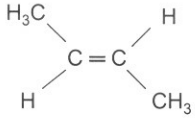


Ethanol
(C_2H_6O)

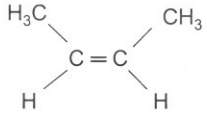


Dimethyl Ether
(C_2H_6O)

Stereoisomer isomer



trans-2-butene

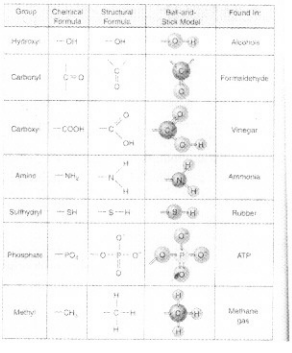


cis-2-butene

The Chemical Building Blocks of Life

- Macromolecules
- Organic molecule : Carbon
  - 4 covalent bonds (C−C, C=C, C≡C)
  - C−H, C−N, C−O
- Hydrocarbon : C-H

Functional Group



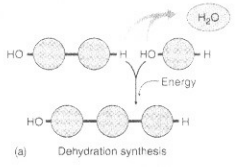
Group	Chemical Formula	Structural Formula	Ball-and-Stick Model	Found In:
Hydroxyl	—OH	—OH		Alcohols
Carbonyl	C=O			Formaldehyde
Carboxyl	—COOH			Vinegar
Amino	$—NH_2$			Ammonia
Sulfhydryl	—SH	—S—H		Rubber
Phosphate	$—PO_4$			ATP
Methyl	$—CH_3$			Methane gas

Biological Macromolecules

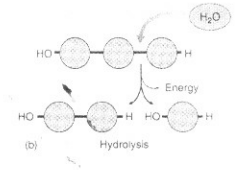
- Carbohydrate
- Lipid
- Protein
- Nucleic acid

Building Macromolecules

- Dehydration synthesis
- Consume energy
- Anabolic reaction

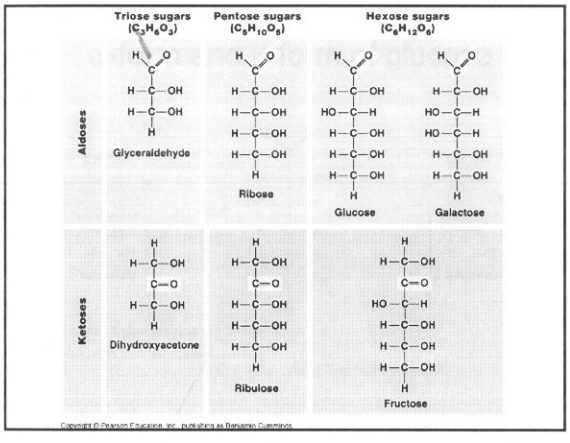


- Hydrolysis
- Release energy
- Catabolic reaction

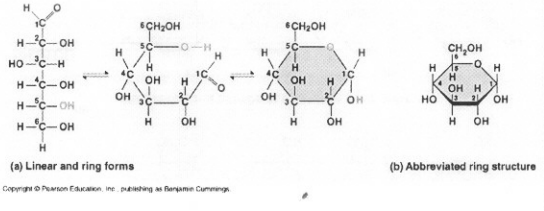


Carbohydrates

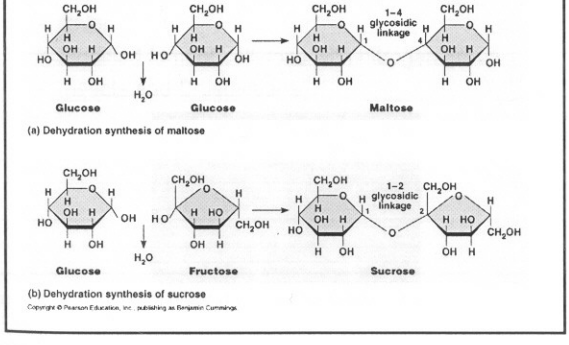
- Carbon : Hydrogen : Oxygen = 1 : 2 : 1
- $(CH_2O)_n$
- Energy storage
- Sugar are simple carbohydrates
  - Monosaccharide
  - Disaccharide
  - Polysaccharide



Monosaccharide

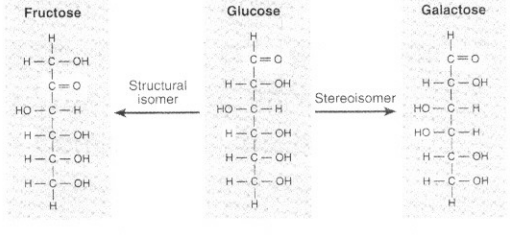


Disaccharide



Sugar Isomer

Structural isomer and Stereoisomer

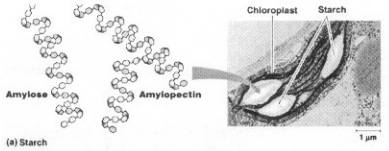


Transport Disaccharide

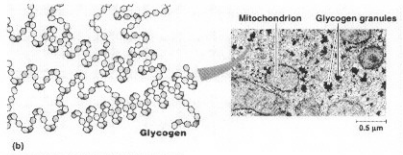
- Sucrose = Glucose + Fructose
- Maltose = Glucose + Glucose
- Lactose = Glucose + Galactose

Storage Polysaccharide

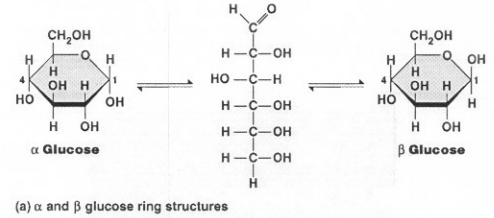
- Starch
  - Amylose
  - Amylopectin



- Glycogen



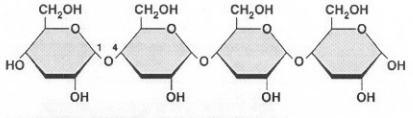
α-form and β-form of glucose



(a) α and β glucose ring structures

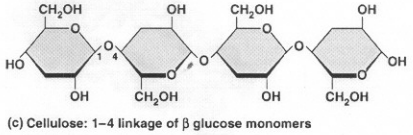
Structural Carbohydrates

Starch



(b) Starch: 1–4 linkage of α glucose monomers

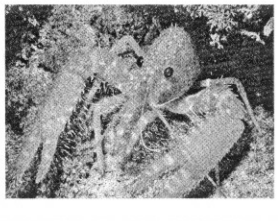
Cellulose



(c) Cellulose: 1–4 linkage of β glucose monomers

Structural Carbohydrates

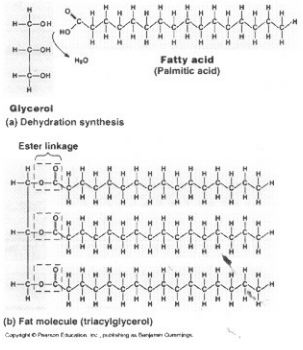
- Chitin
- Modified form of cellulose with nitrogen group
- Insects and Crustaceans

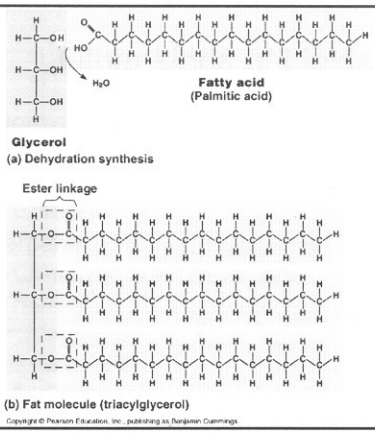


Lipid

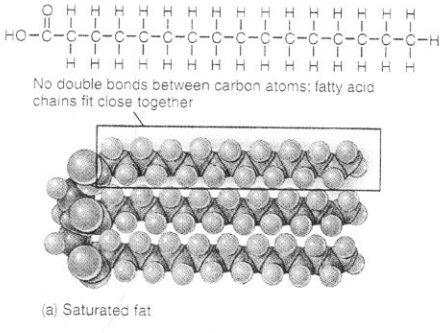
- Hydrogen : Oxygen > 2 : 1
- Nonpolar molecule
- Oil : olive oil, corn oil, coconut oil
- Wax : beewax, earwax
- Composition : 2 subunits
  - –One molecule of Glycerol
  - –Three molecules of Fatty acid

Triacylglycerol (Triglyceride)

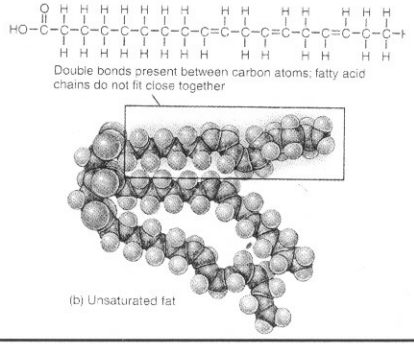




Saturated fatty acid



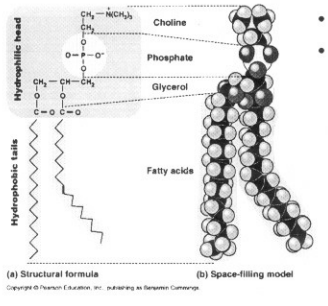
Unsaturated fatty acid



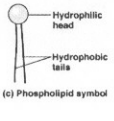
Fat

- > 40 Carbon
- Saturated fat
  - Animal fat (except from fish)
  - Higher melting point
  - More calories
- Unsaturated fat
  - Fat from plant (except from palm and coconut)
  - Lower melting point
  - Less calories

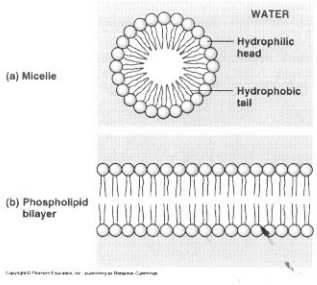
Other kinds of Lipids



- Phospholipid
- Polar molecule
  - Polar head
  - Nonpolar tail

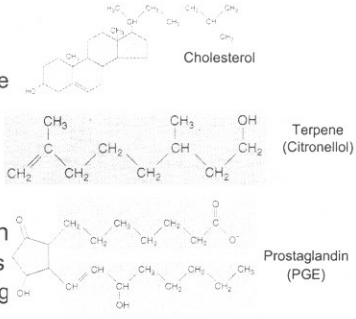


Hydrophobic Reaction



Other kinds of Lipids

- Steroid
  - Cholesterol
  - Testosterone
  - Estrogen
- Terpene
  - Chlorophyll
  - Rubber
- Prostaglandin
  - 2 Fatty acids
  - 5-carbon ring

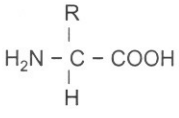


Protein

- Functions
  - –Enzyme catalysis
  - –Defense
  - –Transport protein
  - –Support
  - –Motion
  - –Regulation

Building blocks of Protein

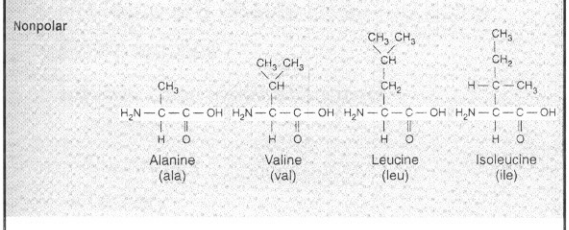
- Amino acids (20)
- Composition
  - –Central carbon
  - –Amino group : $-NH_2$
  - –Carboxyl group : $-COOH$
  - –Hygrogen atom : H



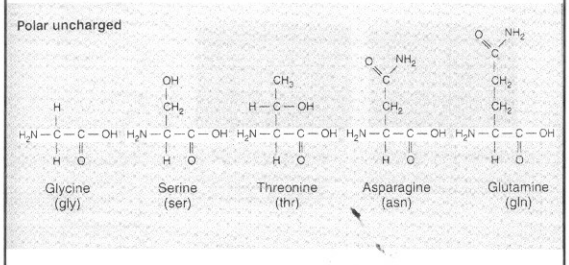
Five groups of Amino acids

1. Nonpolar amino acids
2. Polar and uncharged amino acids
3. Ionizable amino acids
4. Aromatic amino acids
5. Special-function amino acids

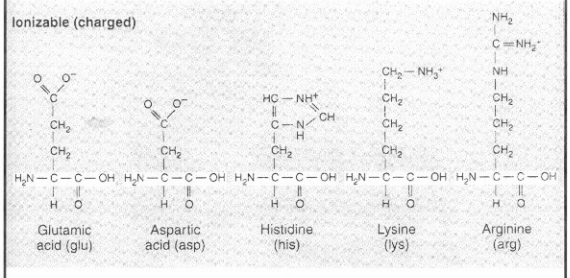
Nonpolar amino acids



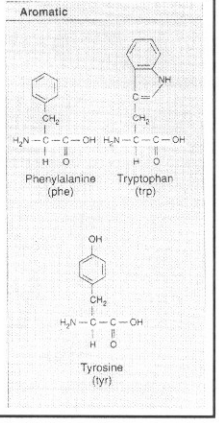
Polar and uncharged amino acids



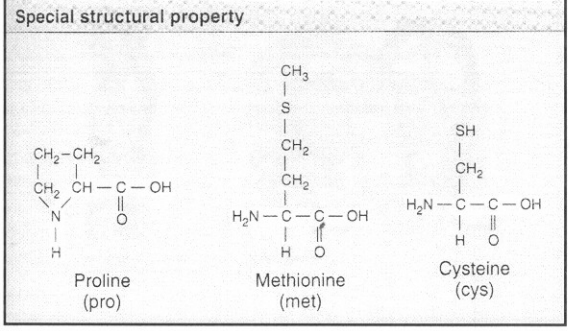
Ionizable amino acids



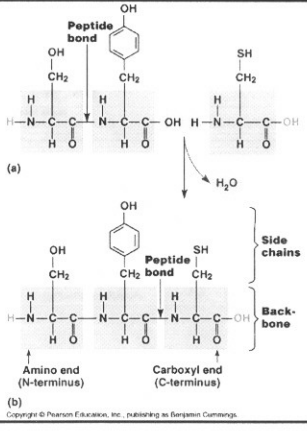
Aromatic amino acids



Special-function amino acids



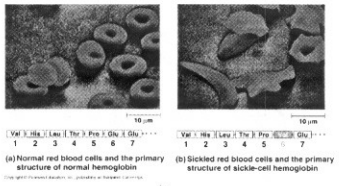
Peptide bond



Protein Structure

- Proteins are chains of amino acids.
- Polypeptides
- Levels of protein structure
  - Primary
  - Secondary
  - Tertiary
  - Quaternary

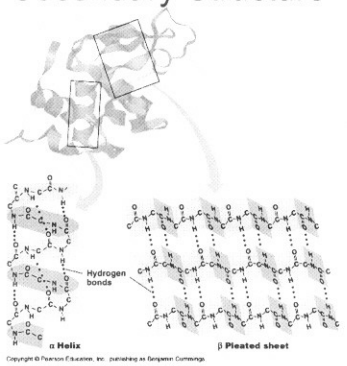
Primary Structure



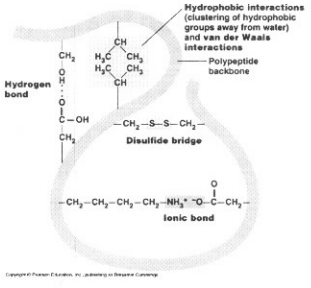
(a) Normal red blood cells and the primary structure of normal hemoglobin

(b) Sickled red blood cells and the primary structure of sickle-cell hemoglobin

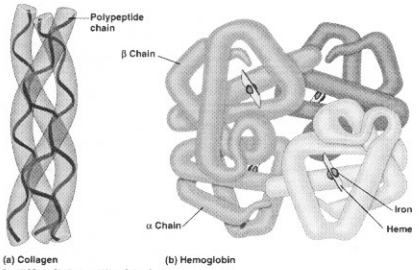
Secondary Structure

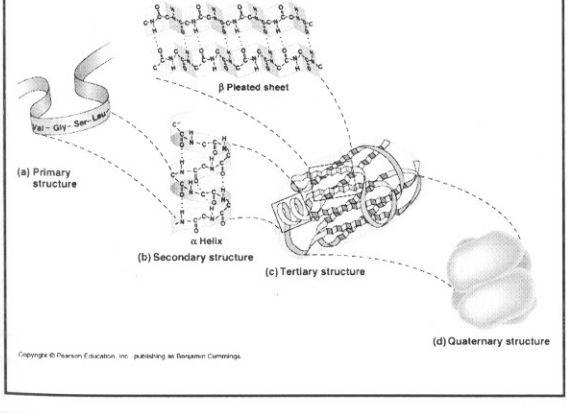


Tertiary Structure



Quaternary Structure





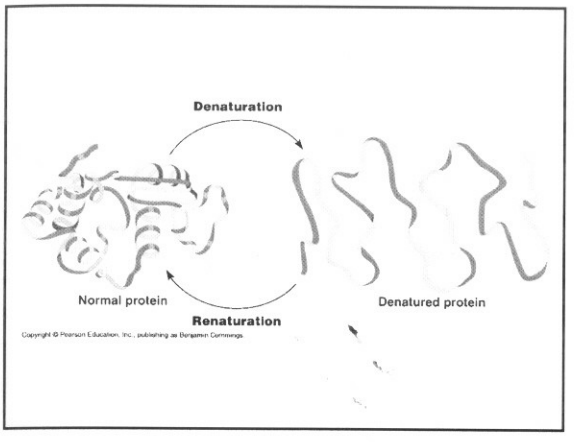
How protein fold?

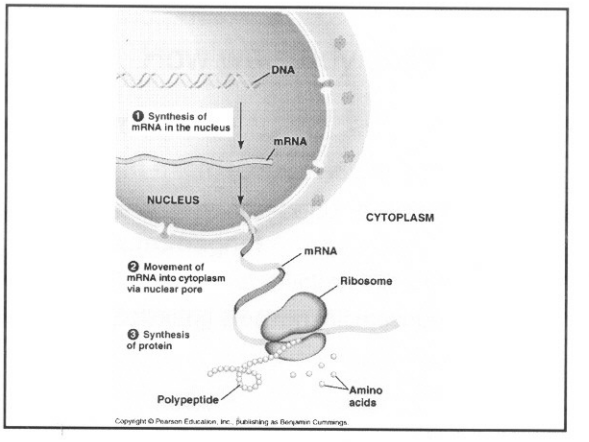
Chaperone proteins

How protein unfold?

- pH
- Temperature
- Changes in ionic concentration

Protein Denaturation

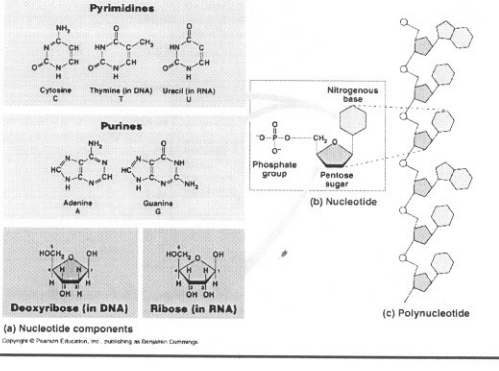




Nucleic acid

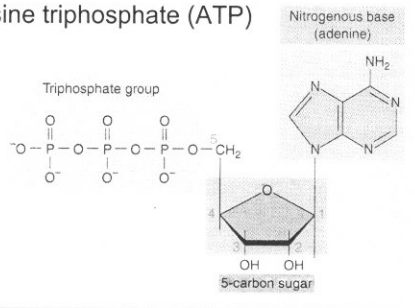
- Long polymers of repeating nucleotide subunits
- Three components of nucleotide
  - a five-carbon sugar
  - a phosphate group
  - a nitrogen-containing base

Structure of Nucleic acid



Nucleotide bases in Other Molecule

- Adenosine triphosphate (ATP)



Nucleotide bases in Other Molecule

- Coenzyme
  - Nicotinamide-adenine dinucleotide (NAD^+)
  - Flavin-adenine dinucleotide (FAD^+)

Cells: Basic unit of life

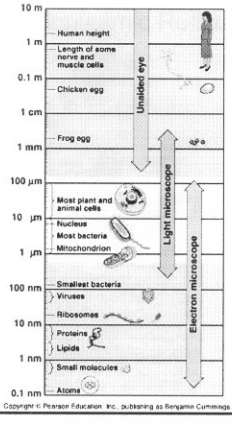
อ. นวลน้อย จูฑะพงษ์

How we study cells

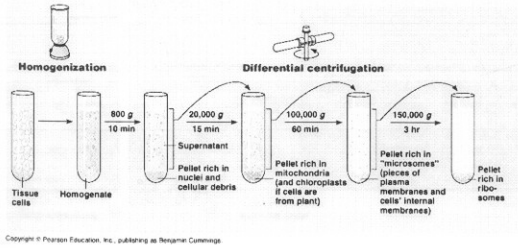
- Microscope
  - –Light microscope: visible light, lens
  - –Electron microscope: electron beam, electromagnet
    - Transmission electron microscope
    - Scanning electron microscope

Microscope

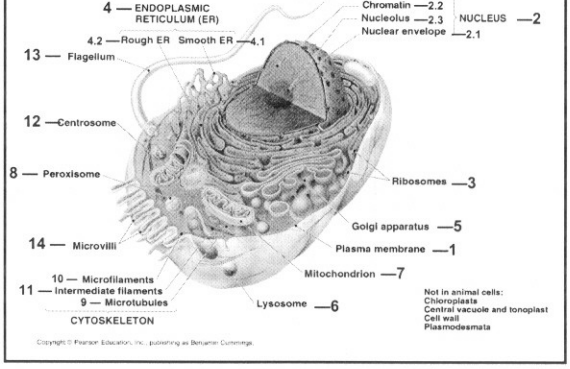
- Two parameters
  - – Magnification
  - – Resolving power (resolution)



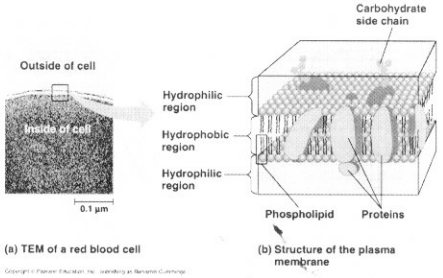
Cell Fractionation



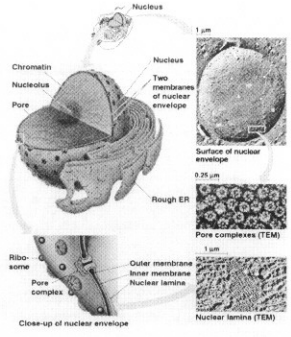
Animal Cell



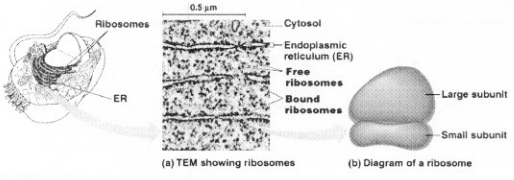
1. Plasma Membrane



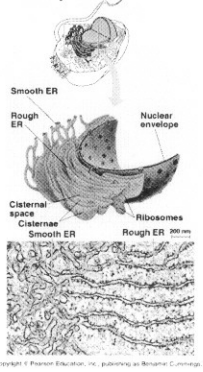
2. Nucleus



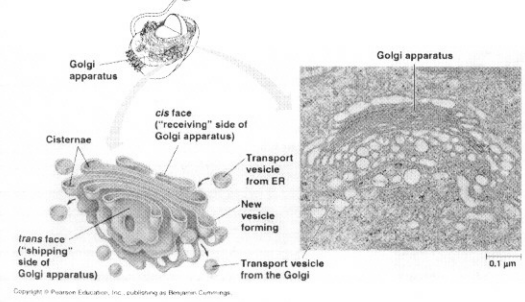
3. Ribosome



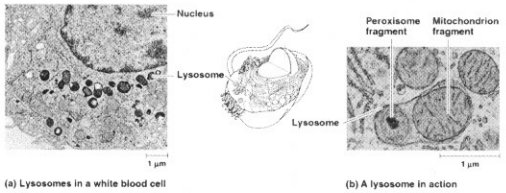
4. Endoplasmic Reticulum



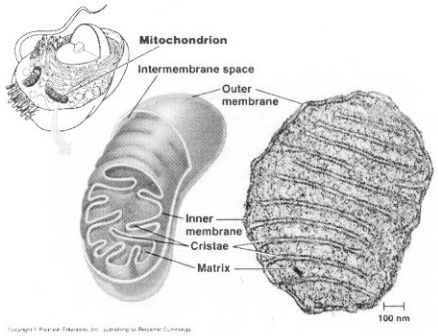
5. Golgi Apparatus



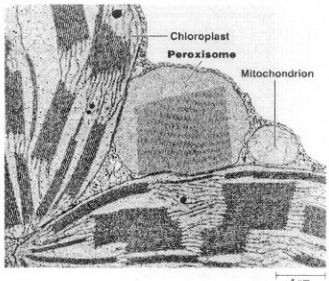
6. Lysosome



7. Mitochondria



8. Peroxisome



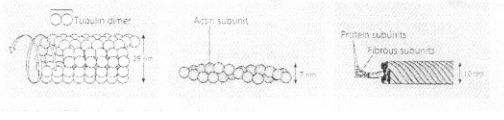
Cytoskeleton

Property	9.Microtubules	10. Microfilament	11. Intermediate Filament
Structure	Hollow tube, Wall:13 columns of tubulin	2 intertwined strands of actin	Fibrous protein supercoilled into thicker cables
Diameter	25 nm with 15-nm lumen	7 nm	8-12 nm
Protein subunit	Tubulin: α-tubulin and β-tubulin	Actin	One protein: Keratin family
Main function	Cell shape Cell motility Chromosome movement Organelle movements	Cell shape Cell motility Muscle contraction	Cell shape Anchorage of nucleus and …..

Cytoskeleton

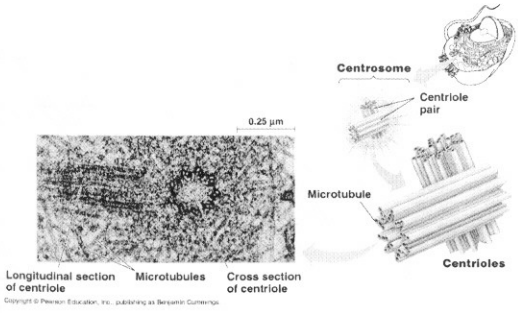
9. Microtubules

11. Intermediate Filament

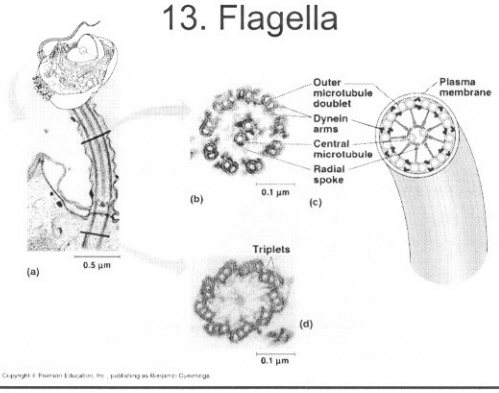


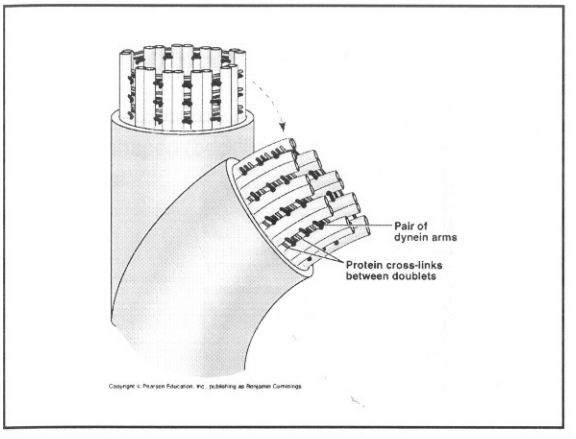
10. Microfilament

12. Centrosome

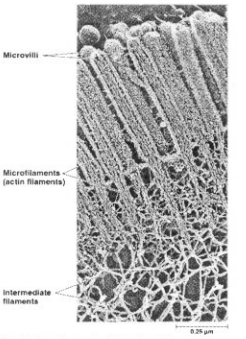


13. Flagella

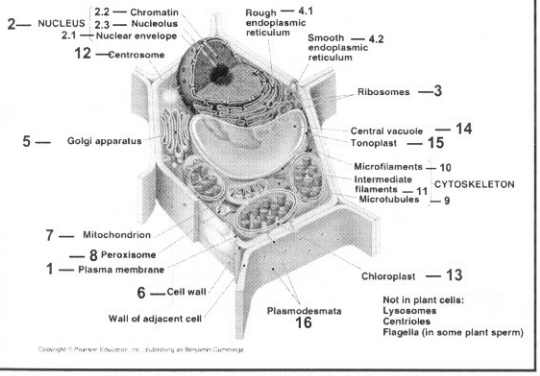




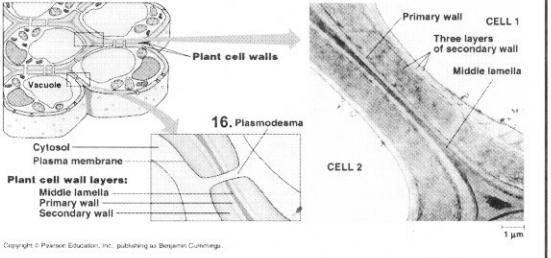
14. Microvilli



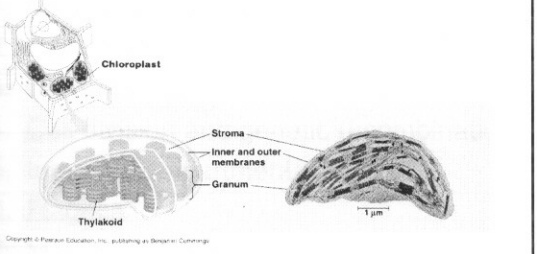
Plant Cell



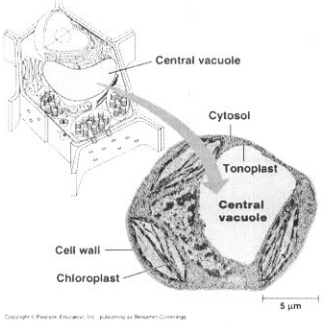
6. Cell Wall



13. Chloroplast

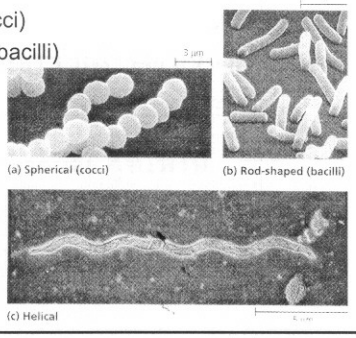


14. Central Vacuole
15. Tonoplast

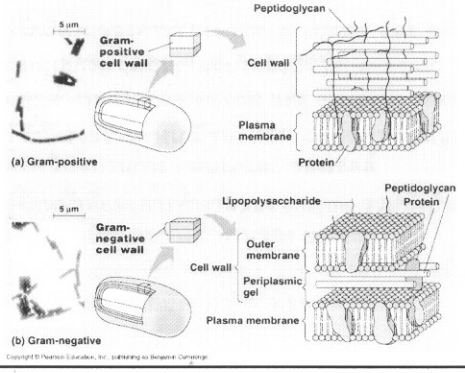


Common Shapes of Prokaryote

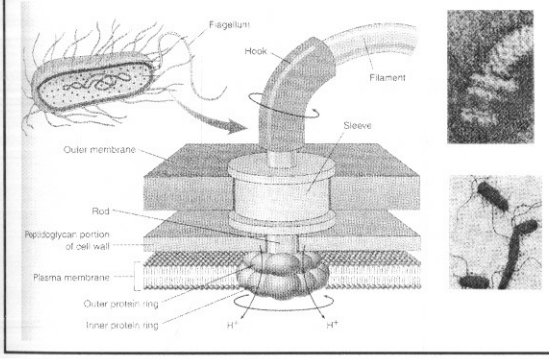
- Spherical (cocci)
- Rod-shaped (bacilli)
- Helical



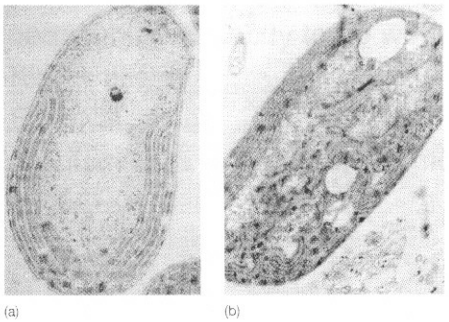
Gram-positive and gram-negative bacteria



Form and function of prokaryotic flagella



Respiratory Membrane / Thylakoid-like Membrane



Differences between Prokaryote and Eukaryote

1. Multicellularity
2. Cell size
3. Chromosomes
4. Cell division and genetic recombination
5. Internal compartmentalization
6. Flagella
7. Metabolic diversity

Energy and Life: Biochemical Reaction and Enzymes

อ. นวลน้อย จูฑะพงษ์

วัตถุประสงค์

1. รู้จักนิยามของคำว่า free energy entropy และ enthalpy
2. รู้จักปฏิกิริยาเคมีที่เกิดขึ้นในสิ่งมีชีวิตและความแตกต่างระหว่าง endergonic และ exergonic reaction
3. รู้จักโครงสร้างทางเคมีของ ATP และความสำคัญของ ATP ในขบวนการ metabolism ของเซลล์
4. รู้จักหน้าที่และการทำงานของ enzyme รวมทั้งปัจจัยต่าง ๆ ที่มีผลต่อการทำงานของ enzyme
5. รู้จักชนิดและการทำงานของ enzyme inhibitor ชนิดต่าง ๆ ในการยับยั้งการทำงานของ enzyme

Metabolism

- Catabolic pathway
  - Complex molecule ⇒ Simple molecule
  - Degradation process
  - Cellular respiration
- Anabolic pathway
  - Simple molecule ⇒ Complex molecule

Energy

- Energy is the capacity to do work.
  - Kinetic energy
  - Potential energy
- Organisms are energy transformers

Laws of Thermodynamic

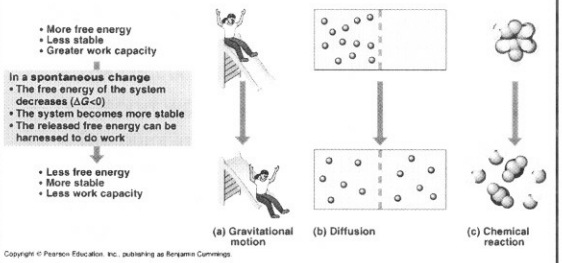
- The first law: The energy of the universe is constant. Energy can be transferred and transformed
- The second law: Every energy transfer or transformation increases the entropy of the universe.
- Entropy = Disorder = Randomness

Free energy

- Free energy is the portion of a system's energy that can perform work when temperature is uniform throughout the system

G = Free energy
H = Enthalpy
S = Entropy
T = Temperture
G = H - TS
Start ⟶ Final
$\Delta G = \Delta H - T\Delta S$

The relationship of free energy to stability



The change in free energy

$\Delta G = G_{\text{final state}} - G_{\text{starting state}}$

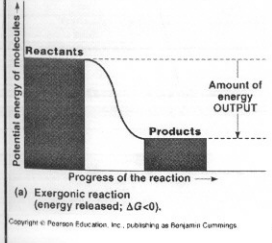
In a spontaneous reaction

$\Delta G < 0$ ($\Delta G \Rightarrow -$)

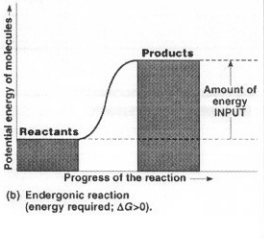
The change in free energy (ΔG)

- $\Delta G = G_{\text{final state}} - G_{\text{starting state}}$
- Exergonic reaction ($\Delta G \Rightarrow -$)
  - Spontaneous process
- Endergonic reaction ($\Delta G \Rightarrow +$)

Exergonic reaction

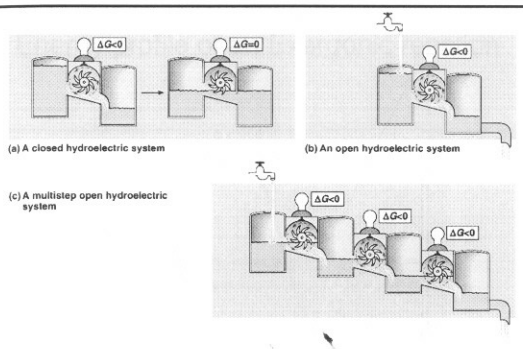


Endogonic reaction



Equilibrium

$\Delta G \Rightarrow 0$



Metabolic disequilibrium

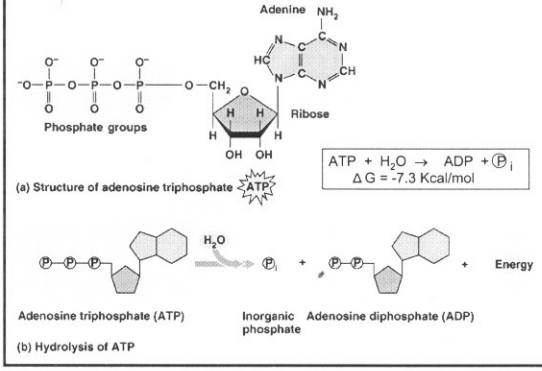
Cellular work

- Mechanical work
  - The beating of cilia
  - The contraction of muscle cell
- Transport work
  - The pumping of substances across membrane
- Chemical work
  - The pushing endergonic reaction

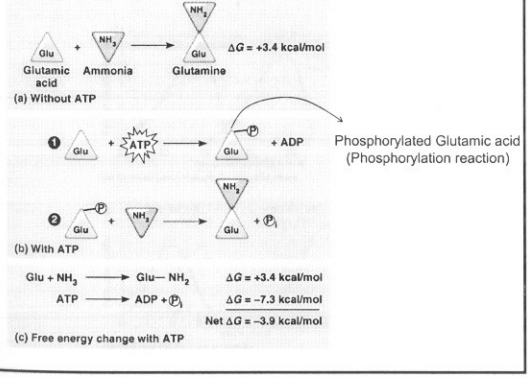
ATP

- Adenosine triphosphate
- ATP powers cellular work by coupling exergonic reactions to endergonic reaction

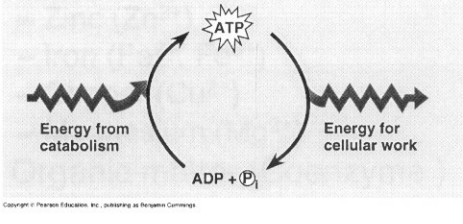
The structure and hydrolysis of ATP



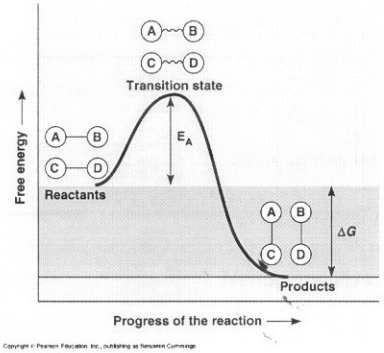
How ATP performs work



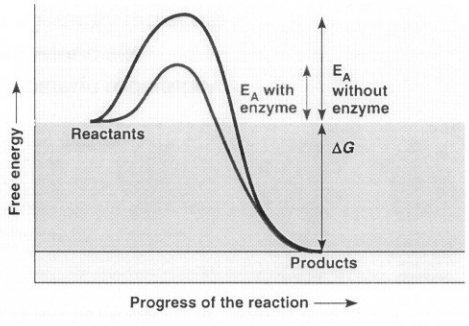
The generation of ATP



Energy profile of an Exergonic reaction



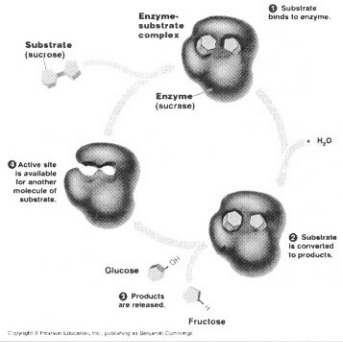
Enzyme lower the barrier of activation energy



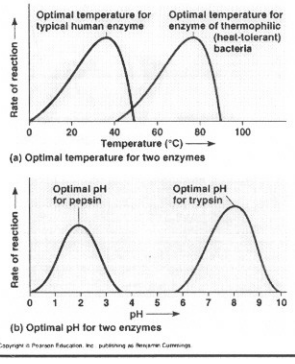
Enzyme

- Catalyst
- Catalytic protein
- Activation energy ⇓
- Δ G ⇔
- Rate of reaction ⇑

The catalytic cycle of an enzyme



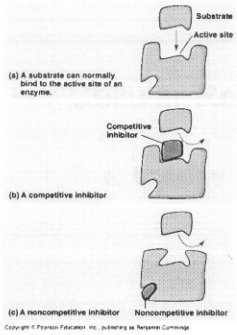
Effects of Temperature and pH



Cofactors

- Inorganic matter
  - Zinc (Zn^{2+})
  - Iron (Fe^{2+}, Fe^{3+})
  - Copper (Cu^{2+})
  - Magnesium (Mg^{2+})
- Organic matter (Coenzyme)
  - NAD^+
  - FAD

Enzyme Inhibitors

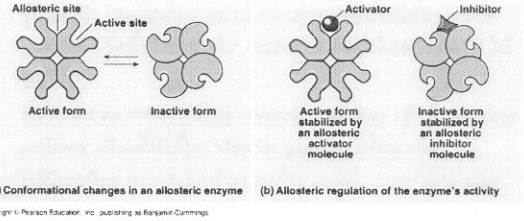


Competitive inhibitor

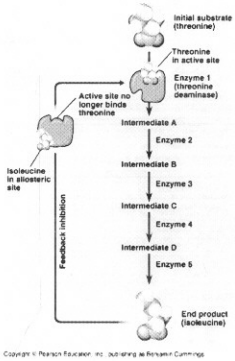
Noncompetitive inhibitors

Control of Metabolism

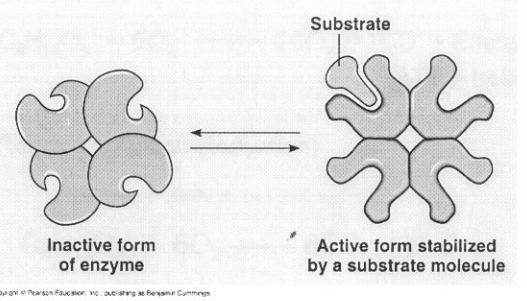
- Regulatory molecule
- Allosteric site
- Allosteric regulatory



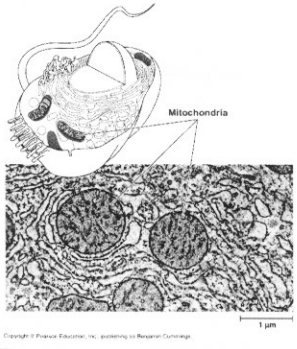
Feedback Inhibition



Cooperativity



The localization of Enzymes



Cellular Respiration

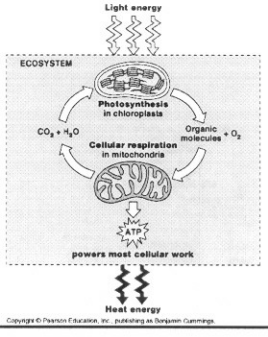
อ. นวลน้อย จูฑะพงษ์

วัตถุประสงค์

1. รู้จักสมการทั่วไปที่แสดงถึงการส่งผ่าน proton (H^+) และ electron จากสารประกอบที่เป็น Hydrogen acceptor เช่น NAD^+
2. รู้จักปฏิกิริยาเคมีในขบวนการ aerobic respiration โดยสามารถบรรยายถึงขั้นตอนต่าง ๆ ในปฏิกิริยาทั้งสามขั้นตอนได้โดยย่อ
3. รู้จักคำว่า Chemiosmosis และสามารถอธิบายได้ว่า proton gradient เกิดขึ้นได้อย่างไร และสามารถนำไปสร้าง ATP ได้อย่างไร
4. ทราบว่าเซลสามารถนำเอา protein และ lipid เข้าสู่ metabolic pathway เช่นเดียวกับการสลาย glucose ได้อย่างไร
5. เปรียบเทียบความแตกต่างระหว่าง aerobic และ anaerobic pathway

Energy flow and chemical recycling in ecosystem

- Autotroph
- Heterotroph



Degradation of Glucose

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + H_2O + \text{Energy (ATP + heat)}$$

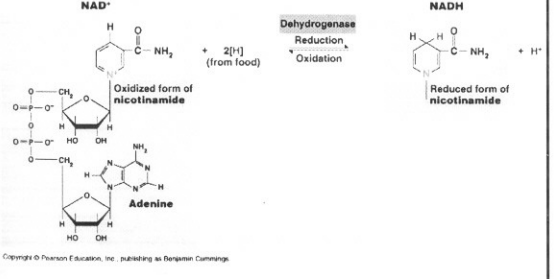
Redox (Oxidation-Reduction)

Oxidation

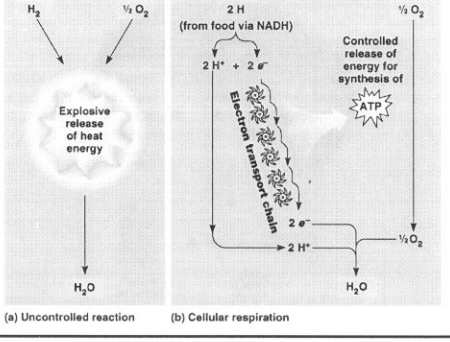
$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + H_2O$$

Reduction

NAD^+ as an electron shuttle



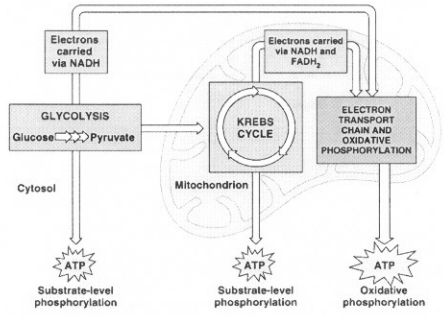
Electron transport chain



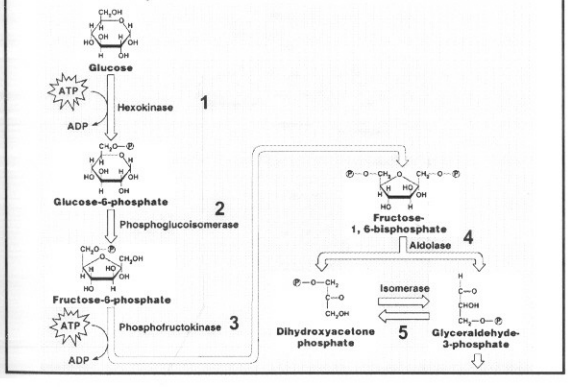
Cellular Respiration

1. Glycolysis
2. Krebs Cycle
3. Electron transport chain and oxidative phosphorylation

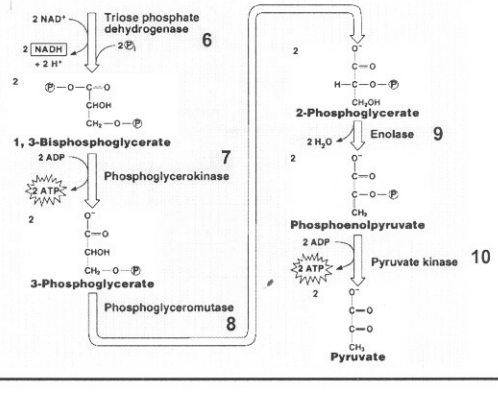
Cellular Respiration



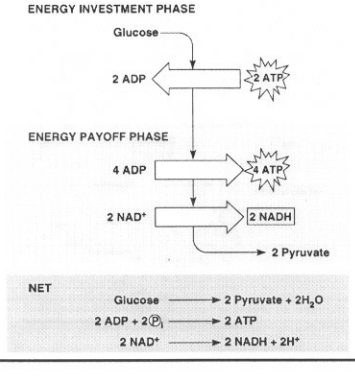
Glycolysis



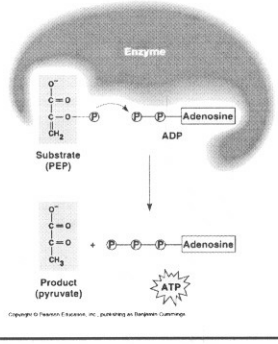
Glycolysis



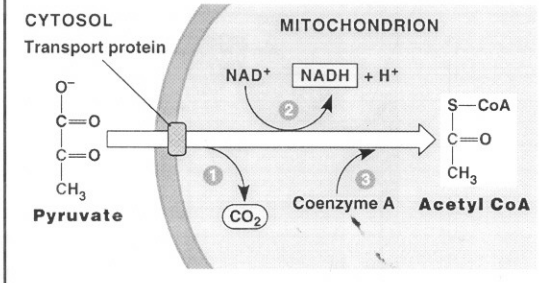
Energy input and output of glycolysis

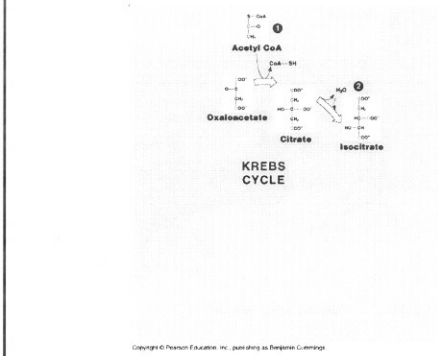


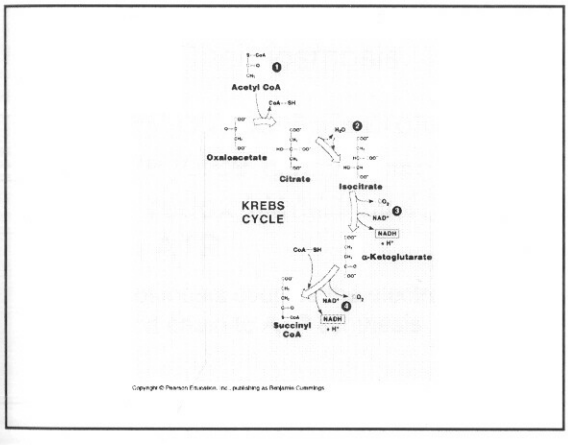
Substrate-level phosphorylation

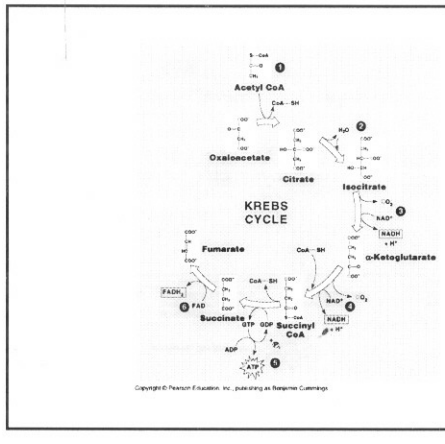


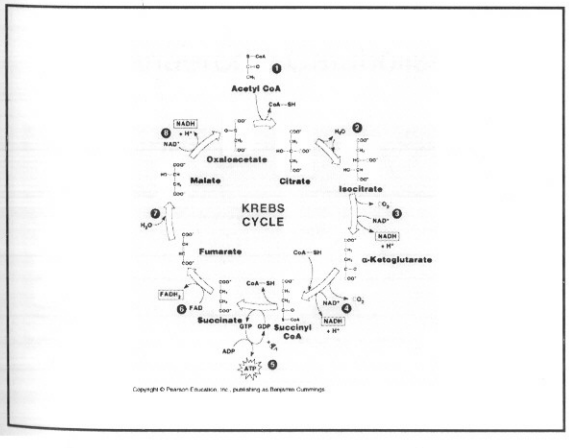
Junction b/w glycolysis and the Krebs cycle

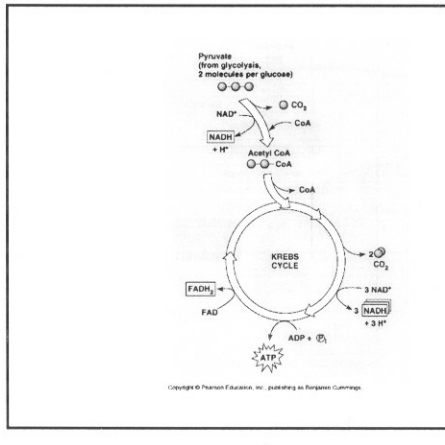




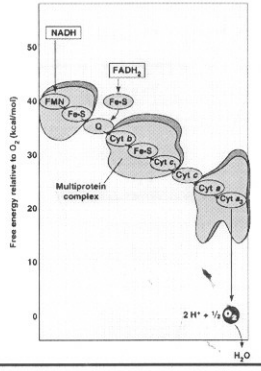


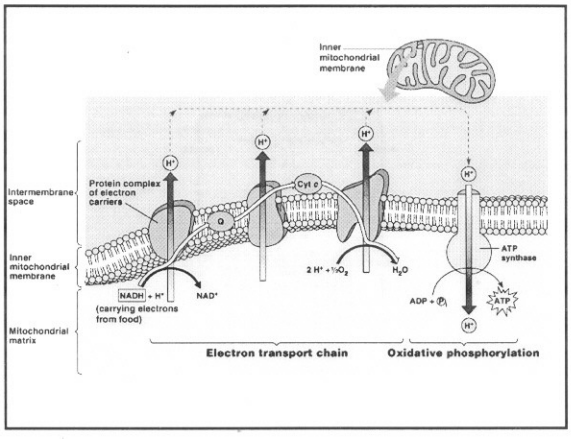






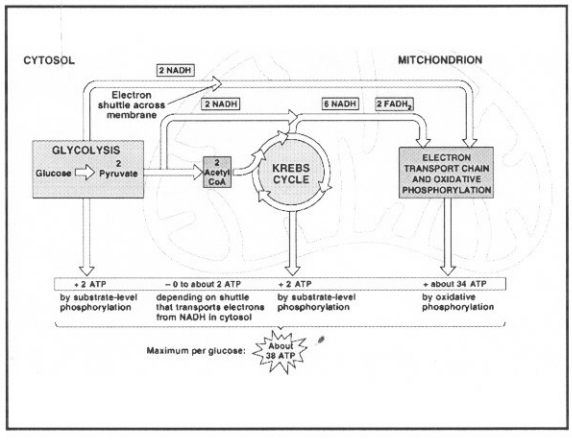
Electron transport chain



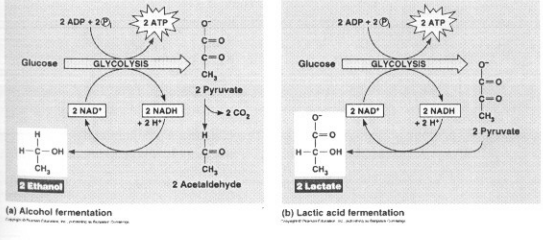


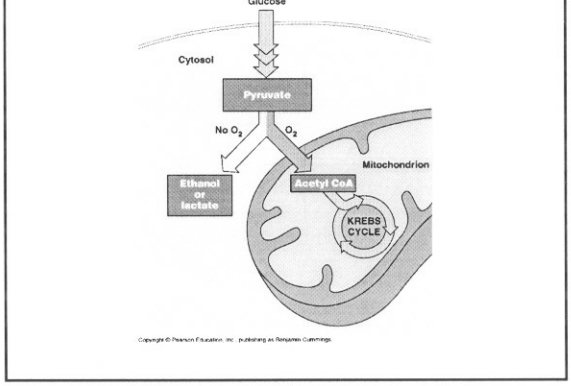
Chemiosmosis

- การใช้ H^+ gradient หรือ proton motive force ในการเปลี่ยนพลังงานจากปฏิกิริยา redox ไปทำให้เกิดงาน ซึ่งในที่นี้คือการสร้าง ATP
- Chemiosmosis couples the electron transport chain to ATP synthesis

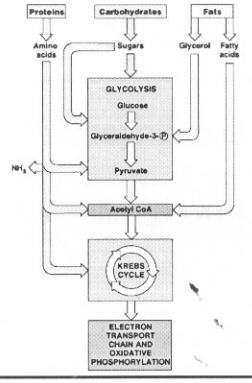


Anaerobic Catabolism

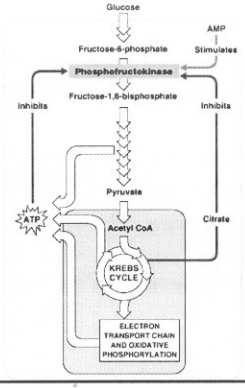




Catabolism of various food molecule



Control of cellular respiration



Photosynthesis

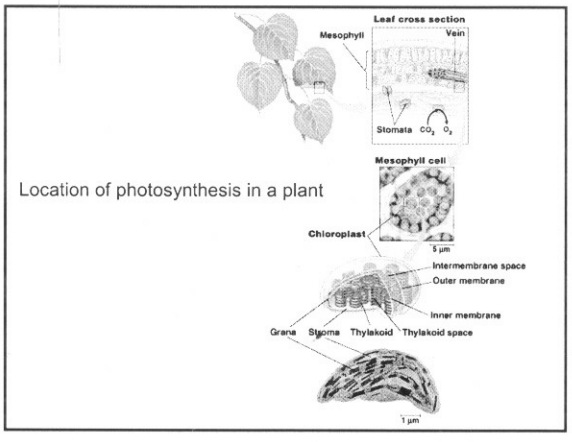
อ. นวลน้อย จูฑะพงษ์

วัตถุประสงค์

1. รู้จักโครงสร้างภายในของ chlorplast และอธิบายได้ว่าโครงสร้างเหล่านี้ทำให้เกิดขบวนการสังเคราะห์ด้วยแสงอย่างไร
2. ทราบปฏิกิริยาในขบวนการ photosynthesis รวมทั้งที่มาของ atom ที่เป็นส่วนประกอบของ end product
3. สามารถแยกความแตกต่างระหว่าง light-dependent และ light-independent reaction ในขบวนการ photosynthesis รวมทั้งสามารถสรุปปฏิกิริยาที่เกิดขึ้นในแต่ละ phase ได้

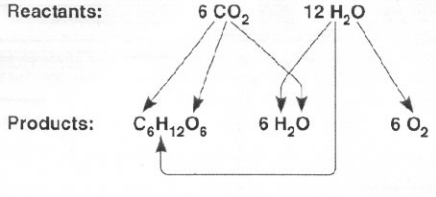
วัตถุประสงค์

4. สามารถบอกความแตกต่างของ cyclic และ noncyclic photophosphorylation ได้
5. เข้าใจภาพรวมของปฏิกิริยาเคมีที่เกี่ยวข้องกับการเปลี่ยน CO2 เป็น glucose ใน Calcin cycle รวมทั้งสามารถบอกถึงจำนวน ATP และ NADPH ที่จำเป็นต้องใช้ในปฏิกิริยาได้
3. สามารถอธิบายได้ว่าพืชนำ proton gradient สร้าง ATP ได้
6. อย่างไร
4. ทราบความแตกต่างระหว่างพืช C3 และ C4
7.

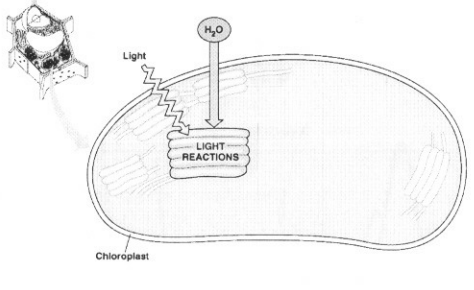


Location of photosynthesis in a plant

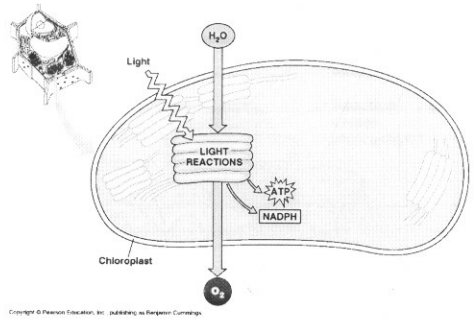
Tracking atoms through photosynthesis



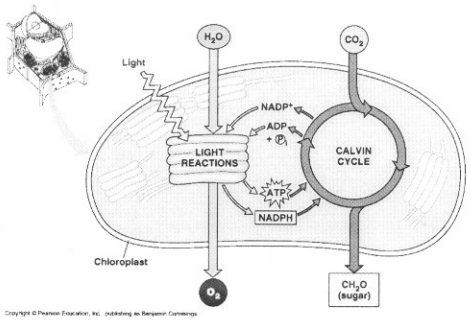
Pathway of photosynthesis



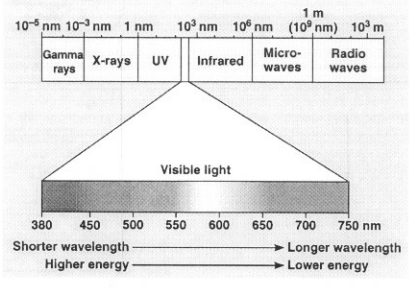
Pathway of photosynthesis



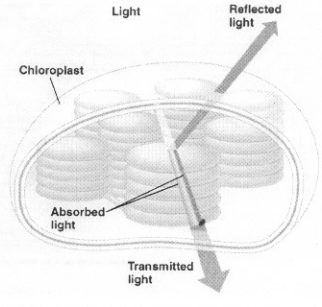
Pathway of photosynthesis



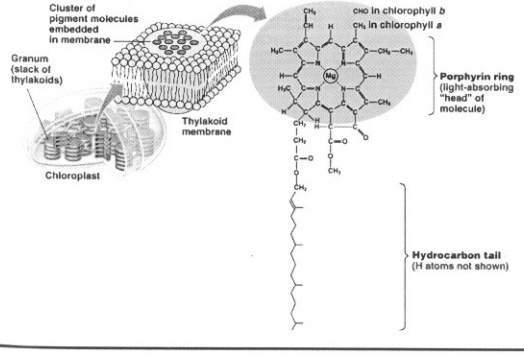
Electromagnetic spectrum



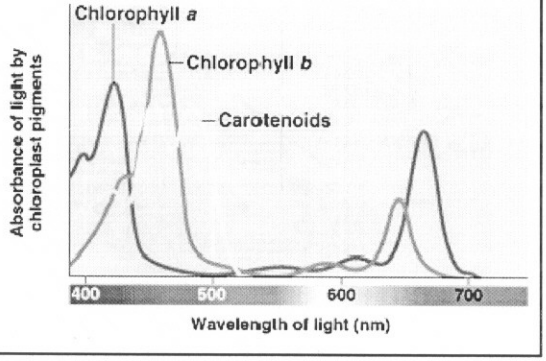
Interaction of light with chloroplast



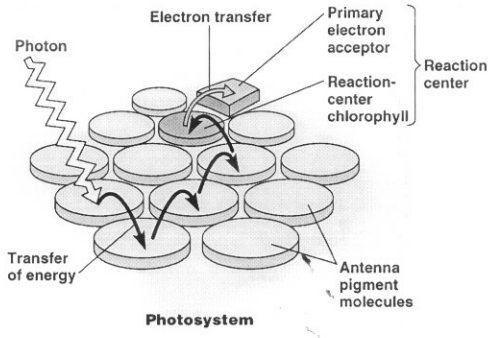
Location and structure of chlorophyll molecules in plants



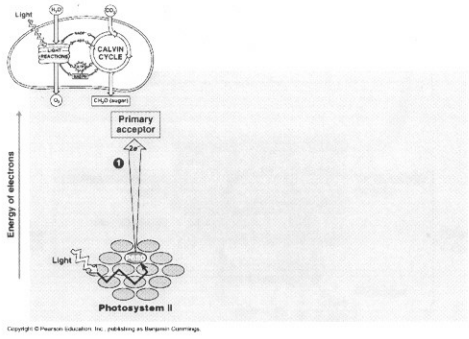
Absorbance spectra of three pigments



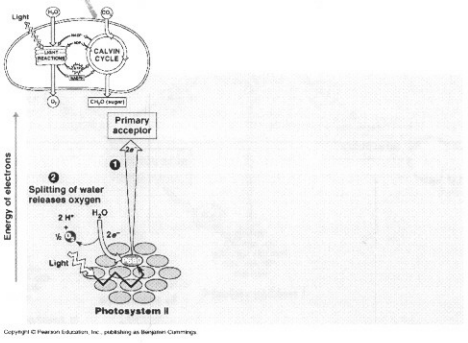
How a photosystem harvests light



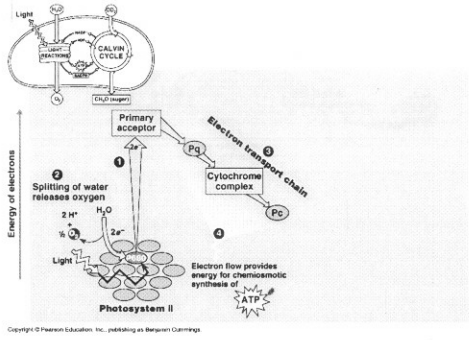
Noncyclic electron flow during the light reaction



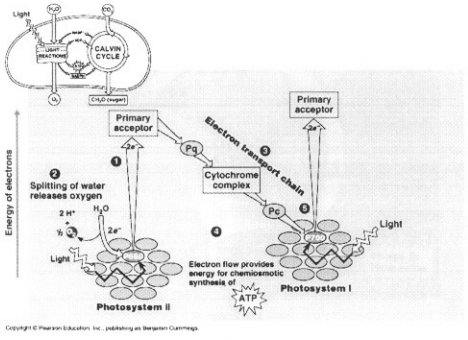
Noncyclic electron flow during the light reaction



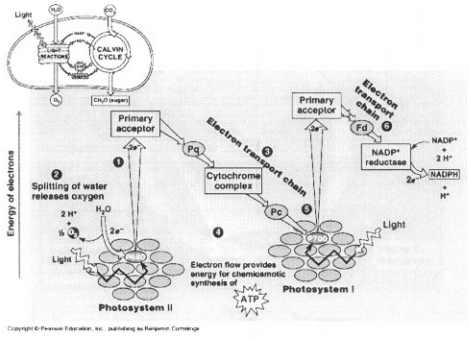
Noncyclic electron flow during the light reaction

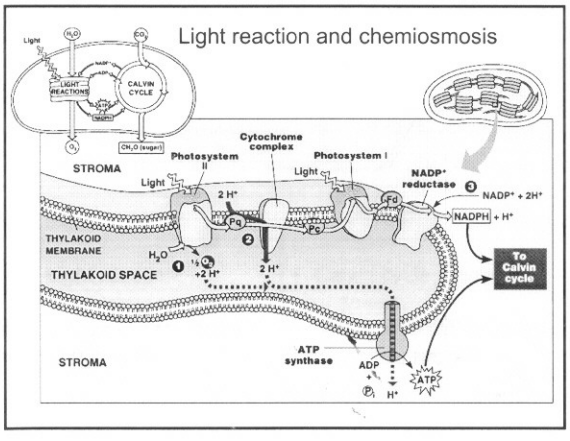


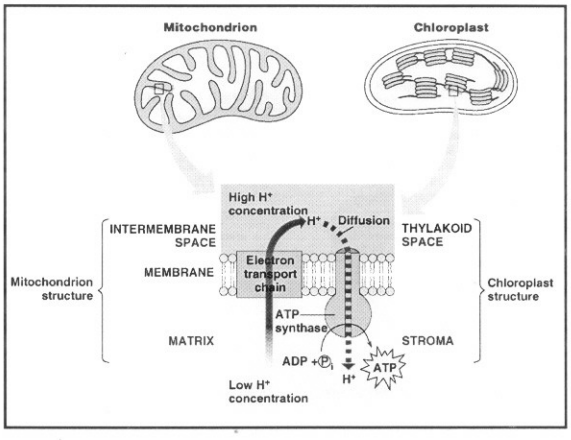
Noncyclic electron flow during the light reaction

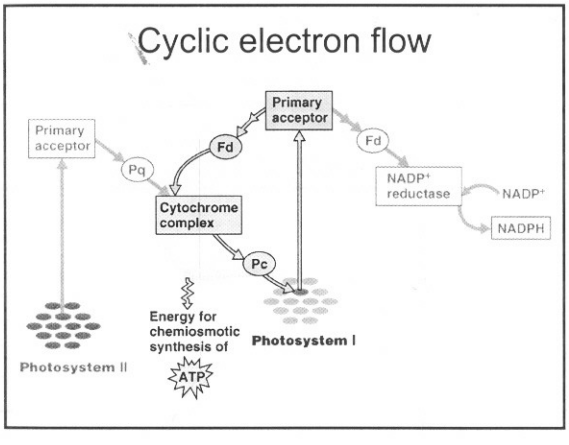


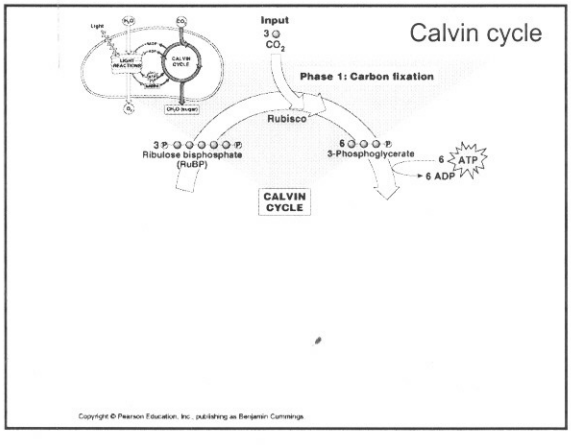
Noncyclic electron flow during the light reaction




Light reaction and chemiosmosis
CALVIN CYCLE
LIGHT REACTIONS
Cytochrome complex
Photosystem II
Photosystem I
STROMA
Light
NADP+ reductase
NADP+ + 2H+
NADPH + H+
THYLAKOID MEMBRANE
THYLAKOID SPACE
To Calvin cycle
ATP synthase
ADP
ATP


Mitochondrion
Chloroplast
High H+ concentration
Diffusion
INTERMEMBRANE SPACE
THYLAKOID SPACE
MEMBRANE
Electron transport chain
Mitochondrion structure
Chloroplast structure
ATP synthase
MATRIX
STROMA
ADP +
ATP
Low H+ concentration


Cyclic electron flow
Primary acceptor
Fd
Pq
Cytochrome complex
Pc
NADP+ reductase
NADP+
NADPH
Energy for chemiosmotic synthesis of
ATP
Photosystem II
Photosystem I


Calvin cycle
Input
3 CO2
Phase 1: Carbon fixation
Rubisco
3-Phosphoglycerate
6 ATP
6 ADP
CALVIN CYCLE
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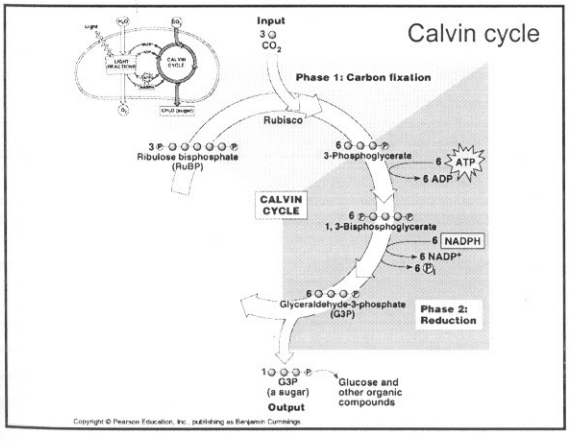
Calvin cycle
Input
3 CO2
Phase 1: Carbon fixation
Rubisco
3-Phosphoglycerate
6 ATP
6 ADP
CALVIN CYCLE
1, 3-Bisphosphoglycerate
6 NADPH
6 NADP+
Glyceraldehyde-3-phosphate (G3P)
Phase 2: Reduction
G3P (a sugar)
Output
Glucose and other organic compounds
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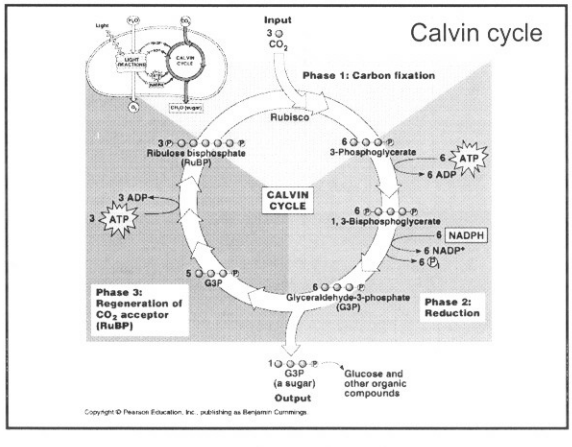
Calvin cycle
Input
3 CO2
Phase 1: Carbon fixation
Rubisco
3-Phosphoglycerate
6 ATP
6 ADP
3 ADP
3 ATP
CALVIN CYCLE
1, 3-Bisphosphoglycerate
6 NADPH
6 NADP+
5 G3P
Phase 3: Regeneration of CO2 acceptor (RuBP)
Glyceraldehyde-3-phosphate (G3P)
Phase 2: Reduction
G3P (a sugar)
Output
Glucose and other organic compounds
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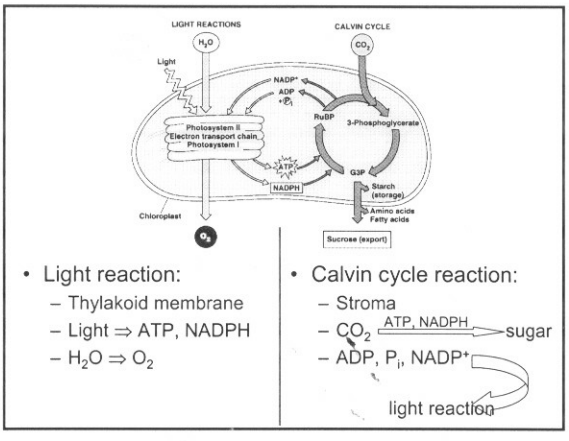
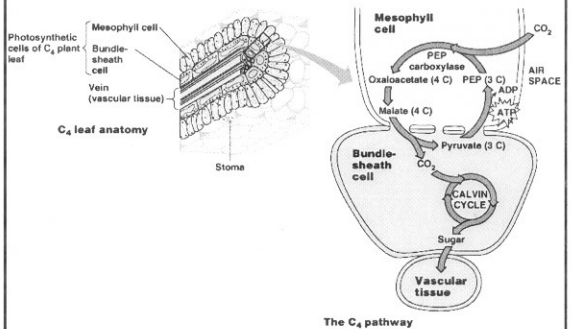


- Light reaction:
  - Thylakoid membrane
  - Light ⇒ ATP, NADPH
  - H_2O ⇒ O_2
- Calvin cycle reaction:
  - Stroma
  - CO_2 —(ATP, NADPH)→ sugar
  - ADP, P_i, $NADP^+$ → light reaction

C_4 leaf anatomy and the C_4 pathway



C_4 and CAM photosynthesis compared