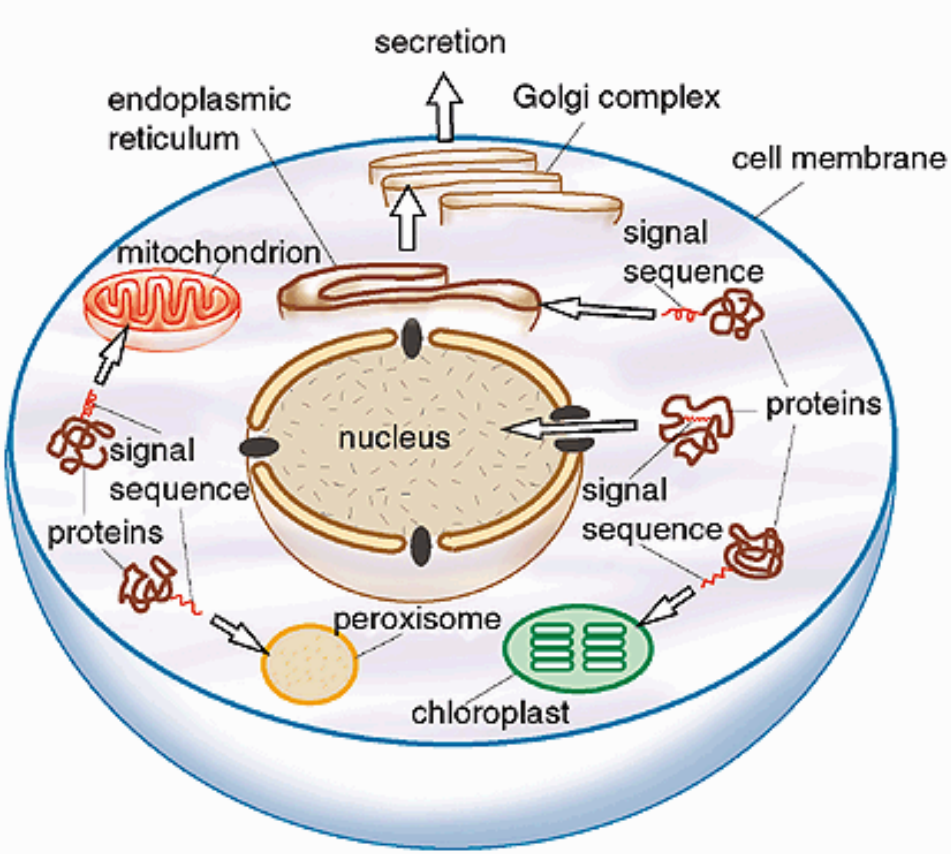
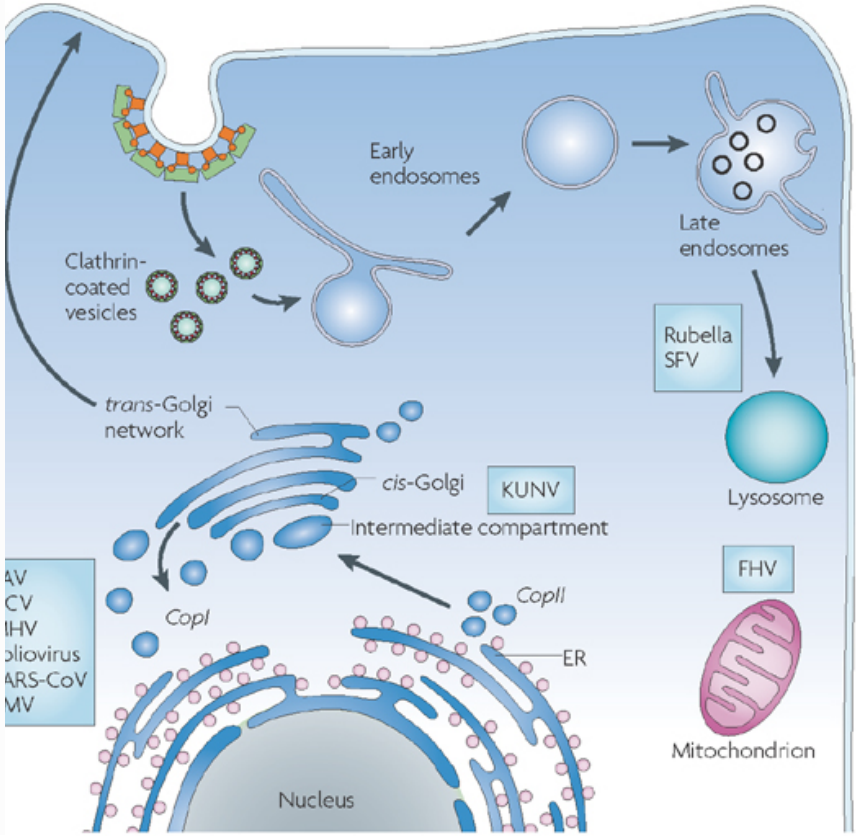
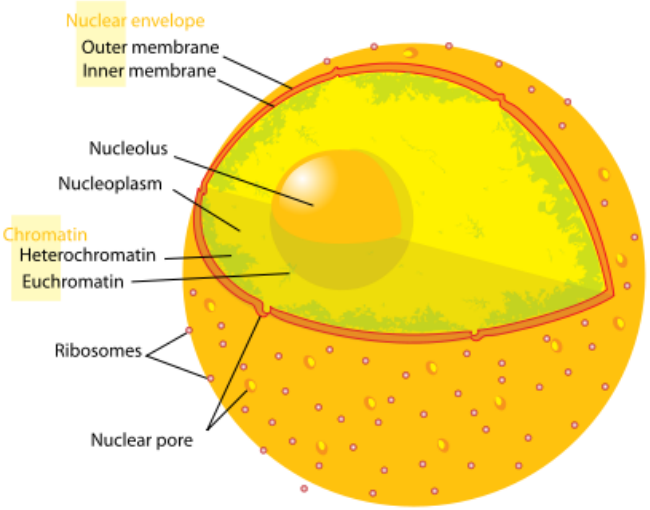
Intracellular organelles
(세포 내 소기관)





Nucleus (핵)

- Controls the cell; houses the genetic material (DNA).
- The nucleus is the largest of the cells organelles.
- Cells can have more than one nucleus or lack a nucleus all together.
  - Skeletal muscle cells contain more than one nucleus whereas red blood cells do not contain a nucleus at all.
- The nucleus is bounded by the nuclear envelope, a phospholipid bilayer similar to the plasma membrane.
- The space between these two layers is the nucleolemma Cisterna.



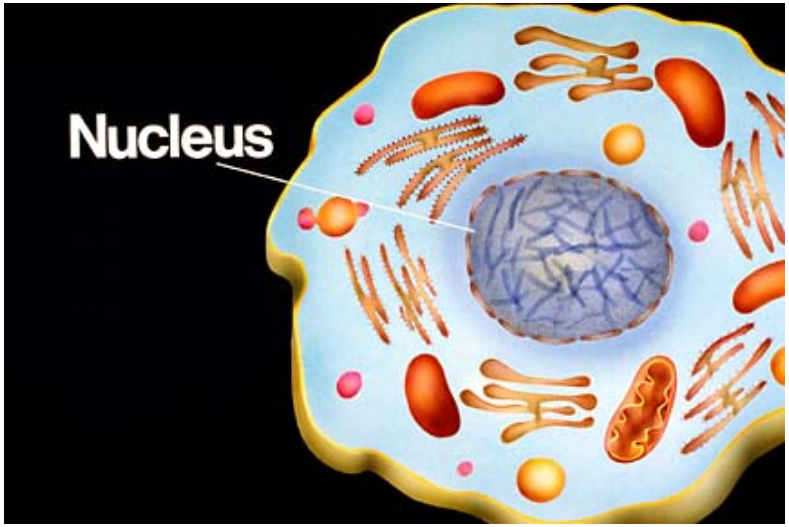
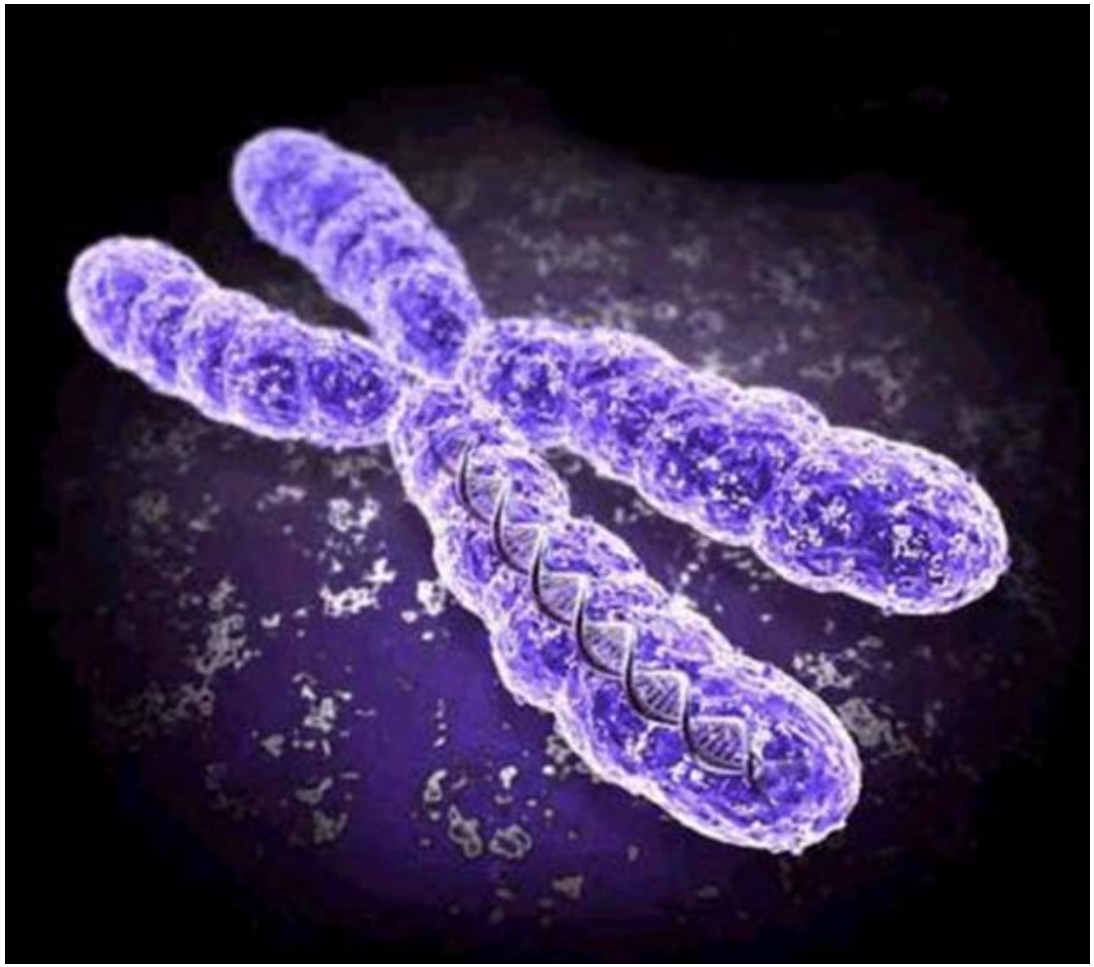


Diagram human cell nucleus

- It contains most of the cell's genetic material, organized as multiple long linear DNA molecules in complex with a large variety of proteins, such as histones, to form chromosomes.

- The genes within these chromosomes are the cell's nuclear genome.



Nucleus and Nucleolus (핵과 핵소체)

핵 (Nucleus)

- 세포의 조절센터
- 이중막으로 둘러싸여 있음
- 핵 내외로 물질이 통과할 수 있는 pore를 가짐
- Chromatin (염색질): DNA 함유

핵소체: (Nucleolus)

- 섬유성 물질로 구성, 둥근 모양
- 주로 DNA, RNA 및 단백질로 구성
- RNA 합성 → 리보소체 형성

- **The function** of the nucleus
  - to maintain the integrity of these genes and to control the activities of the cell by regulating gene expression
  - the control center of the cell.

- **The main structures** making up the nucleus are the
  - ✓ nuclear envelope, a double membrane that encloses the entire organelle and isolates its contents from the cellular cytoplasm
  - ✓ nucleoskeleton (which includes nuclear lamina), a mesh work within the nucleus that adds mechanical support, much like the cytoskeleton, which supports the cell as a whole.

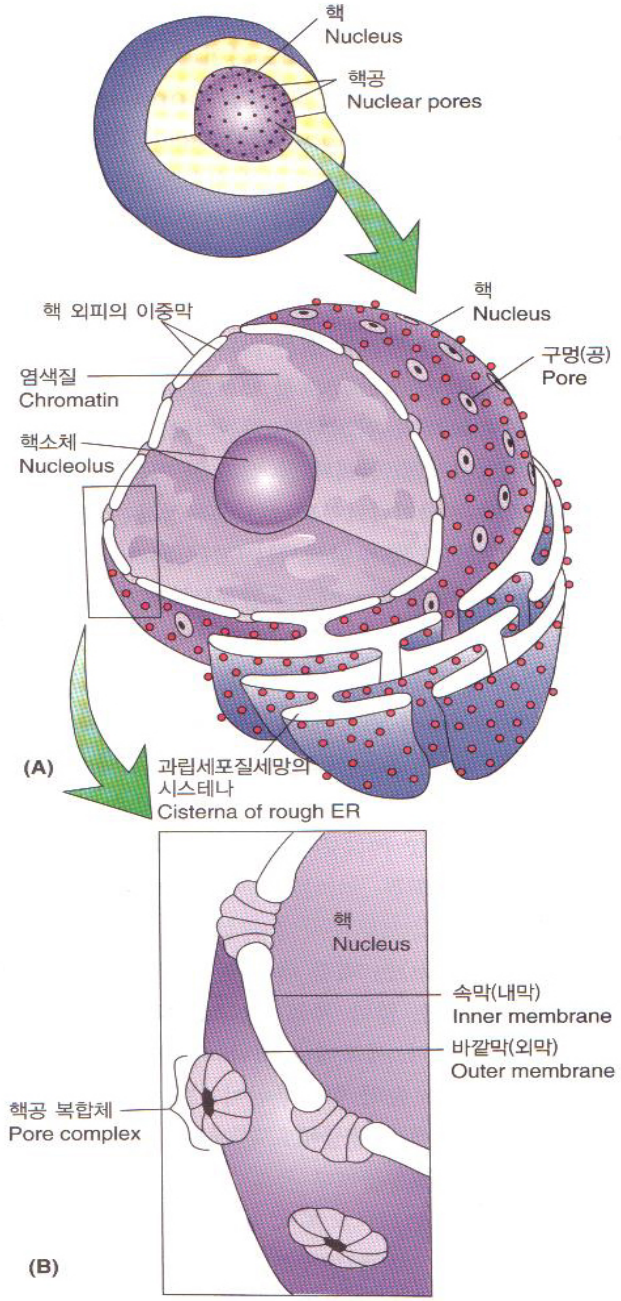
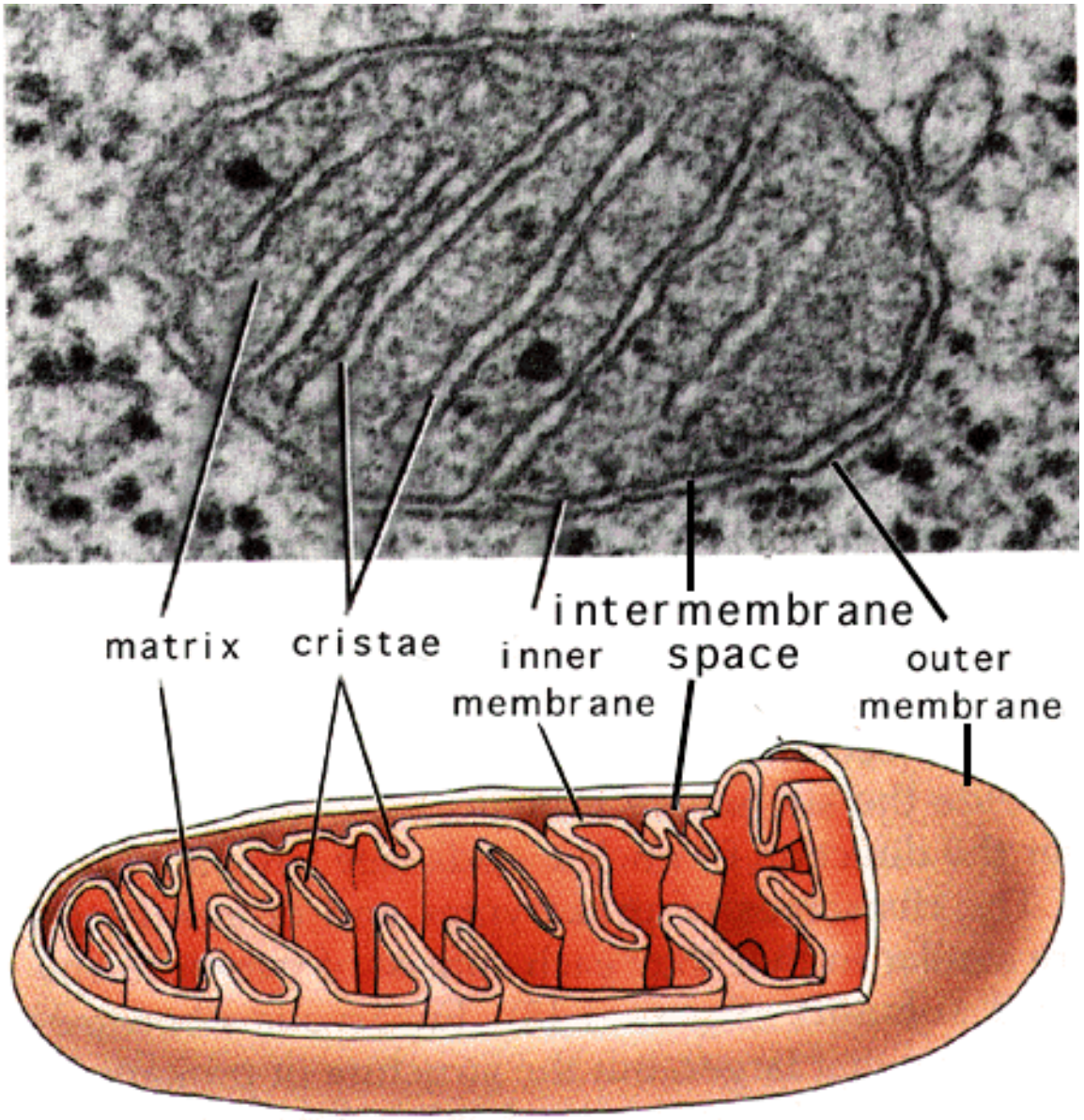


그림 3-6. 핵막 또는 핵 외피의 구조. (A) 핵의 내부구조 및 세포질세망과 외형막의 연결 모식도, (B) 핵공 복합체의 모식도.

MITOCHONDRIA

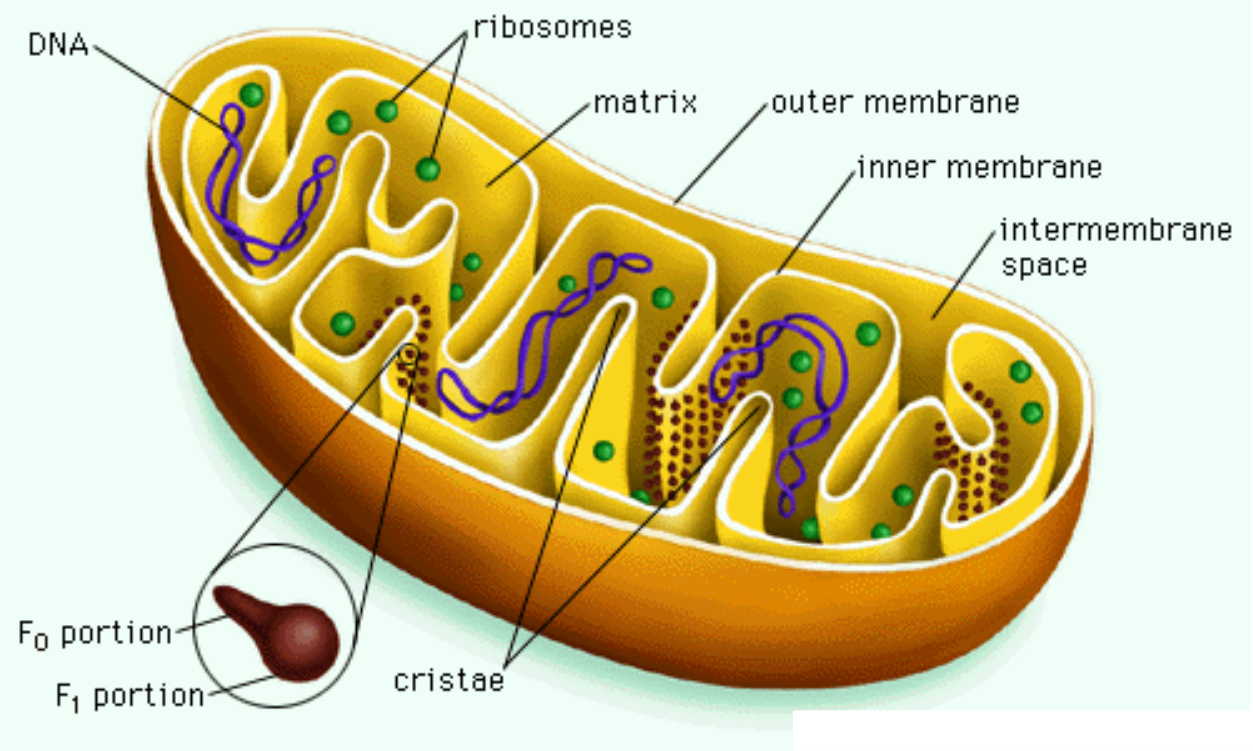


Mitochondria

- Mitochondria are present in virtually every cell of the body.
- They contain the enzymes required for the *citric-acid cycle* , *ATP synthesis*, and the *oxidation of fatty acids*.
- Mitochondria (from the Greek "threadlike grain") have a double membrane.
- The mitochondria are specialized, oval-shaped cellular compartments.
- The outer membrane is smooth, while the inner membrane called cristae contains numerous foldings.
- Attached to the cristae are small granules of unknown composition and function.
- The mitochondria are responsible for the aerobic (oxygen dependent) metabolism of the cell.

Mitochondria

- The enzymes necessary for the citric acid cycle, respiratory chain, and beta fatty acid oxidation, are all compartmentalized in the cristae.
- There is also some DNA present in the mitochondria which is probably responsible for the synthesis of messenger RNA necessary to produce protein enzymes.



Origin

Mitochondria are thought to be aerobic bacterial cells much like *Rickettsia* bacteria that colonized primordial eukaryotic cells without the ability to use oxygen. Thus, these intracellular aerobic bacteria added oxidative metabolism to the eukaryotic cells and eventually evolved into mitochondria. (WUSTL)

A theory on why a bacterium became an organelle has to do with the increase in ambient oxygen tension in Earth's atmosphere approximately 2 billion years ago. Supposedly, the oxygen tension went from 1% to more than 15% of the current levels within about 200 million years; this "environmental trauma" is thought to have pushed the symbiosis that lead to mitochondria organelles in primitive eukaryotes. (Kurland and Andersson 2000)

• Mitochondria (사립체,미토콘드리아)

- 세포 내 호흡생리 담당 (cristae) cristae : 내막의 주름
- 에너지 생산 (ATP 공급), 2중막 구성
- TCA 회로 → 이산화탄소와 물로 산화
- 전자전달계(electron transport chain) → ATP 합성
- 자체 DNA 복제

에너지 전환

미토콘드리아의 주기능은 ATP의 생산으로 해당과정(미토콘드리아의 바깥쪽 세포질에서 이루어진다.)의 주생산물인 피루브산과 NADH 대사를 통하여 이루어진다. ATP의 생성은 세포의 유형이나 산소의 존재유무에 따라 2 가지 방법이 있다.

- **Mitochondria (사립체, 미토콘드리아)**

내막

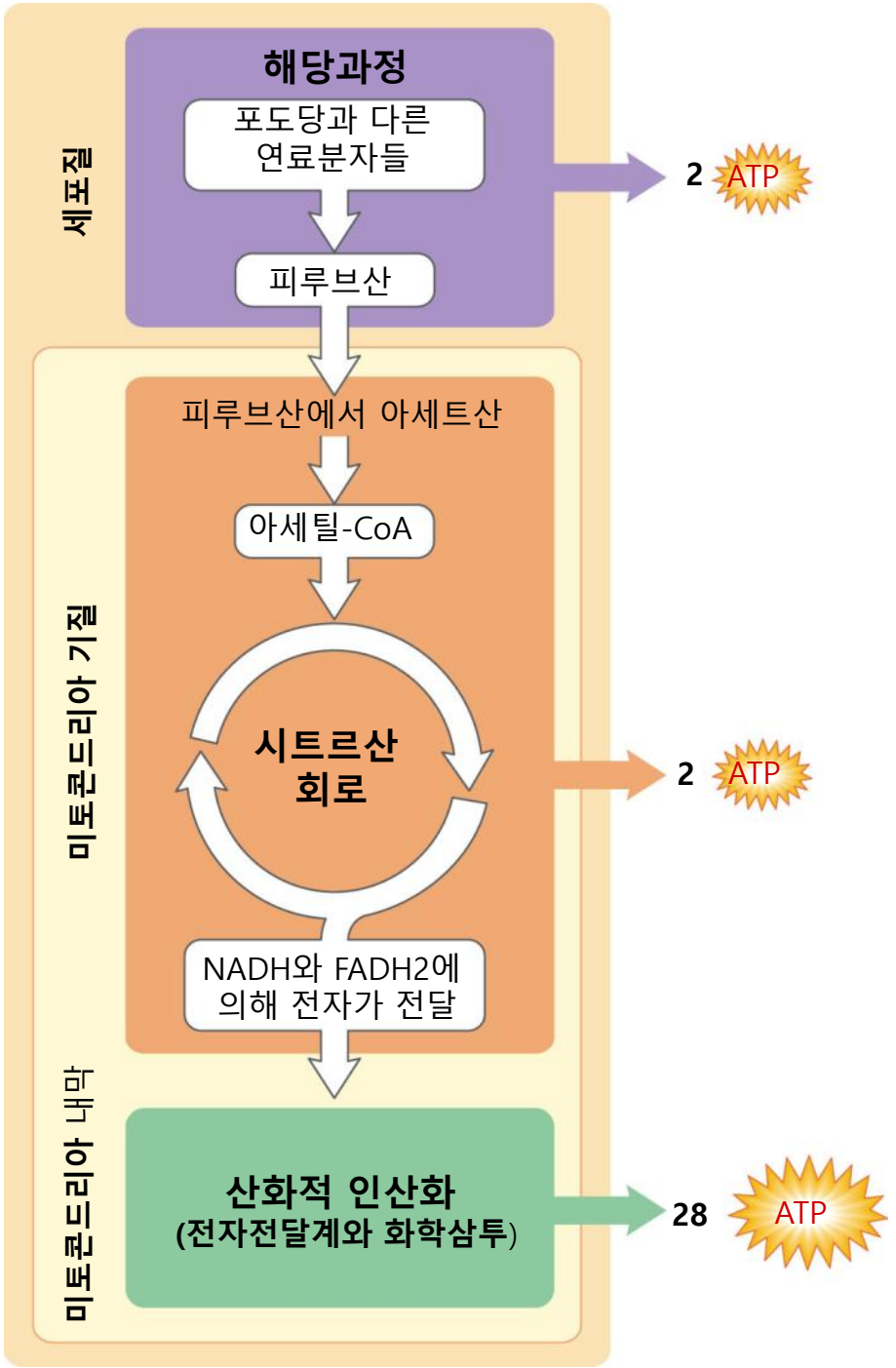
- 4가지 기능을 가진 단백질(효소)를 가지고 있다.[Alberts, 1994]:
  1) 산화효소: 세포호흡
  2) ATP 생성효소
  3) 내막 안팎으로의 대사물질운송
  4) 단백질 수송

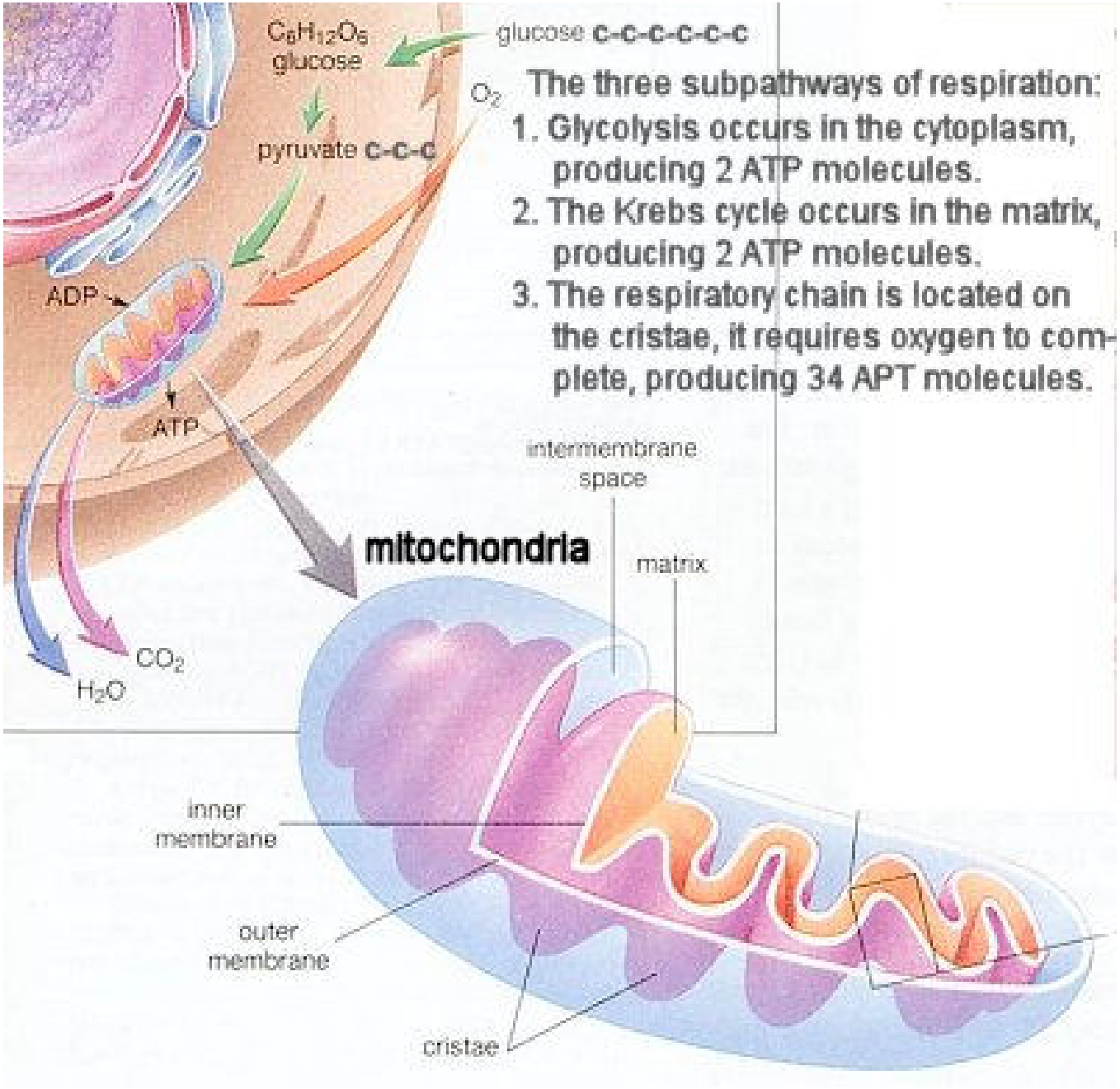
- 막 표면적이 넓어 ATP생성 능력을 높여준다.
  → '크리스타 구조'

Ex) 간의 미토콘드리아는 크리스타를 포함한 내막 표면적이 외막의 5배에 달하며 근육세포와 같이 더 많은 ATP를 요구하는 세포의 경우 간세포의 경우 보다 더 많은 크리스타를 가지고 있다.

(1) ATP 생산

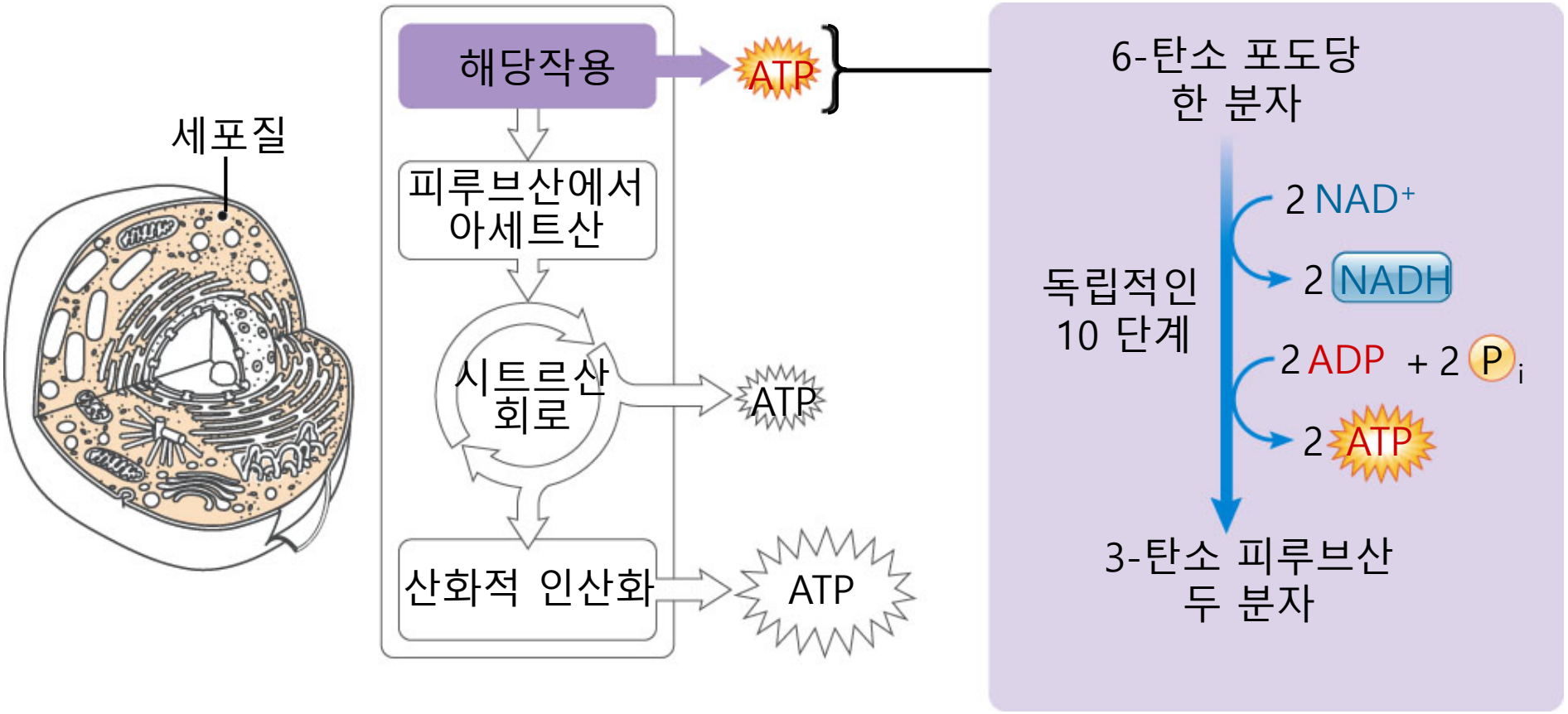
- 세포 내에서 ATP 생산에 여러 단계가 관여(해당과정, 시트르산 회로, 산화적 인산화-이를 **세포호흡**이라 부름)



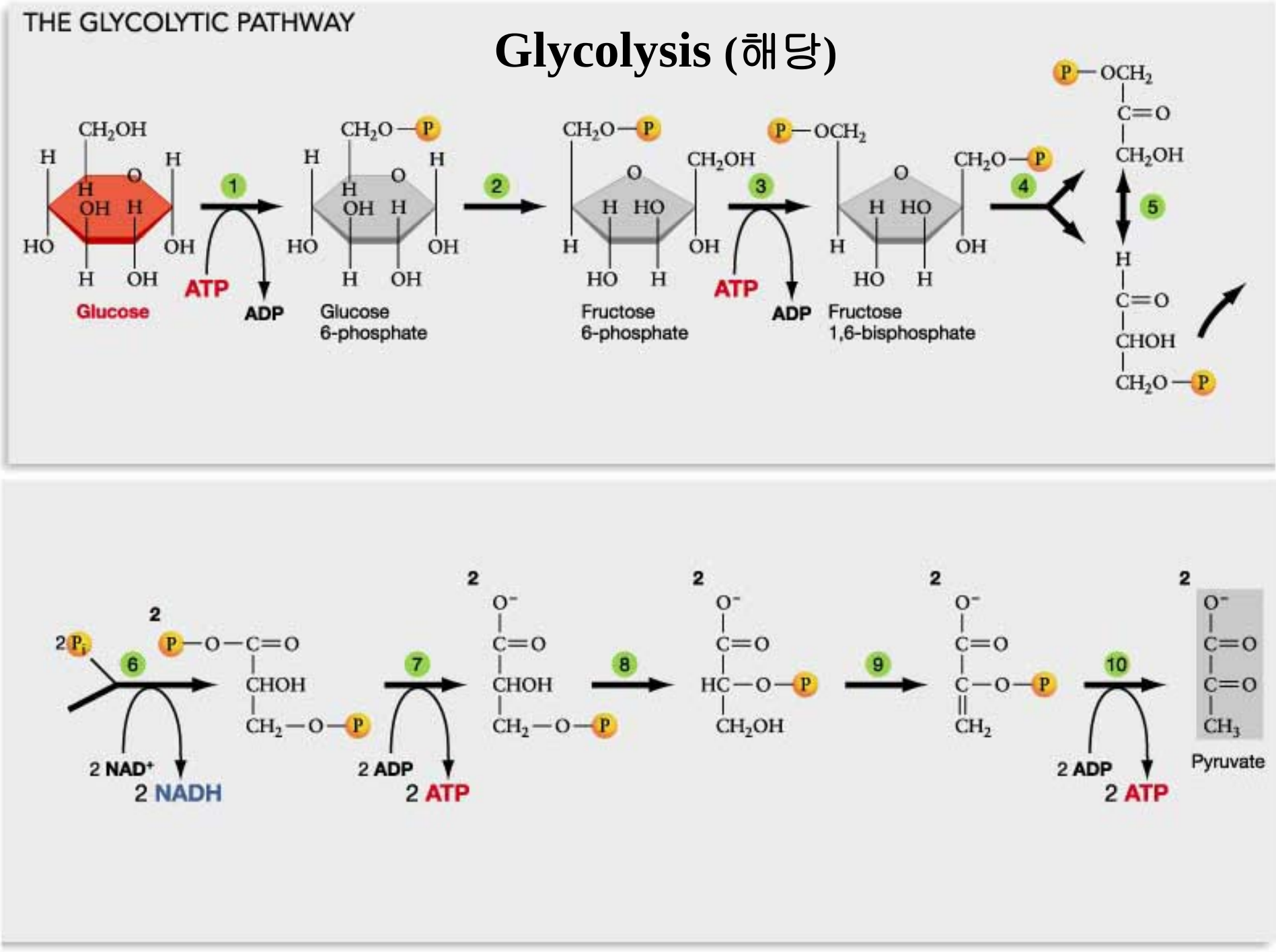

$C_6H_{12}O_6$
glucose
glucose C-C-C-C-C-C
O_2
pyruvate C-C-C
ADP
ATP
CO_2
H_2O
The three subpathways of respiration:
1. Glycolysis occurs in the cytoplasm, producing 2 ATP molecules.
2. The Krebs cycle occurs in the matrix, producing 2 ATP molecules.
3. The respiratory chain is located on the cristae, it requires oxygen to complete, producing 34 APT molecules.
intermembrane space
mitochondria
matrix
inner membrane
outer membrane
cristae

1. 해당과정(glycolysis)

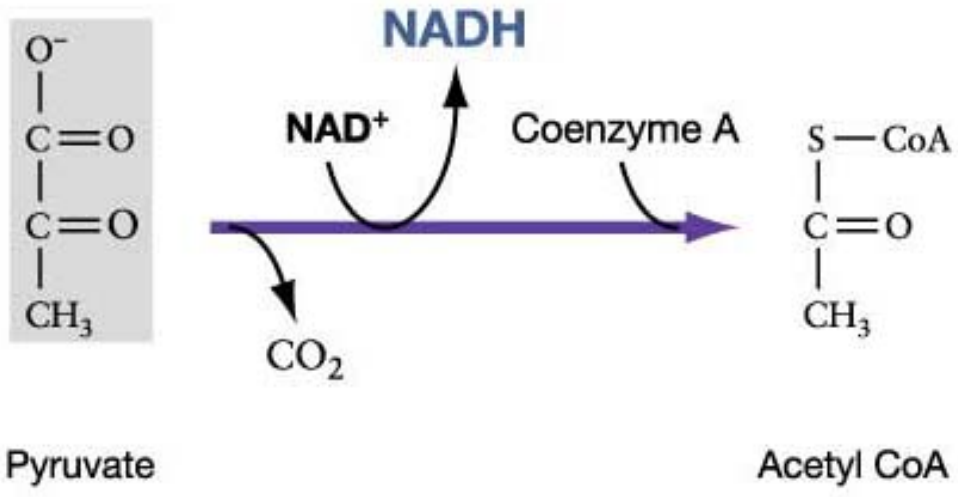
- 6개의 탄소를 갖고 있는 당 분자인 포도당(6탄당)을 두 개의 피루브산(3개 탄소 함유)으로 분해되는 10단계의 화학 과정
- 무기적 과정



Glycolysis (해당)



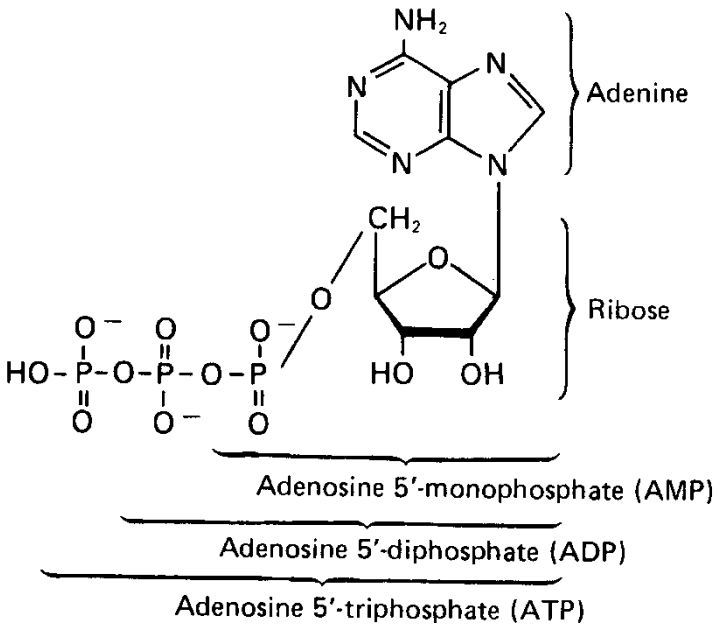
Oxidation of Pyruvate

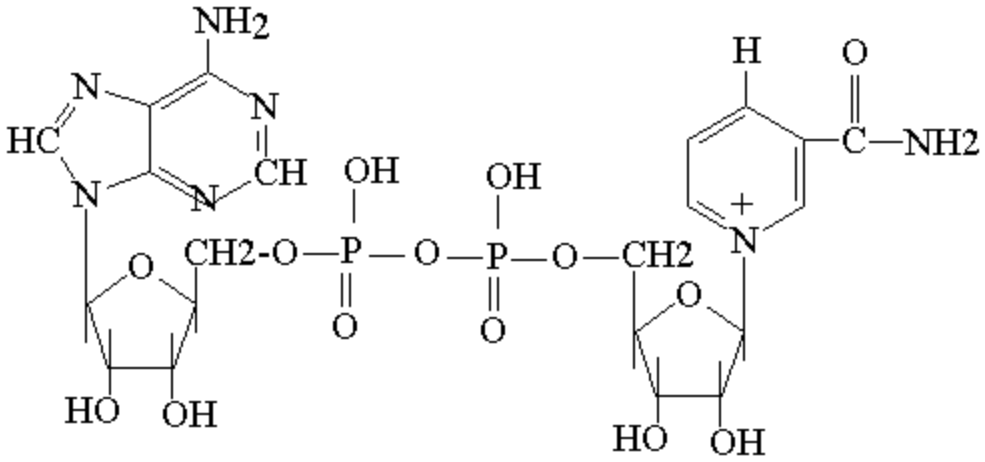


해당과정에서 생성된 피루브산 분자는 능동수송에 의해 미토콘드리아 내막을 거쳐 기질로 들어간다. 기질에 들어간 피루브산은 coenzyme A에 결합해 acetyl CoA를 생성하고, 생성된 acetyl CoA는 TCA회로(구연산회로 또는 Krebs 회로)로 들어가게 된다.

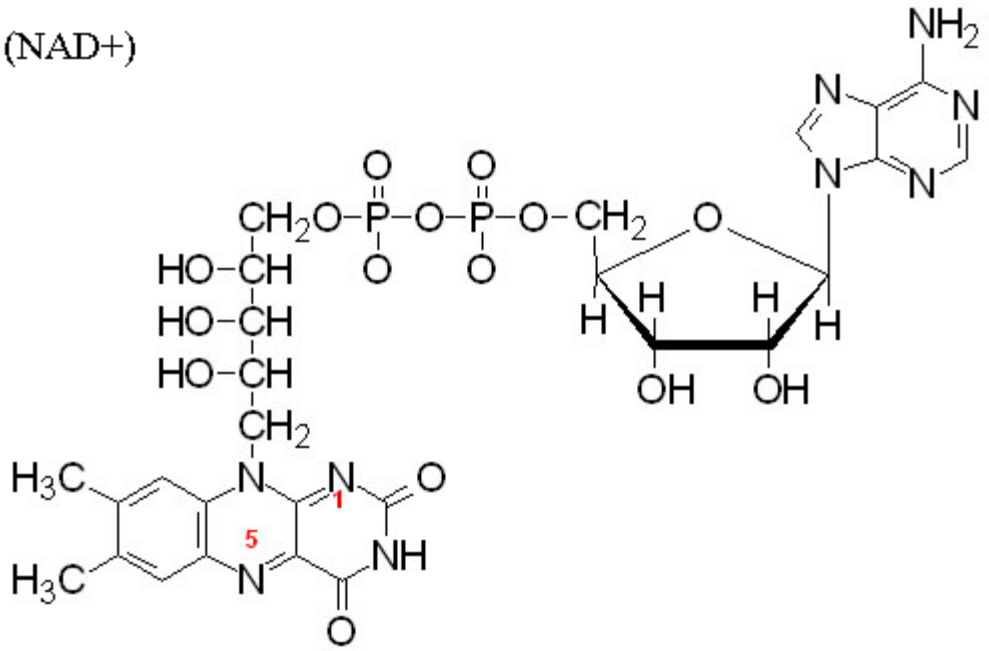
Energy-Transferring Nucleotides

- **Adenosine di(tri)phosphate ADP/ATP**
  - **Adenine + ribose + 2 or 3 phosphates**
  - **Adenine + ribose = adenosine**
- **Nicotinamide adenine dinucleotide (NAD)**
- **Flavin adenine dinucleotide (FAD)**





nicotinamide adenine dinucleotide (NAD+)

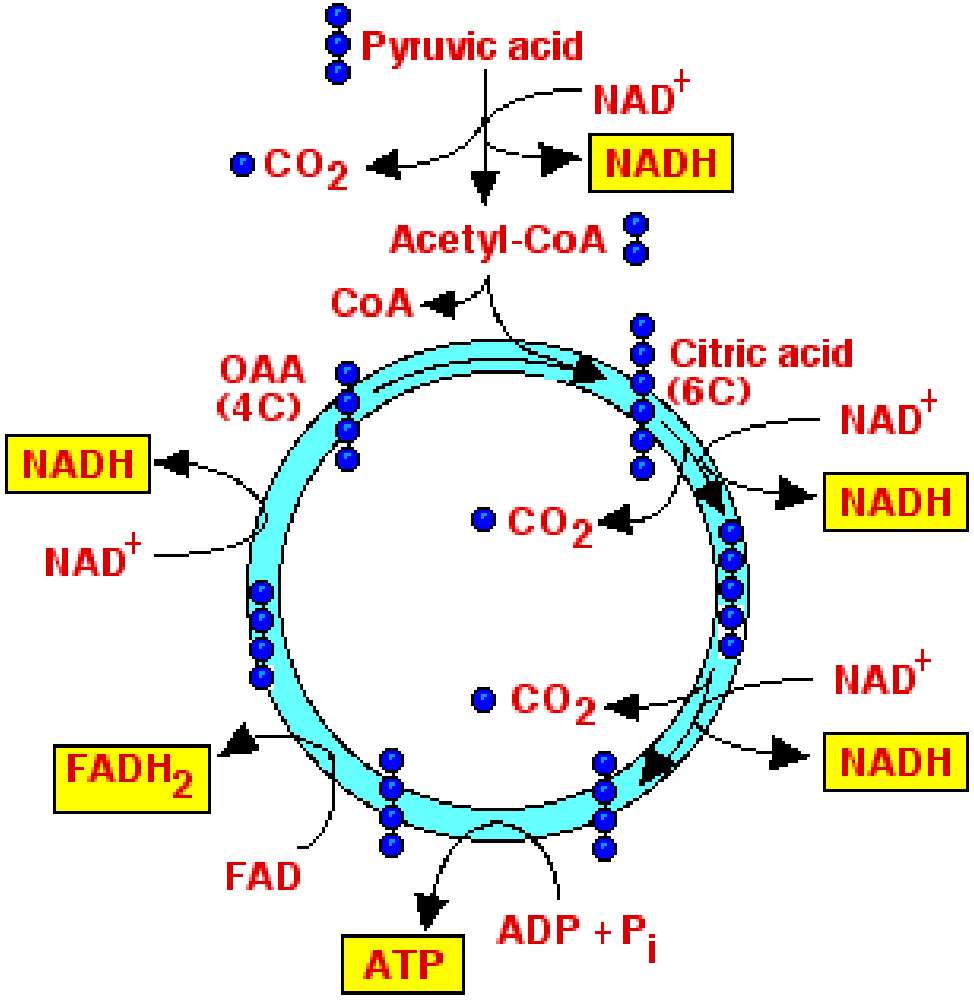


Flavin adenine dinucleotide (FAD)

2. 시트르산 회로(cittic acid cycle)

- 산소가 요구됨
- **TCA 회로[tricarboxylic acid(TCA) cycle]** 또는 **크렙스 회로(Kreb's cycle)**라고도 부름
- 해당과정에서 만들어진 피루브산이 **아세틸-CoA**로 전환된 다음 시트르산 회로로 들어감
- 시트르산 회로는 **미토콘드리아 기질**에 존재하는 효소들에 의해 일어나며 8 단계의 생화학 반응을 거침
- 전자전달계로 들어가기 위한 수소운반체 준비가 중요

Krebs Cycle (Citric Acid Cycle)



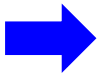
1개의 피루브산에 의해 3개의 NADH와 1개의 $FADH_2$가 생성되어 전자전달계에 관여하게 된다.

미토콘드리아 내막에 붙어있는 숙신산탈수소효소(succinate dehydrogenase)를 제외하고 TCA회로에 관여하는 모든 효소는 미토콘드리아 기질에 녹아있다.

3. 산화적인산화(oxidative phosphorylation)

- 전자가 산소(O_2)로 전이될 때 전자로부터 방출되는 에너지를 이용하여 ATP가 합성

- 두 종류 단백질 집단이 관여:
  전자전달계(electro transport system)와
  ATP합성효소(ATP synthase)



The Electron Transport Chain:

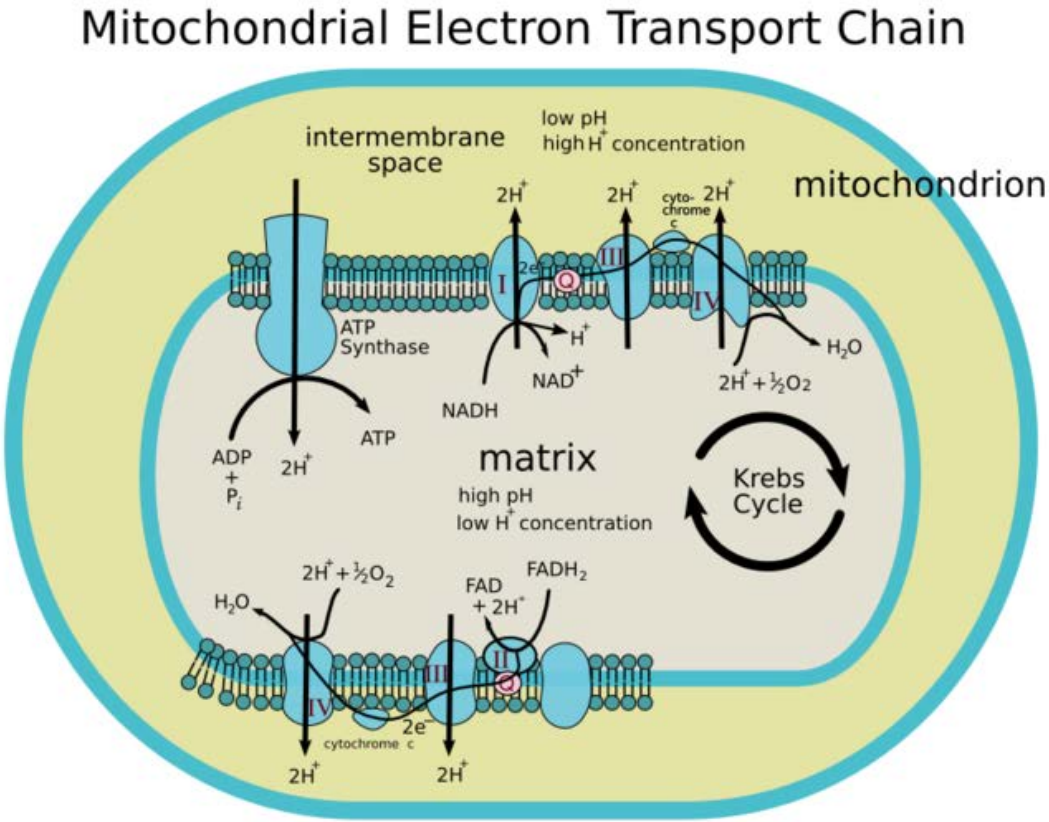
- Uses the high energy electrons from glycolysis and the Krebs Cycle to convert ADP into ATP.
- Takes place in the mitochondria.

The ingredients:

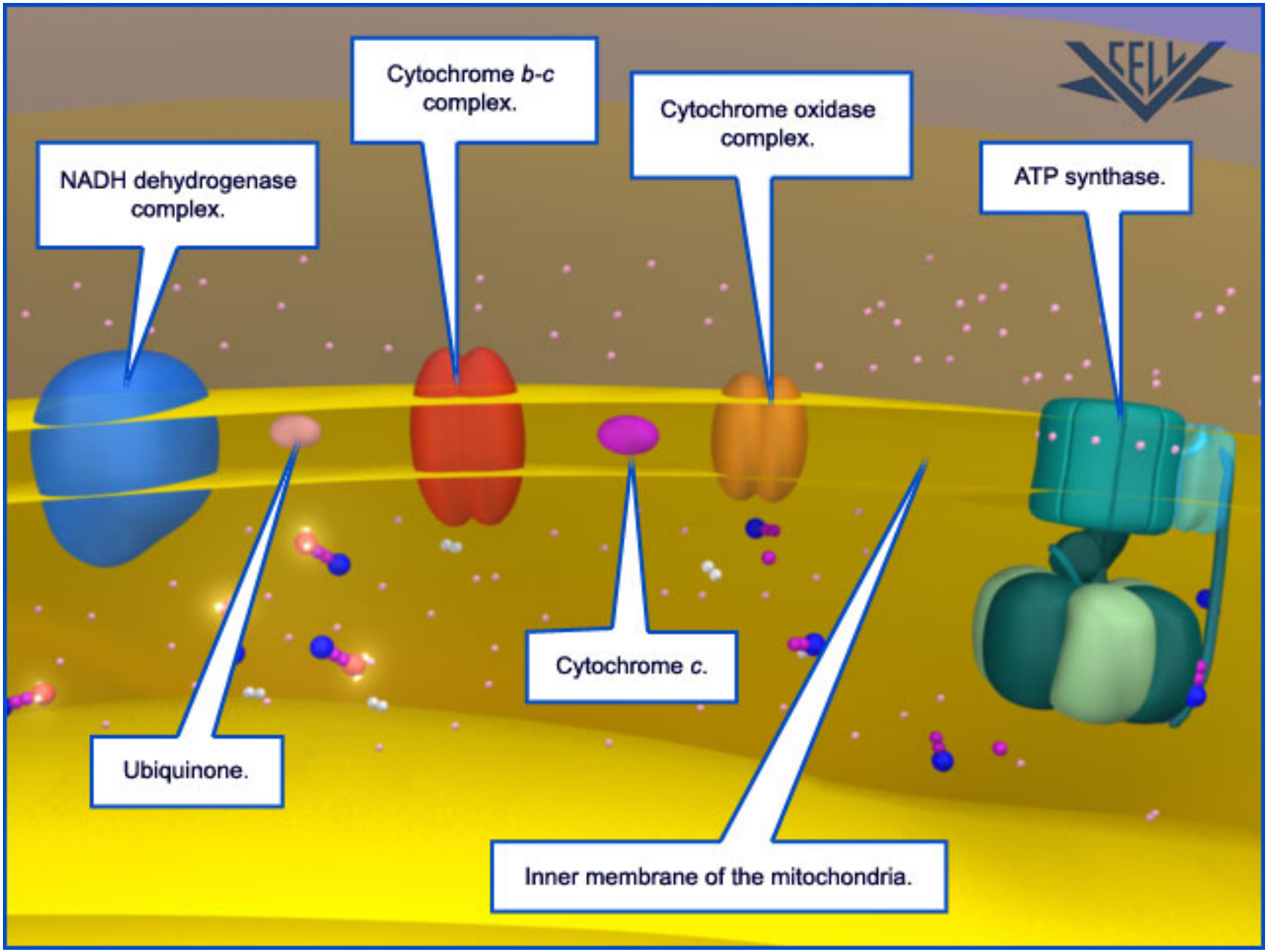
- NADH
- $FADH_2$
- O_2

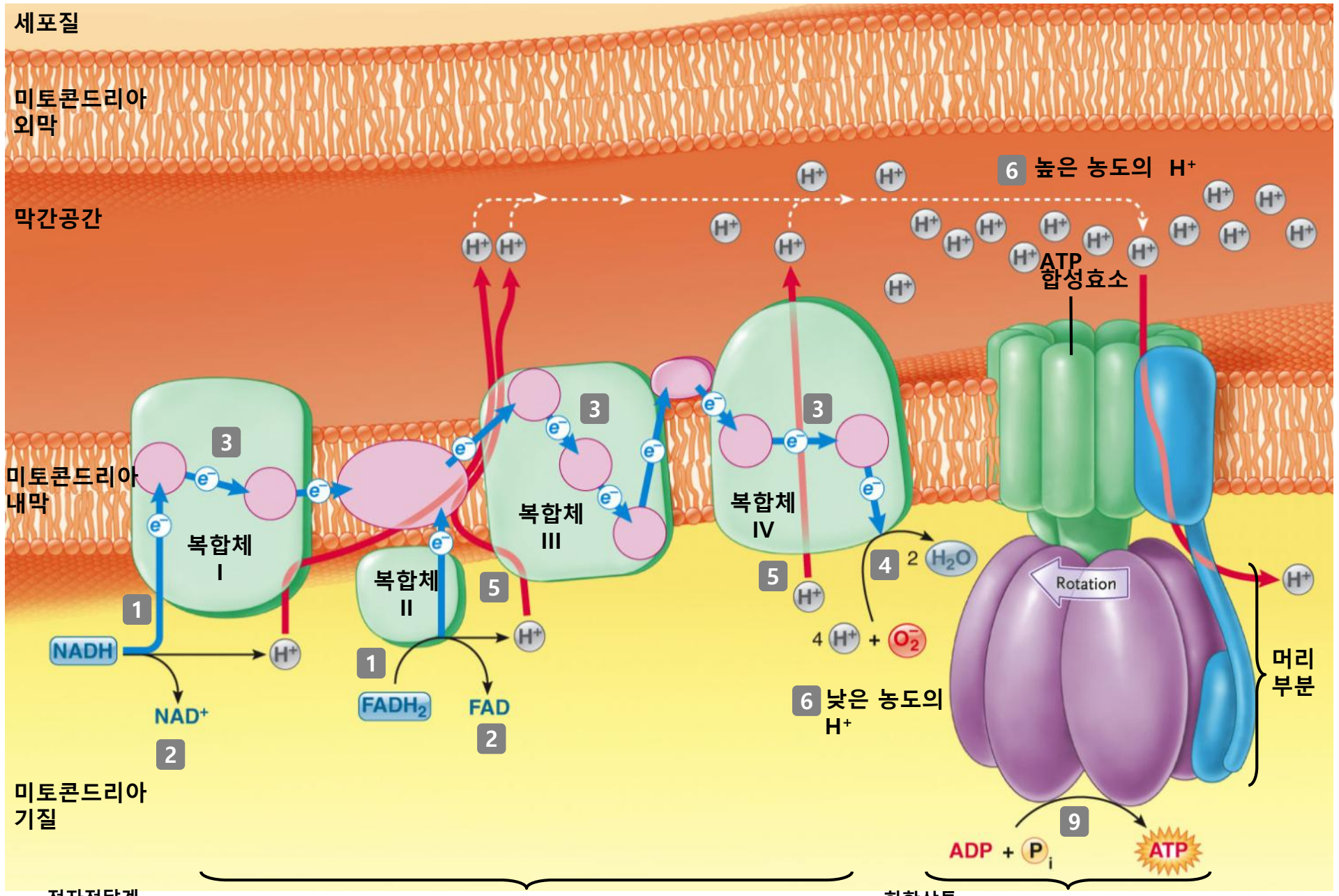
The Products:

- About 34 ATP
- H_2O



http://www.youtube.com/watch?feature=player_detailpage&v=xbJ0nbzt5Kw

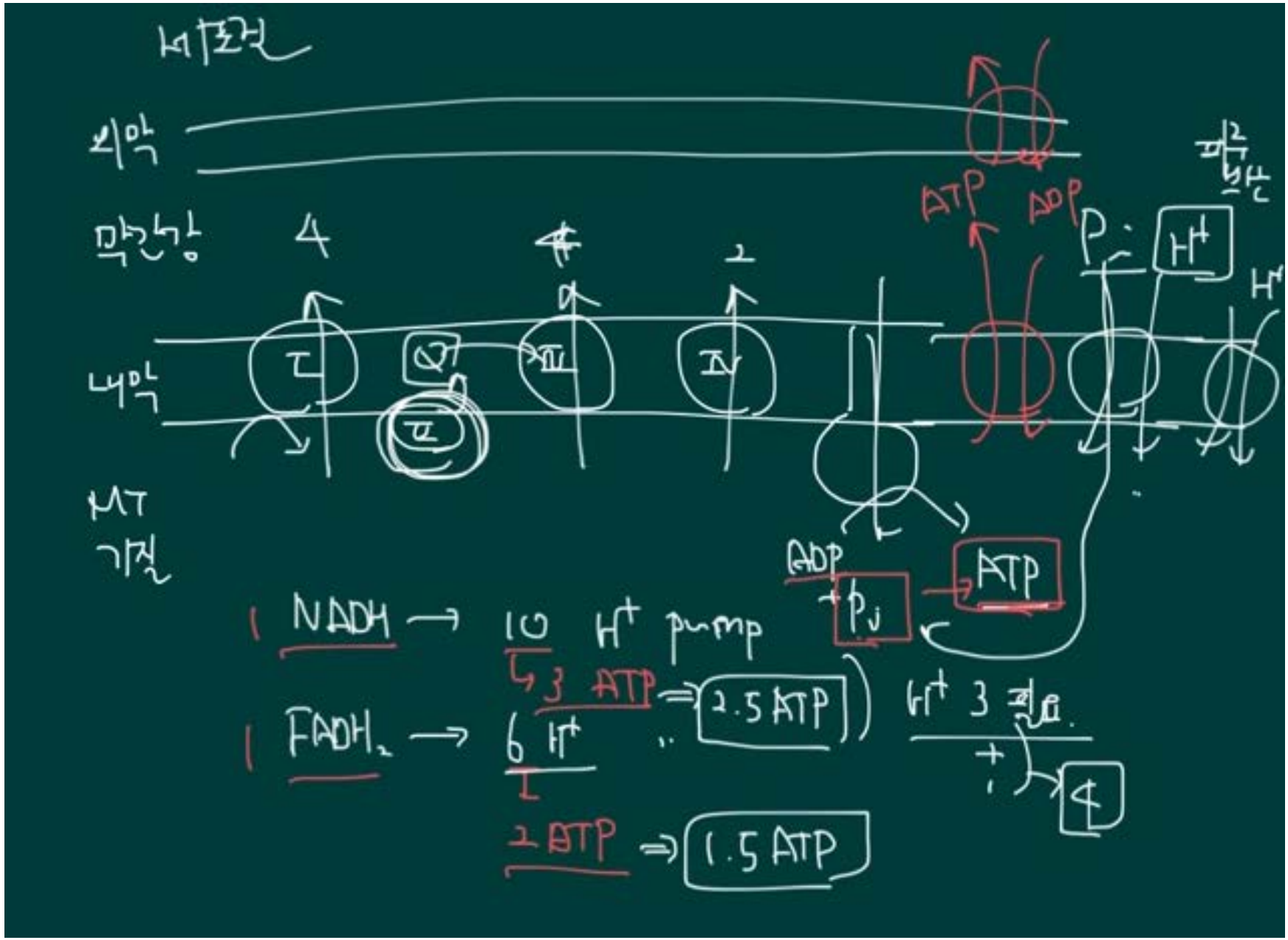

Cytochrome *b-c* complex.
Cytochrome oxidase complex.
NADH dehydrogenase complex.
ATP synthase.
Cytochrome *c*.
Ubiquinone.
Inner membrane of the mitochondria.



전자전달계
전자는 순차적으로 고에너지 수준에서 저에너지 수준으로 전자 운반체를 통해 흘러간다; 이때 방출된 에너지는 미토콘드리아 내막 안팎의 수소이온(H1) 농도기울기 형성에 사용된다.

화학삼투
ATP합성효소는 막 사이 수소이온(H1) 농도기울기의 에너지를 사용하여 ATP 합성을 촉매한다.

산화적 인산화


미토콘드리아
외막
막간공간
내막
기질
ATP
ADP
Pi
H+
NADH → 10 H+ pump
3 ATP ⇒ 2.5 ATP
FADH2 → 6 H+
2 ATP ⇒ 1.5 ATP
H+ 3개씩
4

포도당 —(해당(세포질))→ 피루브산 ×2 ⇒ ATP 2, NADH 2

피루브산 —(NADH, CO_2)→ 아세틸CoA

⇒ CO_2 ×2, NADH ×2

CO_2 2×2 = 4

아세틸CoA
ATP 1
NADH 3
$FADH_2$ 1
CO_2 2
× 2

⇒ ATP 1×2 = 2

NADH 3×2 = 6

$FADH_2$ 1×2 = 2

38 ATP

ATP 4, NADH 10 (30 ATP), $FADH_2$ 2 (4 ATP)

NADH ⇓ 2.5 ATP

$FADH_2$ ⇓ 3 ATP

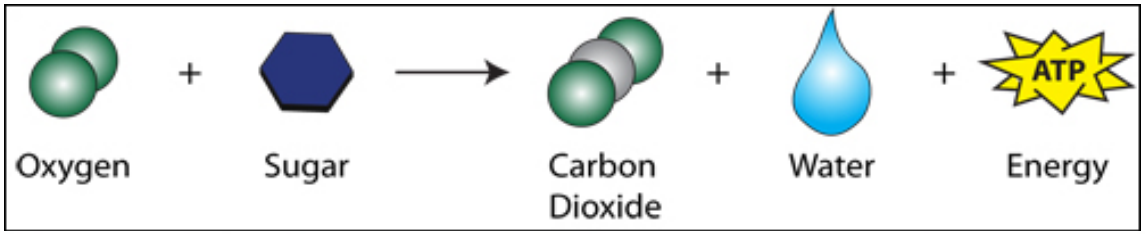
32 ATP

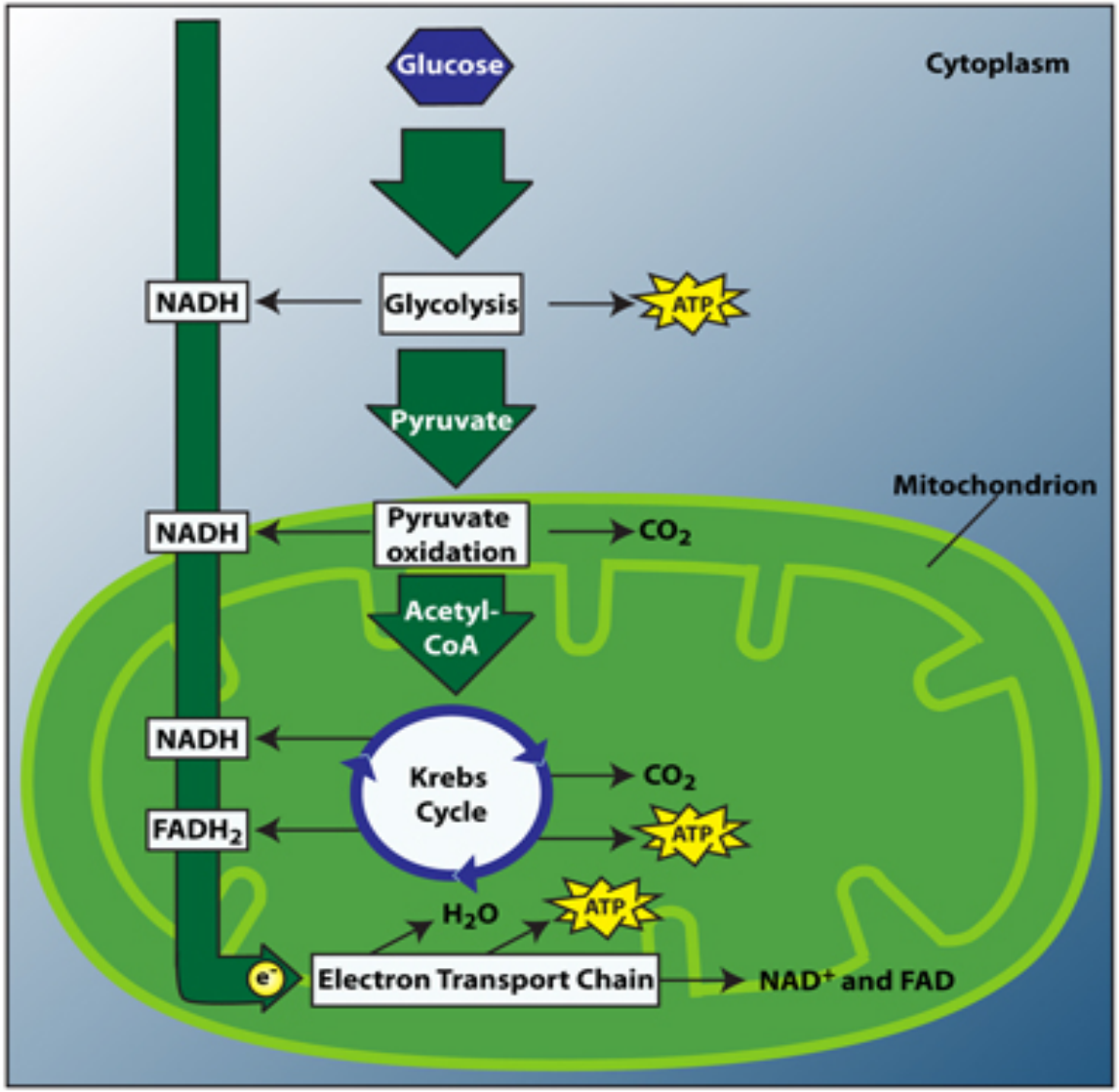
- The **electron transport chain** (**ETC**) is located in the inner membrane of the **mitochondria**.
- **NADH** is the **electron** donor for the ETC.
- Electron donation to the first complex (blue) and **hydrogen ion pumping** are coupled.
- The donated electrons are then passed to the first **mobile carrier** protein (pink).
- The electrons are then passed to the second complex (red). This transfer is again coupled with the pumping of hydrogen ions.
- Electrons are then passed to the second mobile carrier protein (purple).

http://www.youtube.com/watch?feature=player_detailpage&v=xbJ0nbzt5Kw

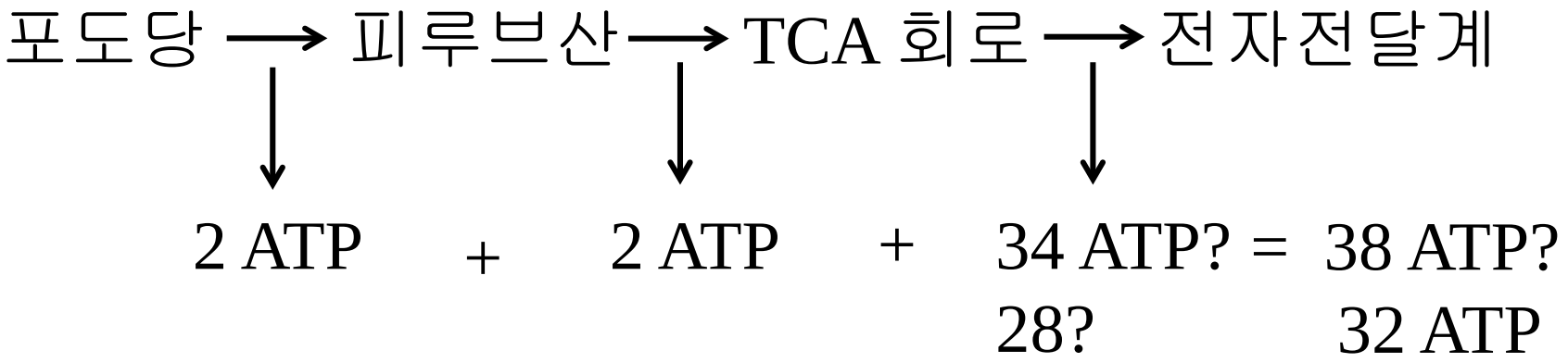
- Next, the electrons are transferred to the third complex (orange).
- While contained by the third complex, the electrons interact with **oxygen** and hydrogen ions.
- The reaction ends with hydrogen ions, or **protons**, being pumped across the membrane and the release of water molecules (**H_2O**).
- The pumping of protons creates a **proton gradient**.
- The hydrogen ion pumping actions of the ETC are coupled with **ATP synthesis**.

http://www.youtube.com/watch?feature=player_detailpage&v=xbJ0nbzt5Kw


Oxygen
Sugar
Carbon Dioxide
Water
ATP
Energy


Glucose
Cytoplasm
NADH
Glycolysis
ATP
Pyruvate
Mitochondrion
NADH
Pyruvate oxidation
CO_2
Acetyl-CoA
NADH
Krebs Cycle
CO_2
$FADH_2$
ATP
H_2O
ATP
e^-
Electron Transport Chain
NAD^+ and FAD

ATP 의 생성과정

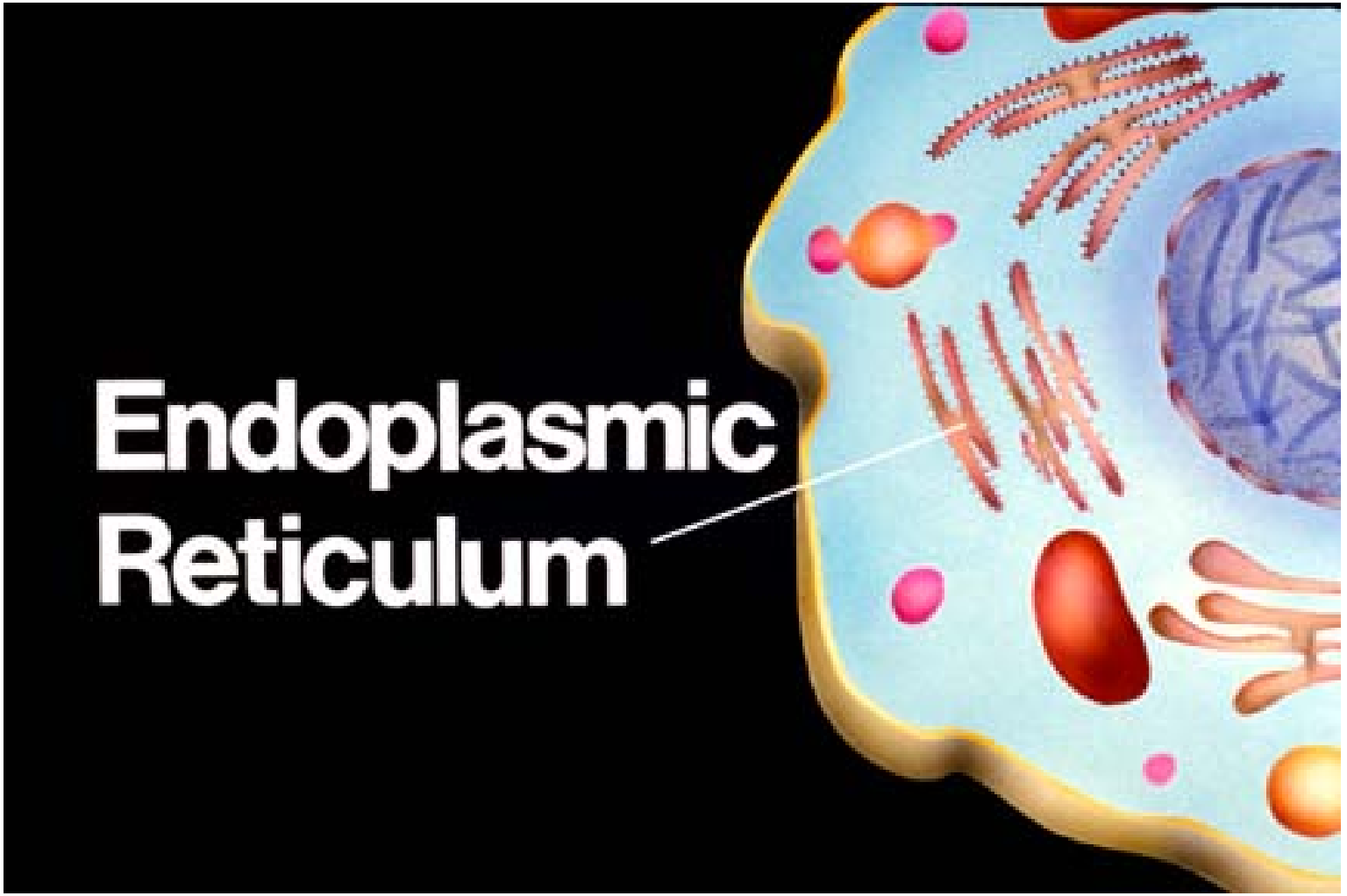


해당과정: 포도당이 피루빈산으로 분해되는 과정

TCA 회로 : 피루빈산이 CO2와 물로 분해되는 과정

전자전달계: 해당과정과 TCA회로에서 생성된
NADH와 FADH2 가 산소와 결합하여
물을 생성하는 과정

Endoplasmic Reticulum and Ribosomes



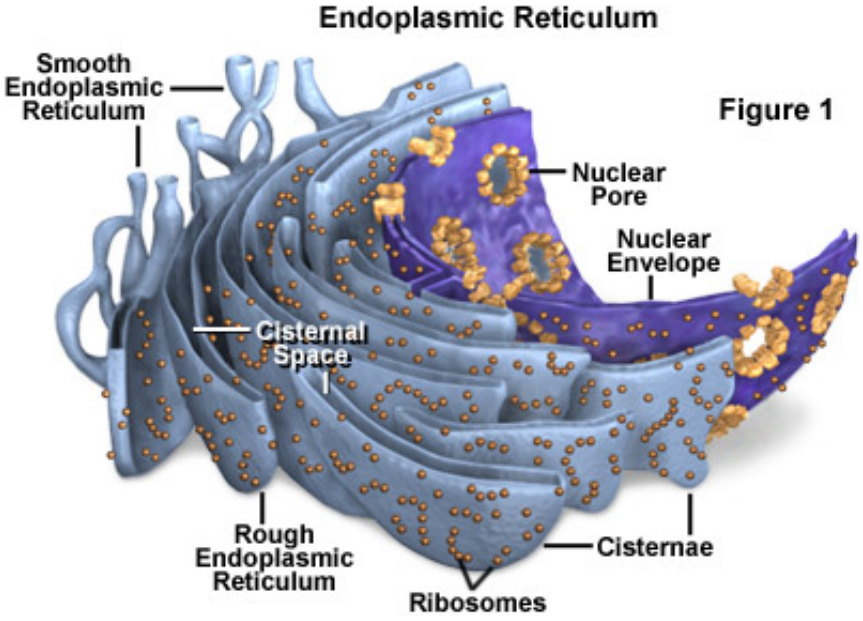
- Two morphological forms of endoplasmic reticulum;
  - rough form with attached ribosomes
    : rough surfaced endoplasmic reticulum (RER)
  - smooth form without ribosomes
    : smooth surfaced endoplasmic reticulum (SER)

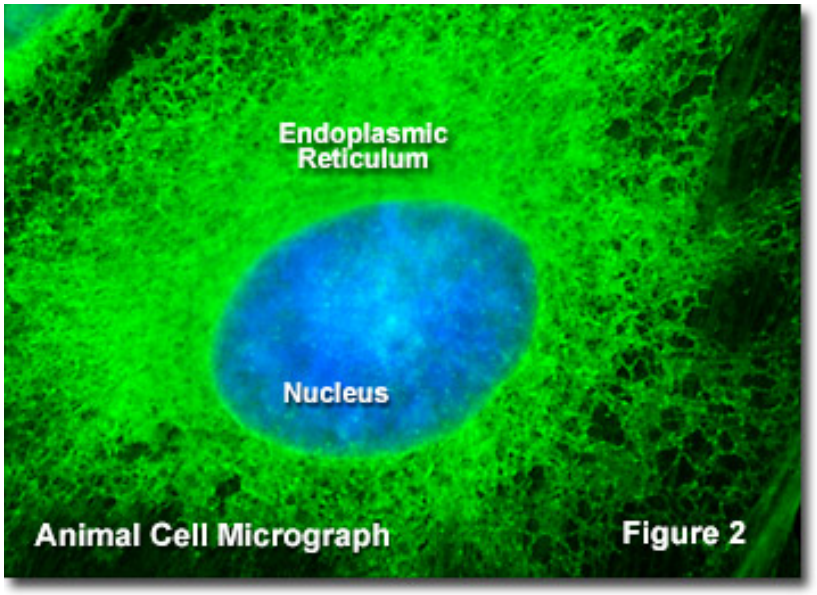
Rough surfaced endoplasmic reticulum (RER)

- involved in the synthesis of *proteins*.
- After synthesis the proteins are either stored in the cytoplasm or exported out of the cell through these channels.

Smooth surfaced endoplasmic reticulum (SER)

- Helps in metabolism of a number of different types of molecules particularly *lipids*.
- They also help to *detoxify the harmful drugs*.
- In some cells SER is responsible for transmission of impulses, e.g. muscle cells, nerve cells.
- In addition, SER also plays an important role in the transport of materials from one part of the cell to the other.
- Endoplasmic reticulum also provides mechanical support to the cell so that its shape is maintained





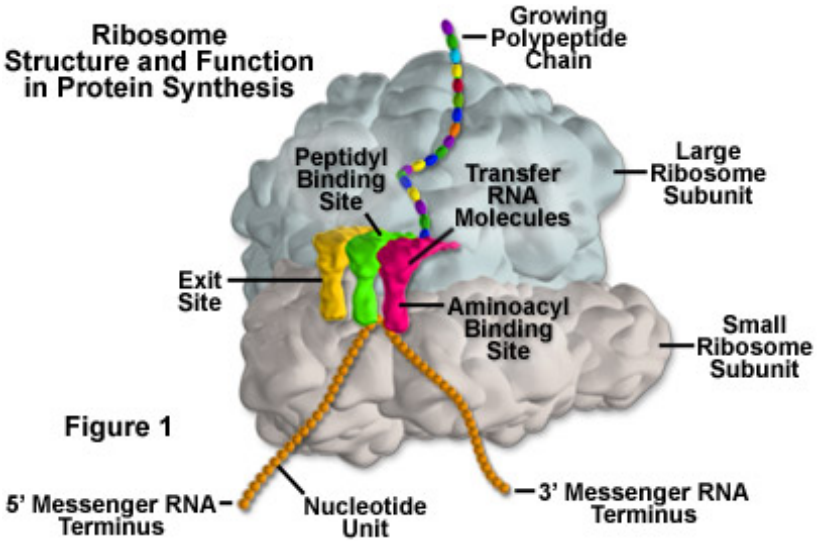
- Rough endoplasmic reticulum is marked by the presence of ribosomes attached to the membranes of endoplasmic reticulum.
- Proteins synthesized on ribosomes are pushed into channels of endoplasmic reticulum, from where they are transported to Golgi apparatus, on their way out of the cell.

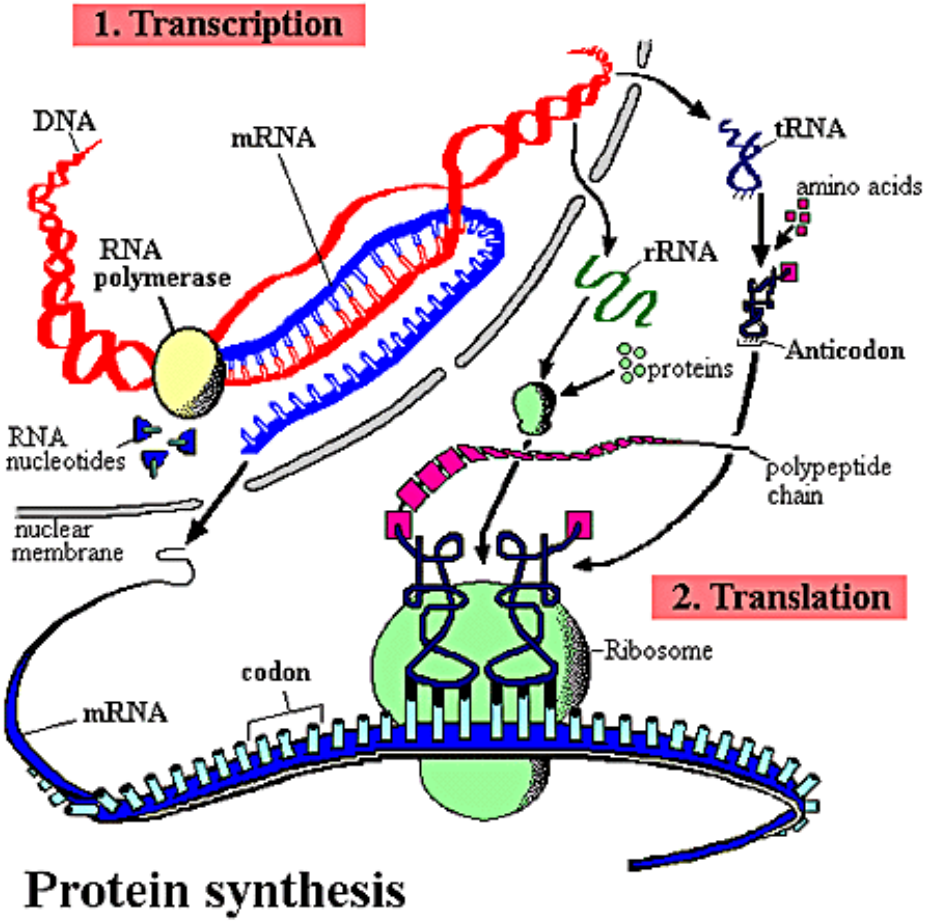
- 세포질세망 (Endoplasmic Reticulum, 소포체)
  - 막이 조밀하게 연속 형성된 소기관
  - 세포의 모든 막 구조물 절반 차지
  - 과립세포질망 (rough ER)
    - 겹쳐진 주머니 모양의 구조, 표면에 리보소체 존재
    - 단백질 합성 -> 세포내의 골지체로 수송
  - 무과립세포질세망 (smooth ER)
    - 막으로 된 것 관 모양의 망상 구조
    - 리보솜 없음, 미토콘드리아와 퍼옥시좀에 필요한 지질 합성
    - 내분비계에서 스테로이드 호르몬 합성 분비 저장
    - 위벽에서 HCl 분비
    - 간에서 해독 작용, 지질 당원질 합성
    - 평활근육세포 칼슘이온(Ca^{++}) 저장소 –근형질세망 (SR)

Ribosomes (리보오좀)

- 세포질 전체에 분포된 과립이며 소포체에 존재
- 단백질(37%)과 RNA (67%)로 구성
- 작은 구형체 (150~250 Å)
- 효소와 세포복구 및 생식에 필요한 단백질 생성에 관여
  → 아미노산으로 부터 단백질 합성 기능

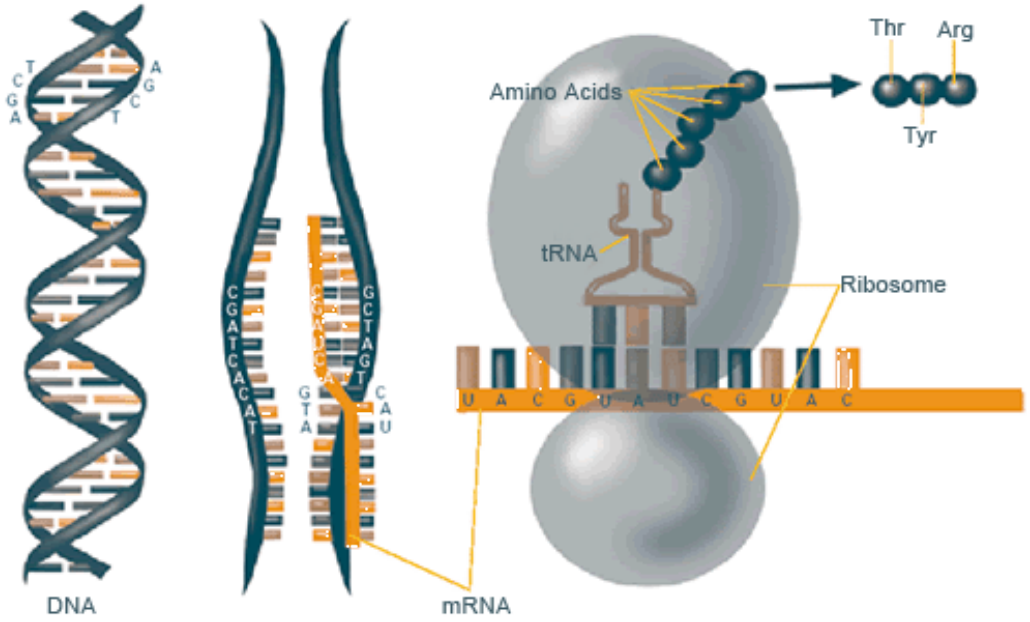
Ribosomes

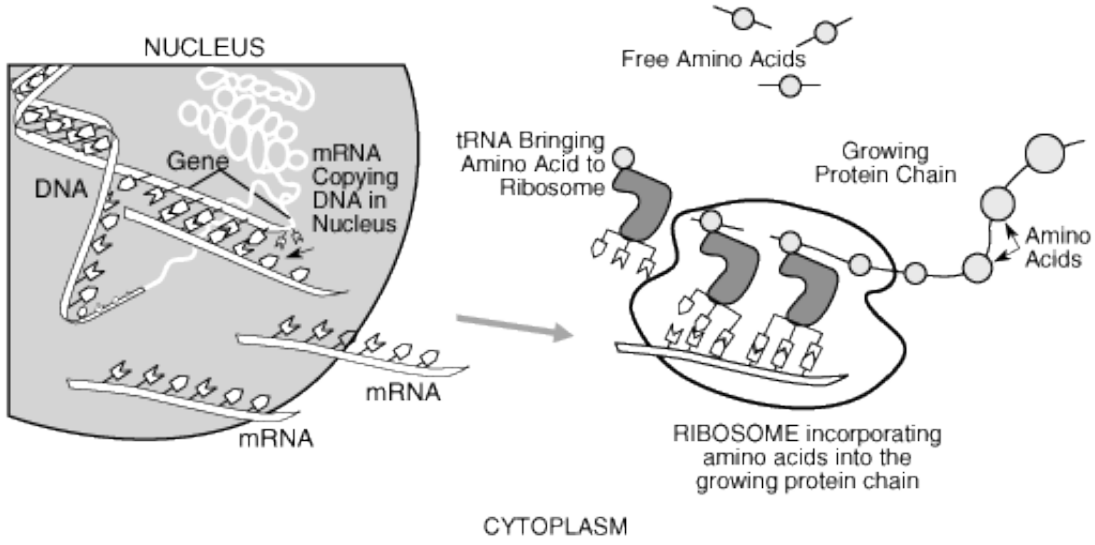


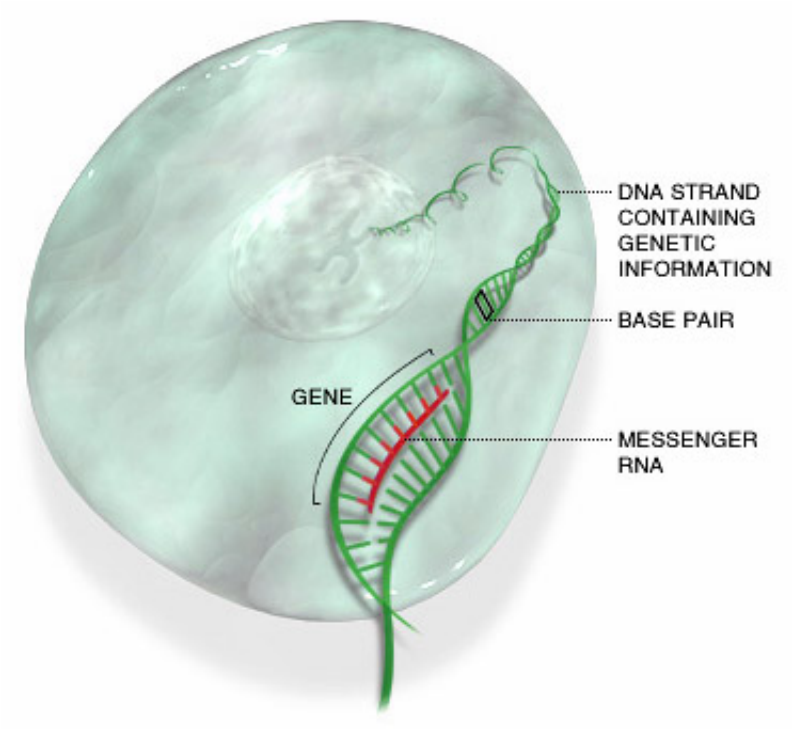


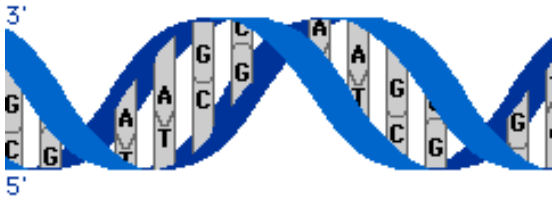
Protein synthesis

TRANSCRITION





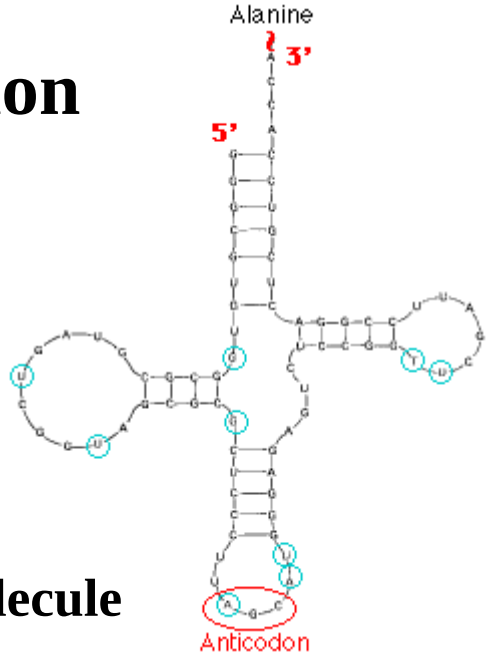




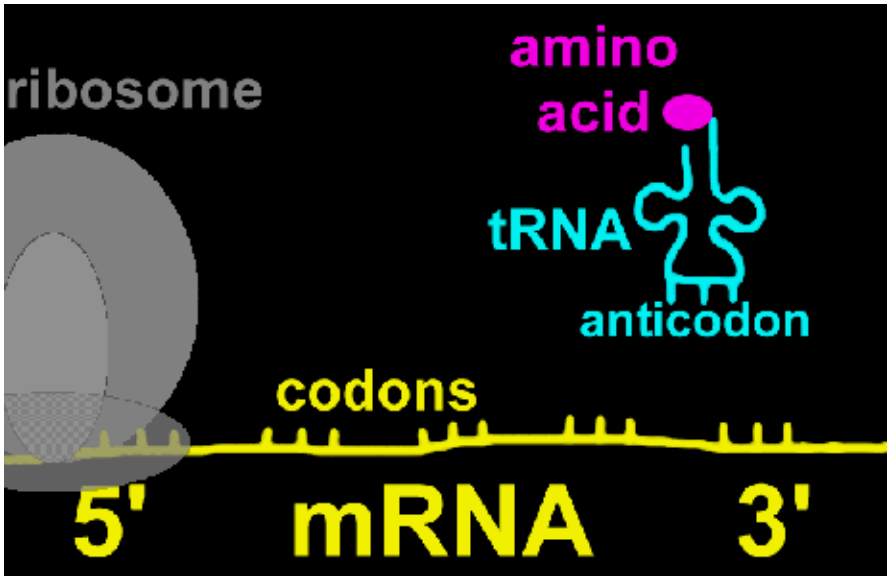
http://www.youtube.com/watch?v=ztPkv7wc3yU&feature=player_embedded

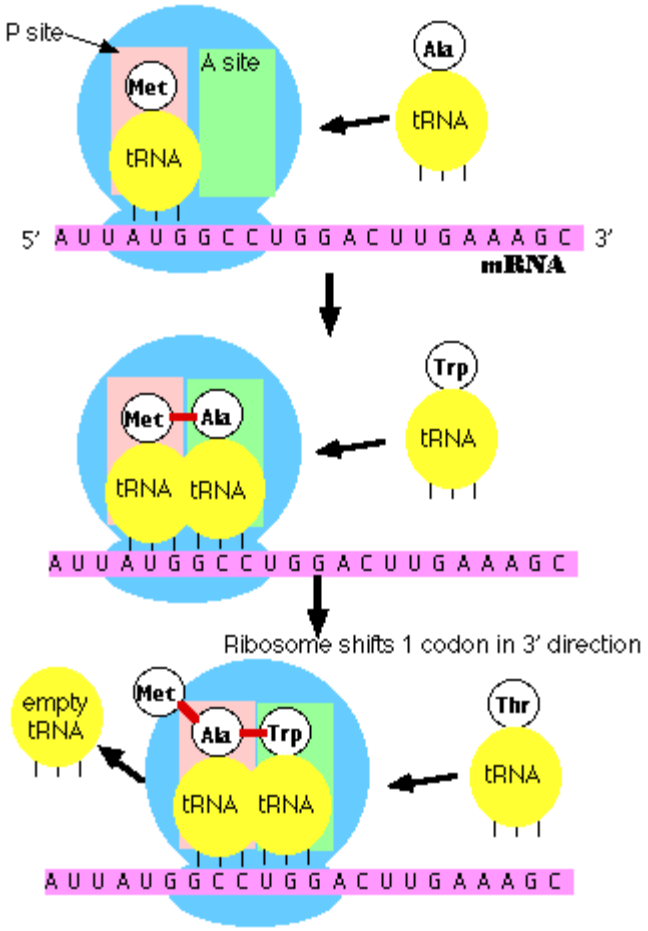
http://www.youtube.com/watch?feature=player_detailpage&v=8nQH0GqFn6k#t=37s

Translation



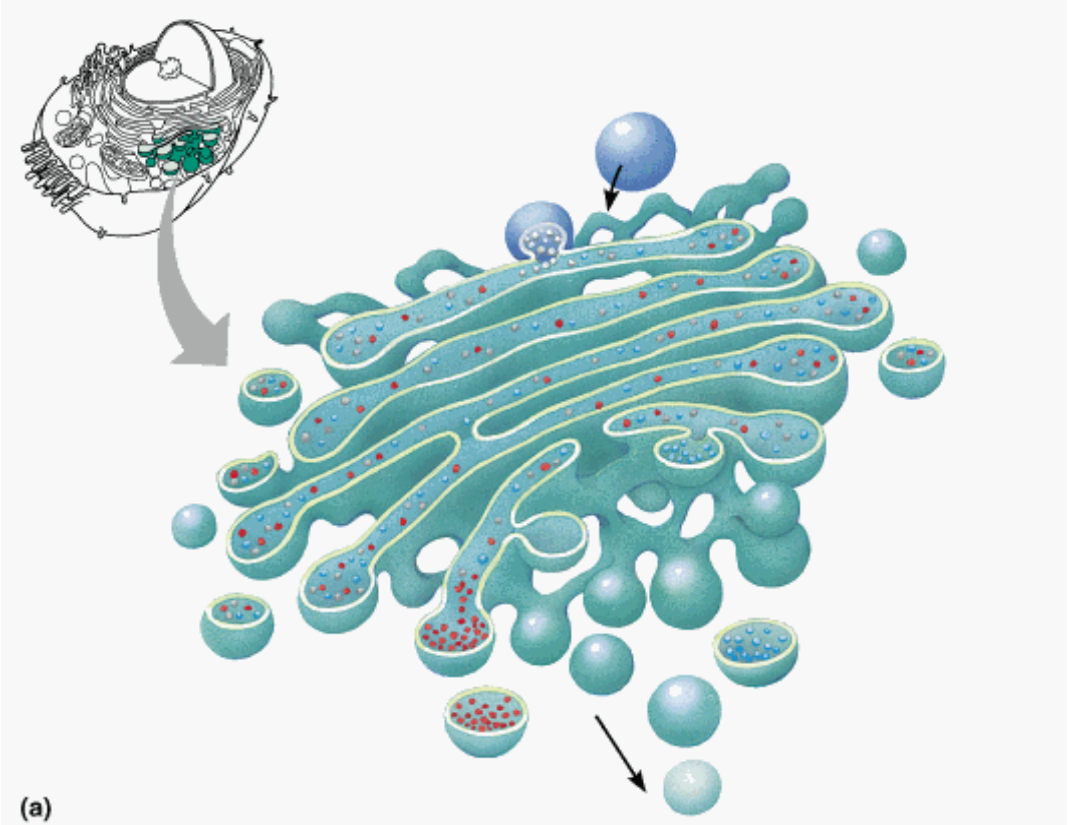
tRNA molecule



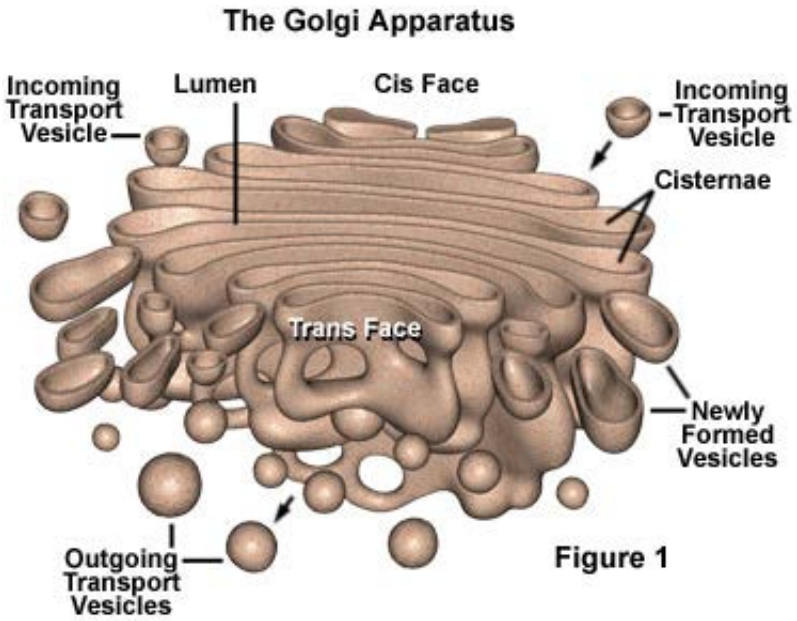


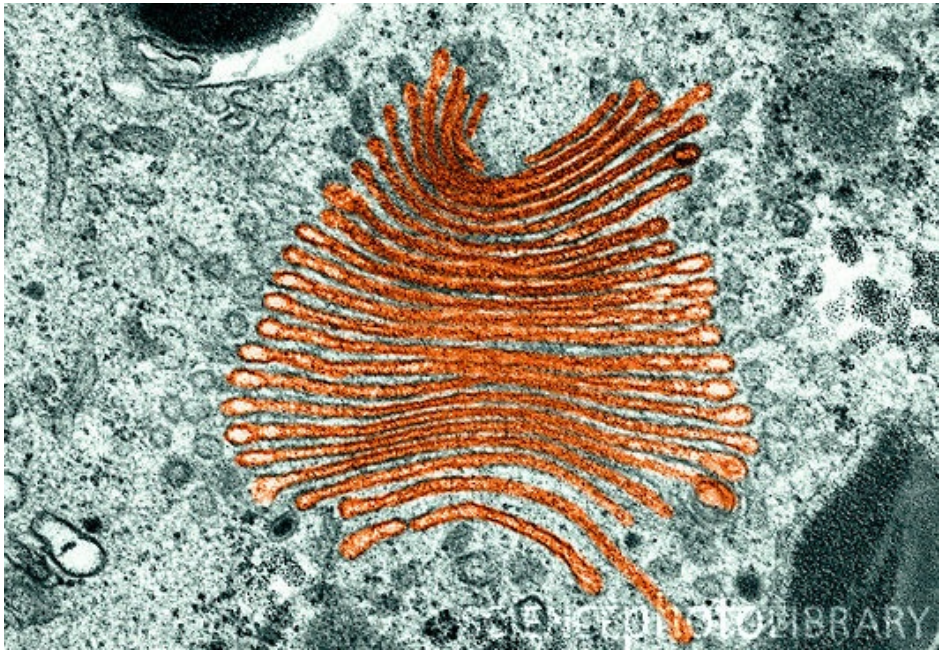
http://www.youtube.com/watch?v=B6O6uRb1D38&feature=player_embedded

Golgi apparatus

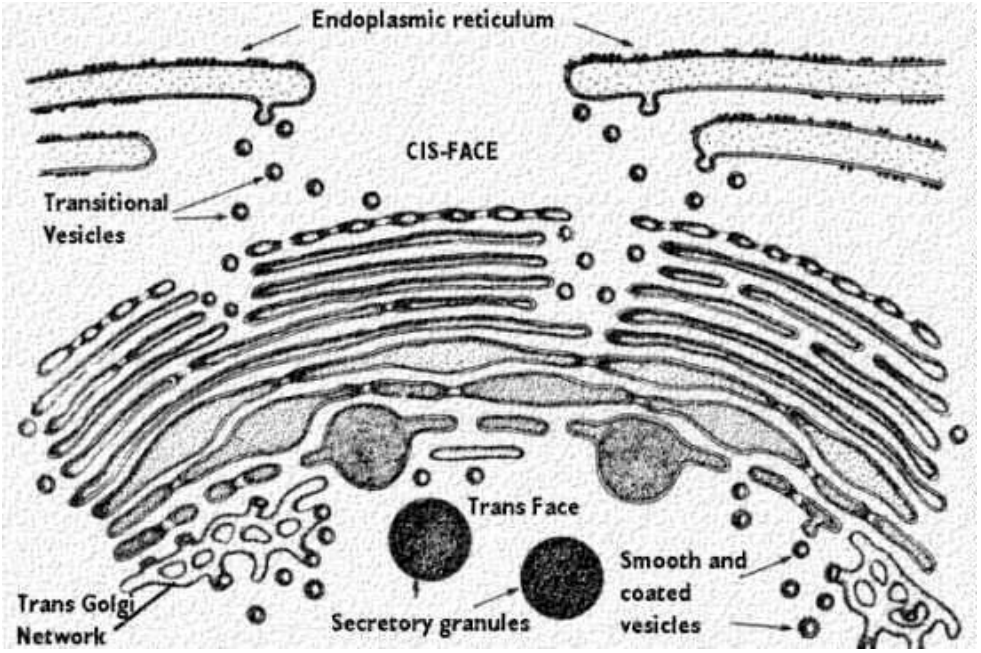


Golgi apparatus





The Golgi apparatus is integral in modifying, sorting, and packaging macromolecules for cell secretion (exocytosis) or use within the cell.



Golgi apparatus (골지체)

- 시스테나 (cisternae) (납작한 주머니가 여러 층으로 포개져 있는 것), 골지 소낭
- 소포체로부터 단백질을 전달 받아 기능에 맞는 형태로 저장
- 일부 단백질을 소낭을 이용하여 세포 밖으로 분비 (세포외 배출)
- 핵과 가깝게 존재
- 각 막층에 많은 소포(vecuole) 부착

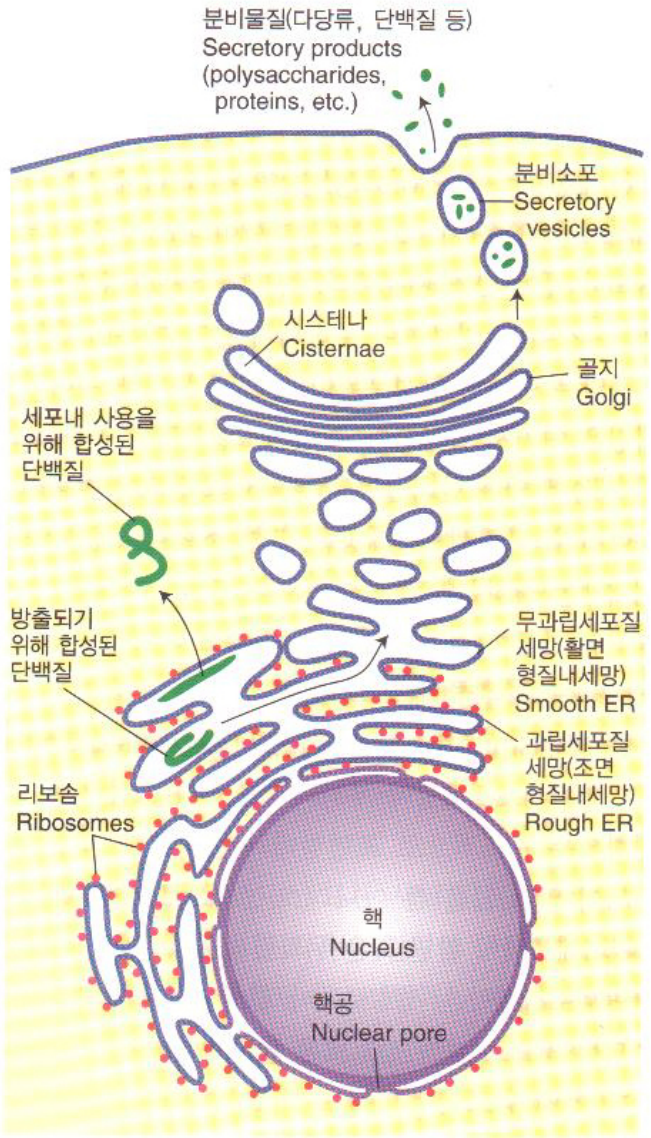
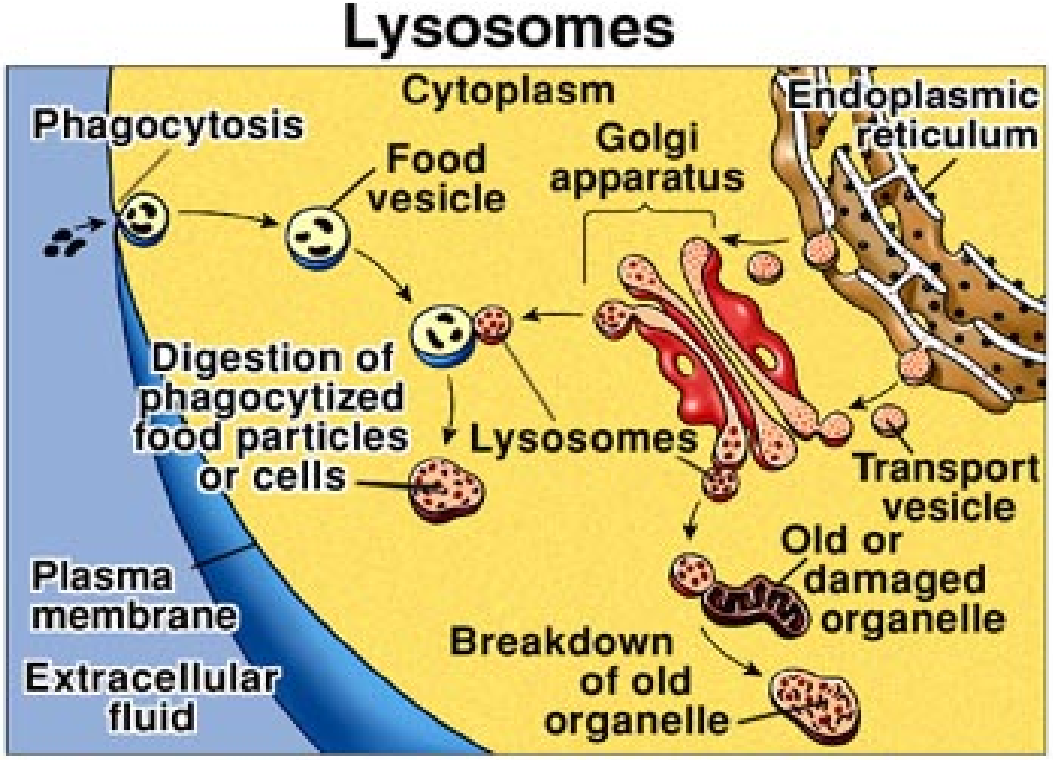


그림 3-9. 세포질세망과 골지체의 구조 및 속성

http://bcs.whfreeman.com/thelifewire/content/chp04/0402002.html

Lysosomes (용해소체) 리소좀

- 골지체에서 만들어지는 구형모양
- 단백질, 다당류, 지방 같은 고분자를 세포 내로 취해 소화시킴
- 단층의 인지질 막
- 가수분해 효소 포함 → 세포속 손상 or 노화 세포 소기관 분해
- 백혈구에 많음



http://highered.mcgraw-hill.com/olc/dl/120067/bio01.swf

Peroxisome (퍼옥시좀)

- 간과 신장의 세포에 많이 존재하는 용해소체
- 0.4~1.3㎛ 정도의 직경, 내부 격자모양의 과립이 존재
  - 산화효소가 과산화수소 생성
  - 과산화수소는 백혈구 내에서 살균작용, 지질대사에 관여하는 효소 등에 함유
  - catalase 과산화수소를 물과 산소로 분해

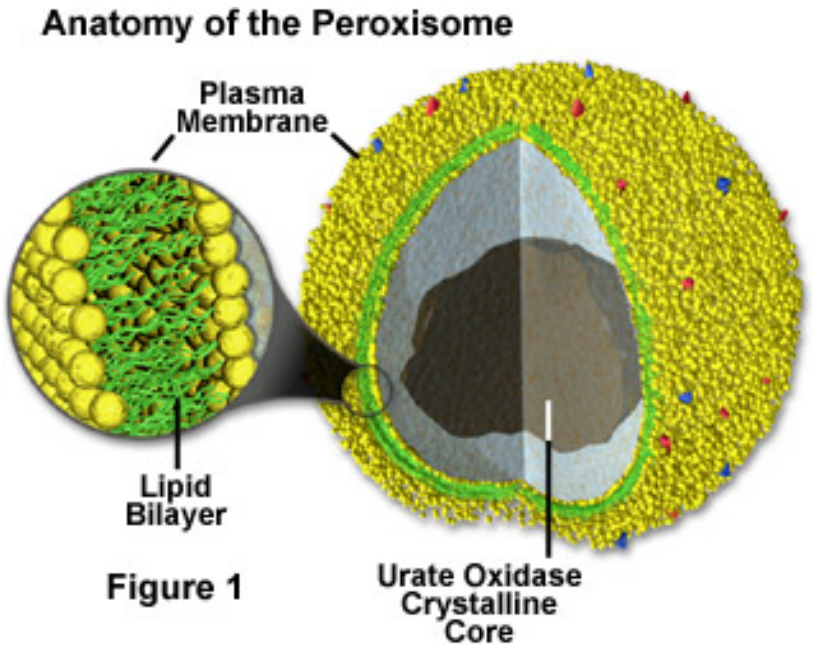


Figure 1

Summary

Centrioles - Centrioles are self-replicating organelles made up of nine bundles of microtubules and are found only in animal cells. They appear to help in organizing cell division, but aren't essential to the process.

Cilia and Flagella - For single-celled eukaryotes, cilia and flagella are essential for the locomotion of individual organisms. In multicellular organisms, cilia function to move fluid or materials past an immobile cell as well as moving a cell or group of cells.

Endoplasmic Reticulum - The endoplasmic reticulum is a network of sacs that manufactures, processes, and transports chemical compounds for use inside and outside of the cell. It is connected to the double-layered nuclear envelope, providing a pipeline between the nucleus and the cytoplasm.

Endosomes and Endocytosis - Endosomes are membrane-bound vesicles, formed via a complex family of processes collectively known as **endocytosis**, and found in the cytoplasm of virtually every animal cell. The basic mechanism of endocytosis is the reverse of what occurs during exocytosis or cellular secretion. It involves the invagination (folding inward) of a cell's plasma membrane to surround macromolecules or other matter diffusing through the extracellular fluid.

Golgi Apparatus - The Golgi apparatus is the distribution and shipping department for the cell's chemical products. It modifies proteins and fats built in the endoplasmic reticulum and prepares them for export to the outside of the cell.

Summary

Intermediate Filaments - Intermediate filaments are a very broad class of fibrous proteins that play an important role as both structural and functional elements of the cytoskeleton. Ranging in size from 8 to 12 nanometers, intermediate filaments function as tension-bearing elements to help maintain cell shape and rigidity.
Lysosomes - The main function of these microbodies is digestion. Lysosomes break down cellular waste products and debris from outside the cell into simple compounds, which are transferred to the cytoplasm as new cell-building materials.
Microfilaments - Microfilaments are solid rods made of globular proteins called actin. These filaments are primarily structural in function and are an important component of the cytoskeleton.
Microtubules - These straight, hollow cylinders are found throughout the cytoplasm of all eukaryotic cells (prokaryotes don't have them) and carry out a variety of functions, ranging from transport to structural support.
Mitochondria - Mitochondria are oblong shaped organelles that are found in the cytoplasm of every eukaryotic cell. In the animal cell, they are the main power generators, converting oxygen and nutrients into energy.
Nucleus - The nucleus is a highly specialized organelle that serves as the information processing and administrative center of the cell. This organelle has two major functions: it stores the cell's hereditary material, or DNA, and it coordinates the cell's activities, which include growth, intermediary metabolism, protein synthesis, and reproduction (cell division).

Summary

Peroxisomes - Microbodies are a diverse group of organelles that are found in the cytoplasm, roughly spherical and bound by a single membrane. There are several types of microbodies but peroxisomes are the most common.

Plasma Membrane - All living cells have a plasma membrane that encloses their contents. In prokaryotes, the membrane is the inner layer of protection surrounded by a rigid cell wall. Eukaryotic animal cells have only the membrane to contain and protect their contents. These membranes also regulate the passage of molecules in and out of the cells.

Ribosomes - All living cells contain ribosomes, tiny organelles composed of approximately 60 percent RNA and 40 percent protein. In eukaryotes, ribosomes are made of four strands of RNA. In prokaryotes, they consist of three strands of RNA.

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