

Biol 266 - Cell Biology

UNIT 1

"Cells and Organelles - I"

What is "cell biology" anyway?

The study of cells and their structure, function and behaviour

Requires creative instruments and techniques

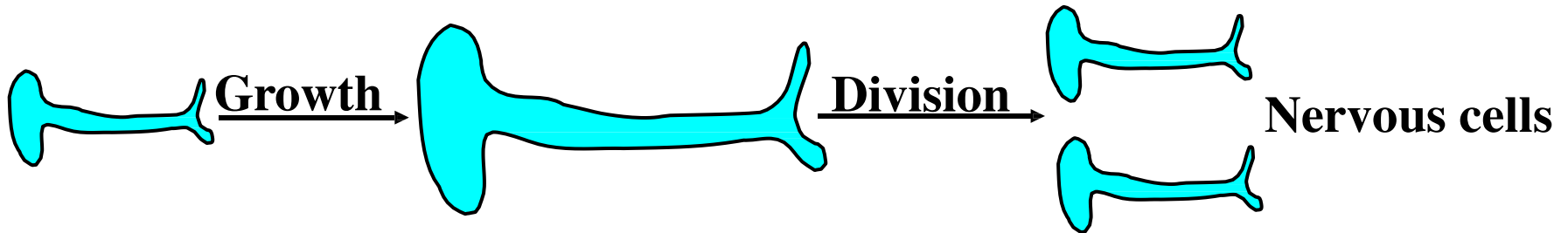
Reductionist - studying the parts can explain the whole

Cell biology as a reductionist science

The cell = the fundamental unit of life,
arises from pre-existing cell

Cells are the smallest units exhibiting the characteristics of **LIFE**

they are able to reproduce themselves by their own efforts



Organelles are NOT the smallest units exhibiting the characteristics of life

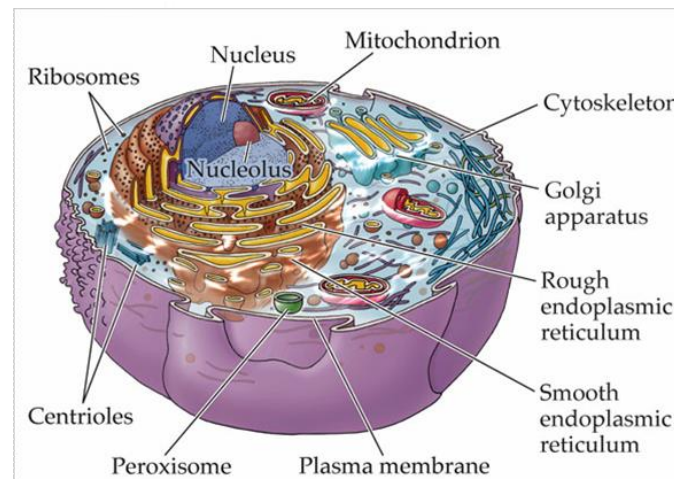
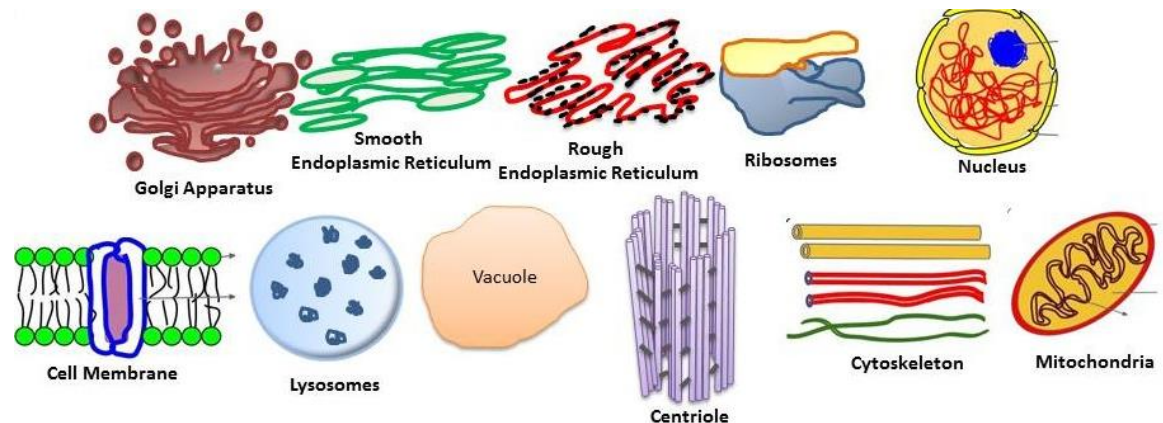
they are NOT able to reproduce themselves by their own efforts outside of the host cell

Organelle = specialized structure in a cell that performs a specific function

Living cell is when they can divide themselves.

Not living cells:

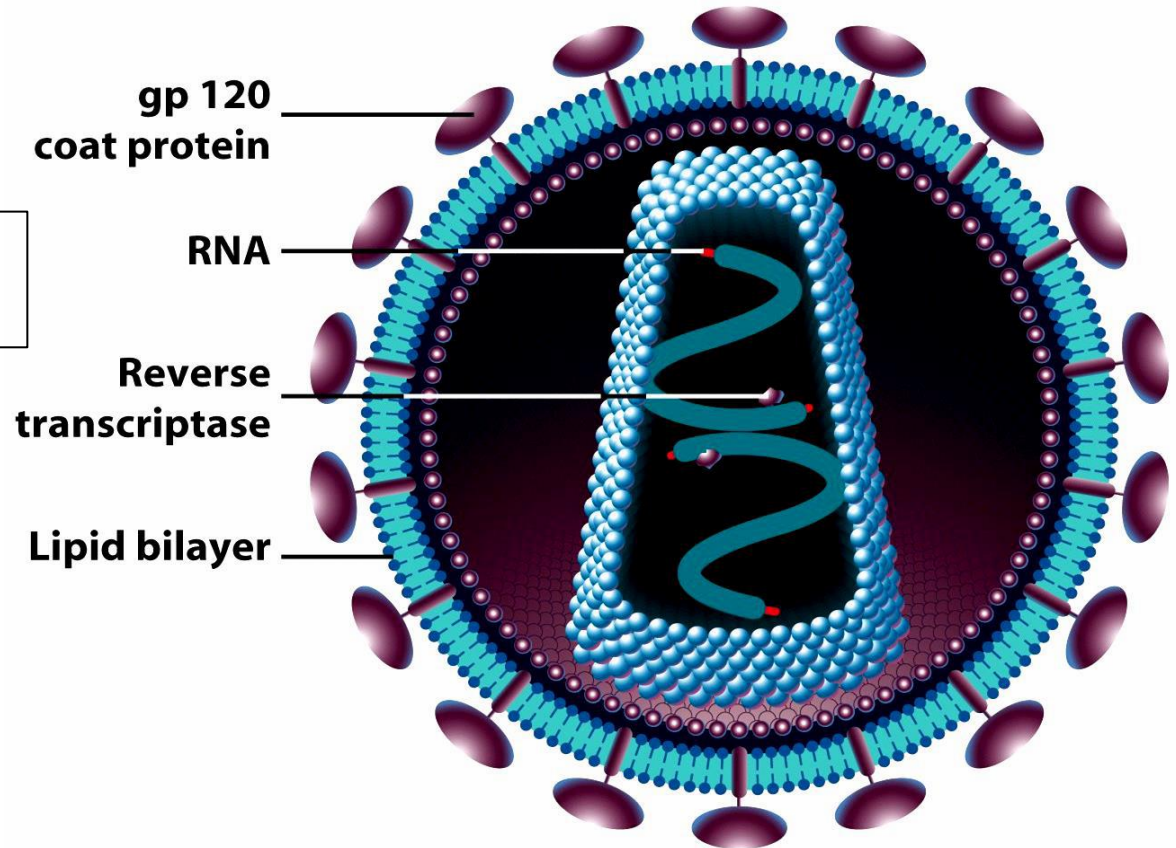
- Golgi can't divide
- Organelles can't divide
- Viruses



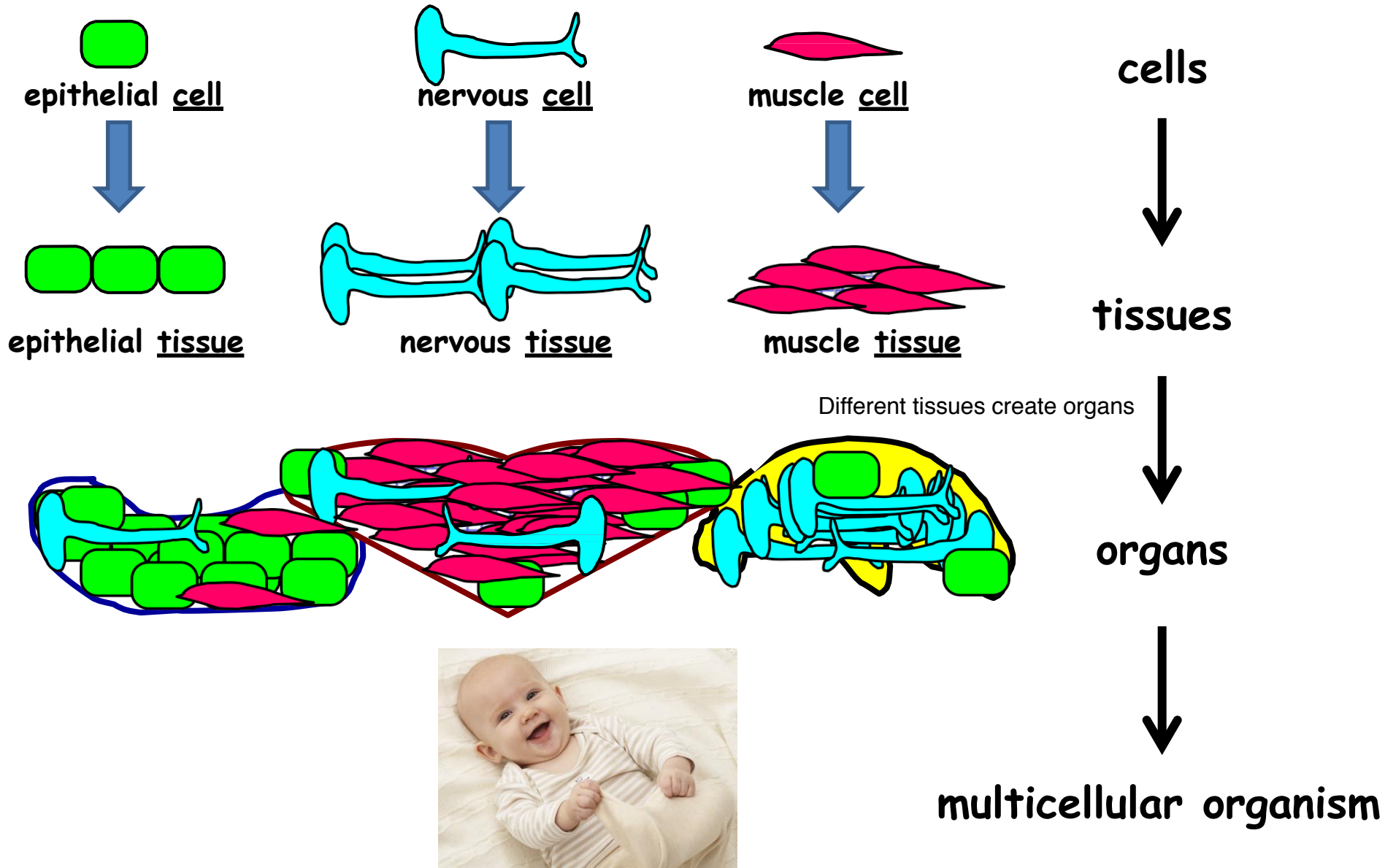
Viruses are NOT the smallest units exhibiting the characteristics of life

they are NOT able to reproduce themselves by their own efforts; they use the host reproductive machinery

Human Immunodeficiency
Virus (HIV)

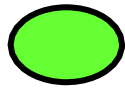


The cell is the fundamental unit of life, the building block from which all organisms are constructed



Cells are small: typically 5 - 20 μm (0.005 - 0.02 mm) in diameter

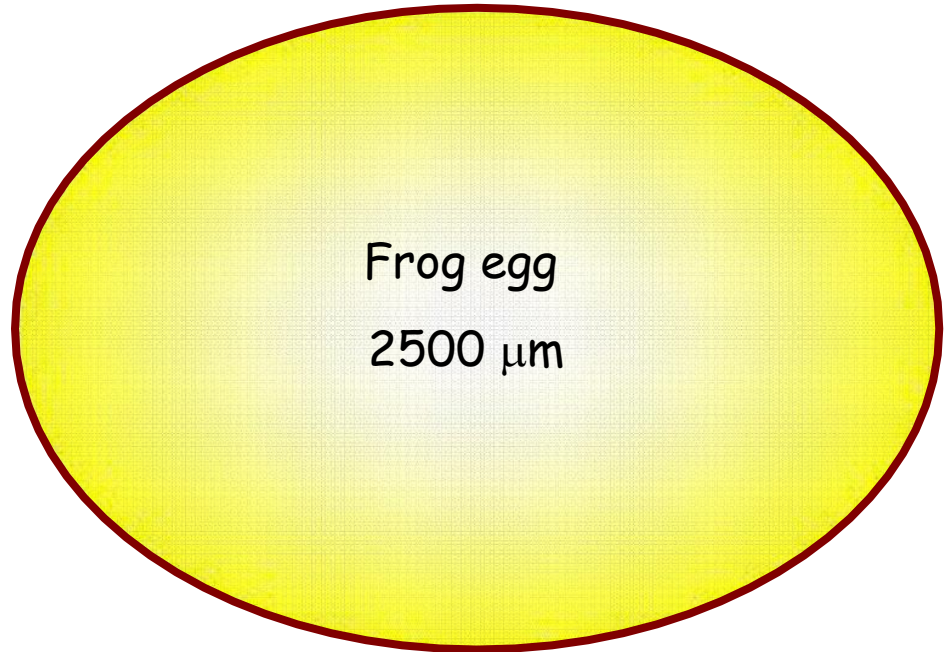
bacterium



1 μm

Frog egg

2500 μm



Most cells are invisible to the naked eye, so scientists did not know of their existence prior to the invention of the light microscope in the 17th century

Robert Hooke's light microscope, 1665, later refined by Anton Leewenhoek

A thin slice of cork, showing the network of pores

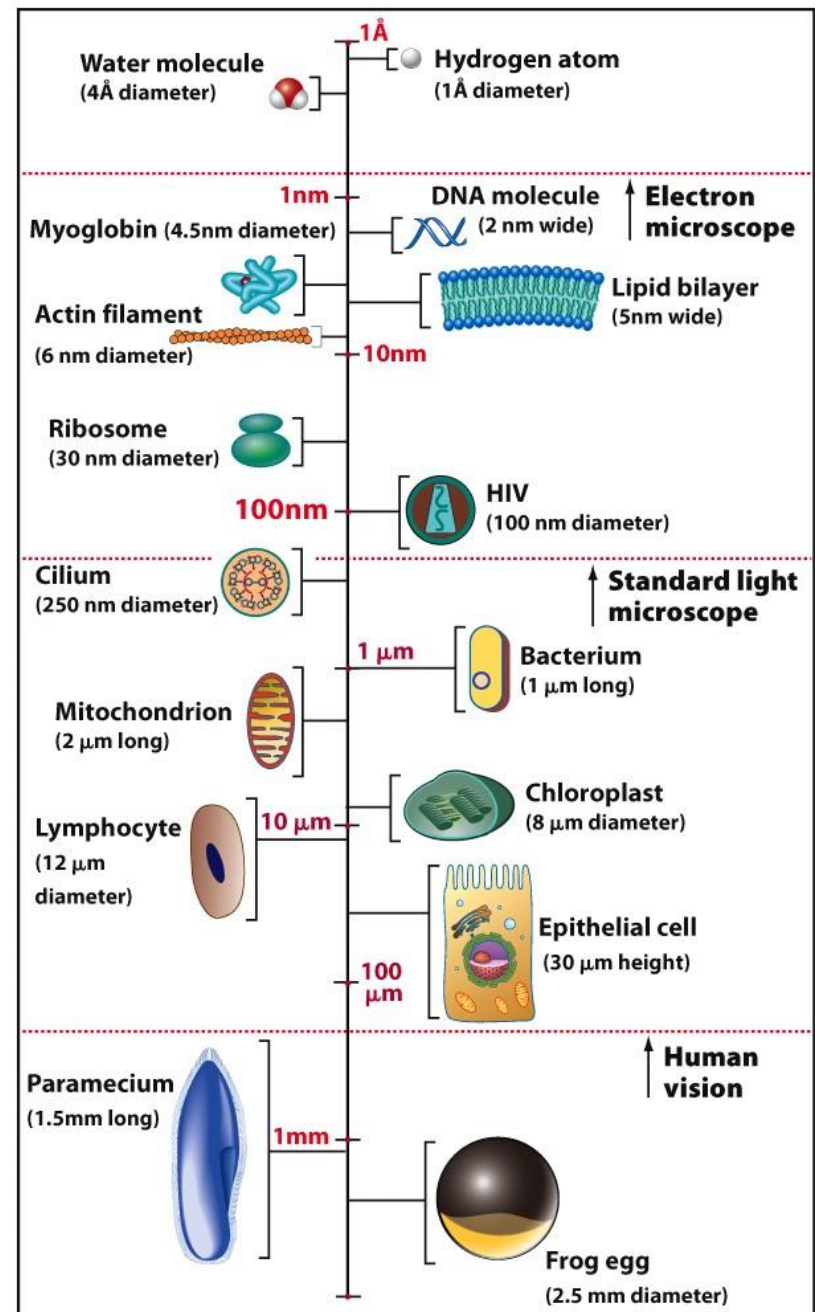
Hooke called the pores *cells* (from the Latin *cellula* meaning "small room") because they reminded him of the small rooms inhabited by monks living in a monastery



Relative sizes of cells and cell components, and the units in which they are measured

** review meter system small

$$1 \text{ m} = 10^6 \mu\text{m} = 10^9 \text{ nm} \\ = 10^{10} \text{ angstrom } (\text{\AA})$$

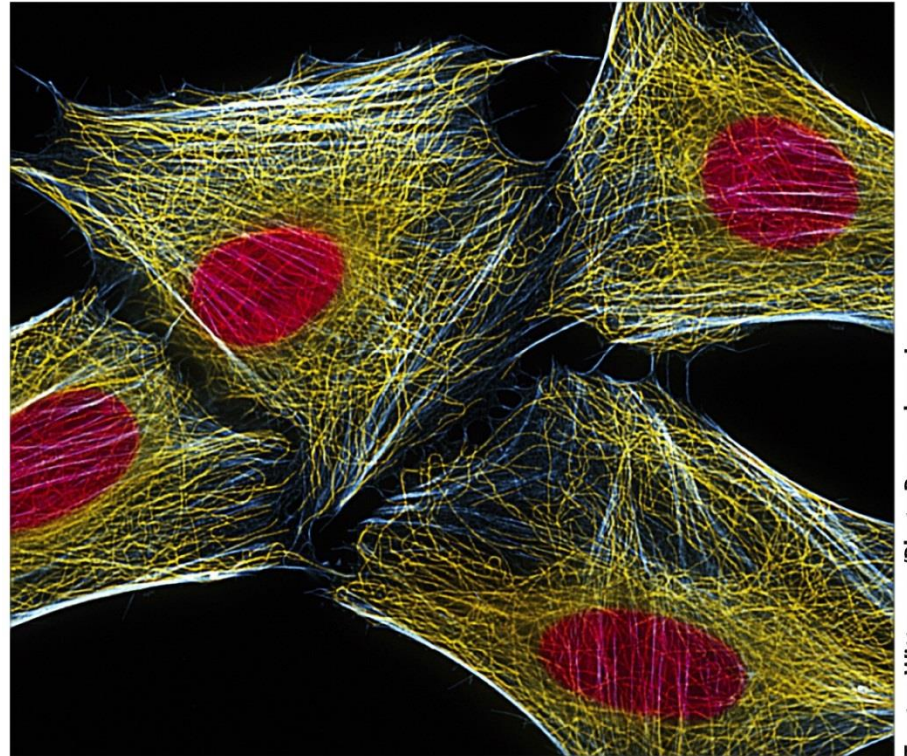


Basic Properties of Cells

1. Life is the most basic property of cells.

Cells can **grow** and **reproduce** in culture for extended periods.

- HeLa cells are cultured tumor cells isolated from a cancer patient (Henrietta Lacks) by George Gey in 1951.
- Cultured cells are an essential tool for cell biologists.



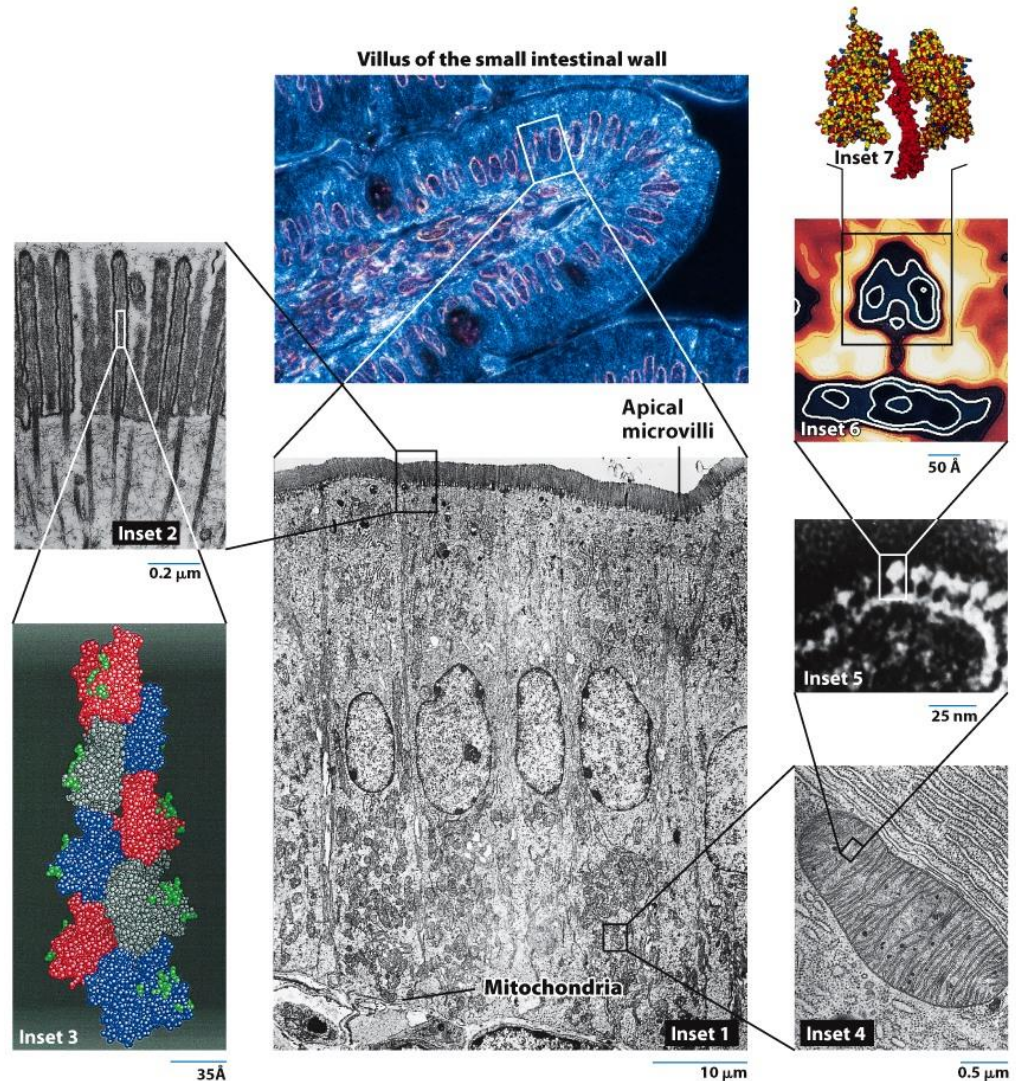
Torsten Wittmann/Photo Researchers, Inc.

HeLa: first human cells for extended culturing

Basic Properties of Cells

2. Cells are highly complex and organized

- Cellular processes are highly regulated.
- Cells from different species share similar structure, composition and metabolic features that have been conserved throughout evolution.



Levels of cellular and molecular organization

Basic Properties of Cells

3. Cells possess a **genetic program** and the means to use it
- Genes encode information to build each cell, and the organism.
 - Genes encode information for cellular reproduction, activity, and structure.

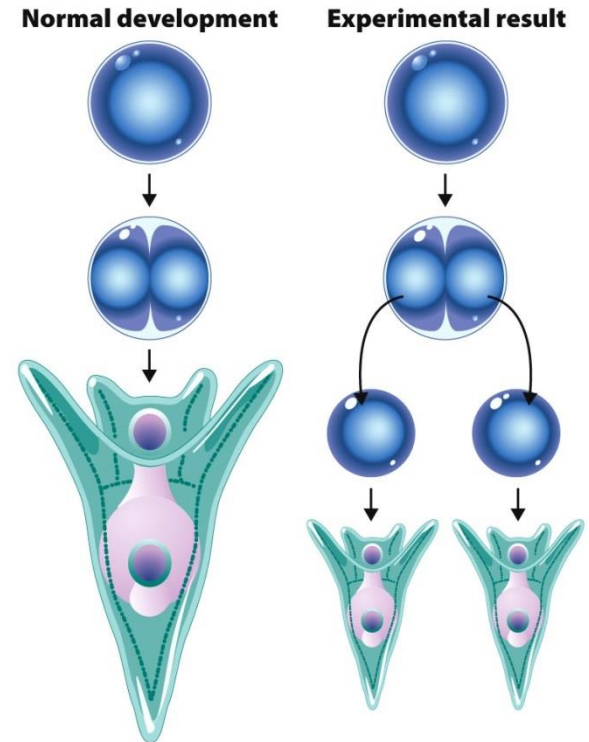
blood cell don't have a nucleous

4. Cells are **capable of producing more of themselves**
- Cells reproduce, and each daughter cell receives a complete set of genetic instructions.
5. Cells **acquire and utilize energy**
- Photosynthesis provides fuel for all living organisms.
 - Animal cells derive energy from the products of photosynthesis, mainly in the form of glucose.
 - Cell can convert glucose into ATP—a substance with readily available energy.

Basic Properties of Cells

6. Cells carry out a variety of **chemical reactions**, the sum of which is called **metabolism**
7. Cells engage in **mechanical activities**
8. Cells are able to **respond to stimuli**
9. Cells are capable of **self-regulation**
10. Cells **evolve**

adjusting to their environment = evolve



Self-regulated development in the sea urchin during normal (L) and cell separation experiments (R)

Two types of cells

- **Prokaryotic and eukaryotic** - distinguished by their size and type of organelles.
- **Prokaryotes** are all bacteria, which arose ~3.7 billion years ago. bacterias
- **Eukaryotes** include protists, animals, plants and fungi. more parts; more organised

All cells contain **DNA** (deoxyribonucleic acid) as a store of genetic information

Prokaryotic cells

- > From the Greek words *pro*, meaning "before", and *karyon*, meaning "nucleus"
- > DNA **is not segregated** within a defined nucleus

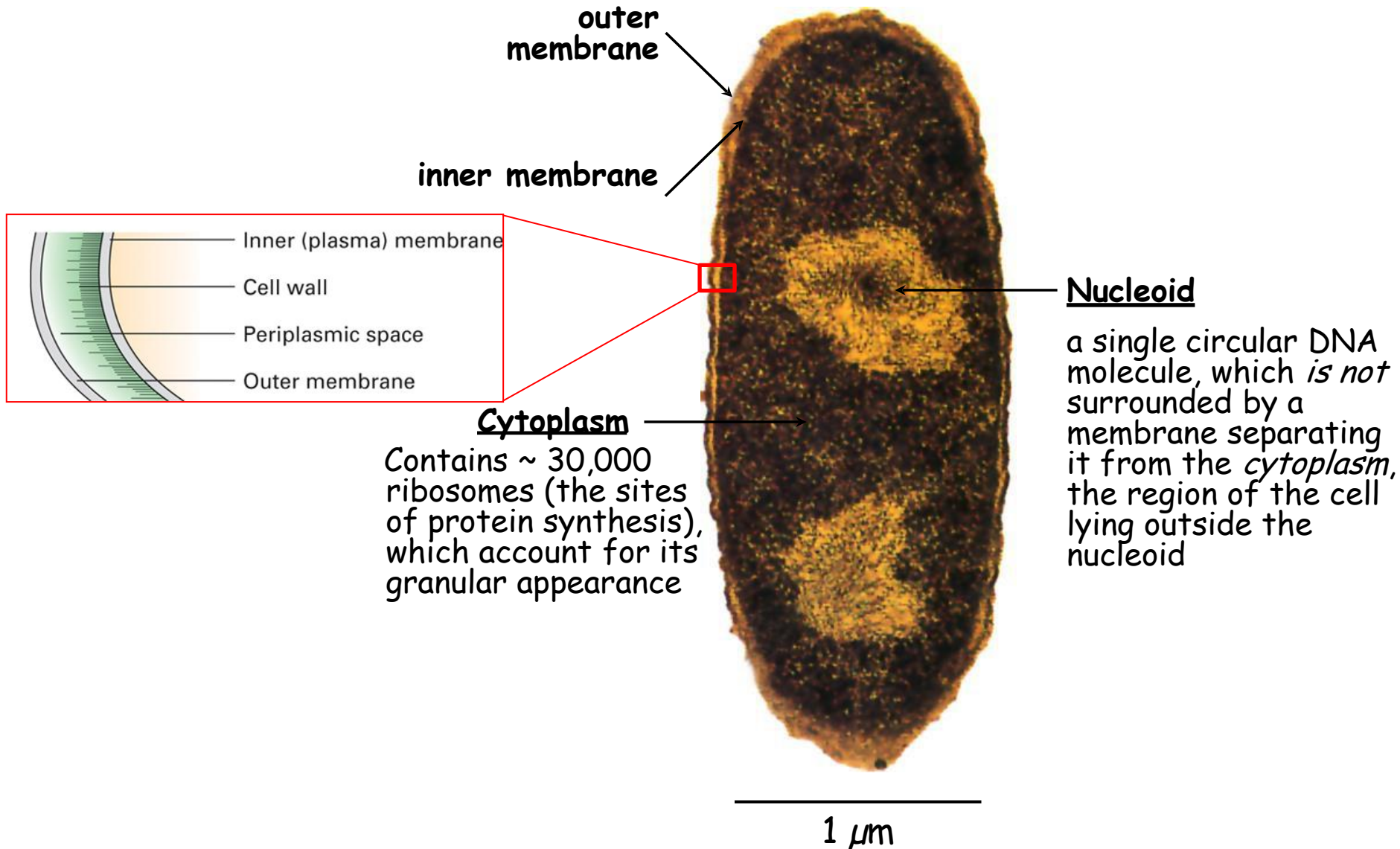
NO
NUCLEUS

Eukaryotic cells

- > From the Greek words *eu*, meaning "truly" or "well", and *karyon*, meaning "nucleus"
- > DNA **is segregated** within a defined nucleus

NUCLEUS

Prokaryotes comprise a single membrane-limited compartment



Electron micrograph of a typical prokaryotic cell, the bacterium, *Escherichia coli*

Common features of prokaryotic and eukaryotic cells

- Plasma membrane of similar construction
- Genetic information in DNA, using identical genetic code
- Both store chemical energy in the form of ATP
- Shared metabolic pathways (glycolysis, TCA cycle)
- Proteasomes (for protein degradation) of similar construction

Features of eukaryotic cells not found in prokaryotic cells

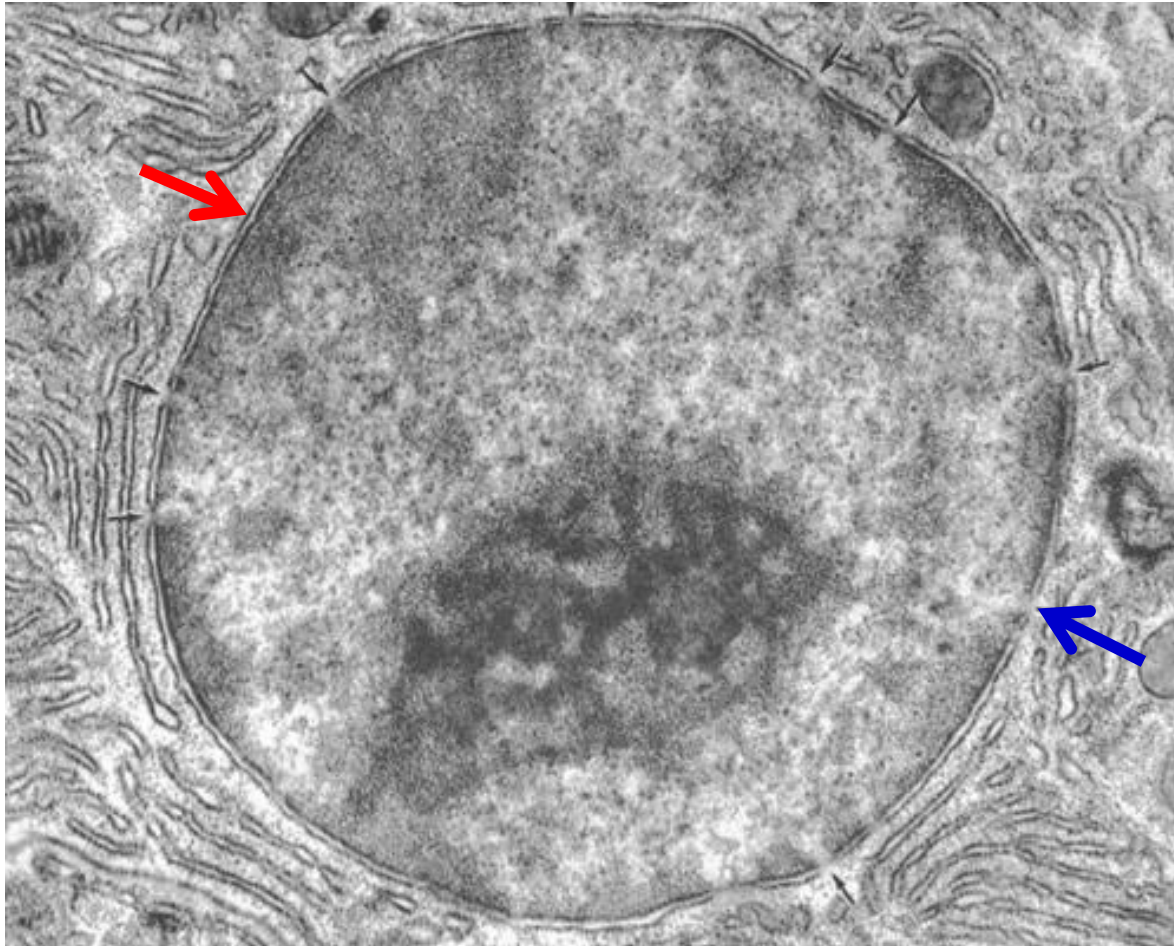
- Nuclear envelope, separating nucleus from cytoplasm
- Complex chromosomes that compact into mitotic structures
- Membrane-bound cytoplasmic organelles
- Cytoskeleton with associated motor proteins

Characteristics that distinguish prokaryotic and eukaryotic cells

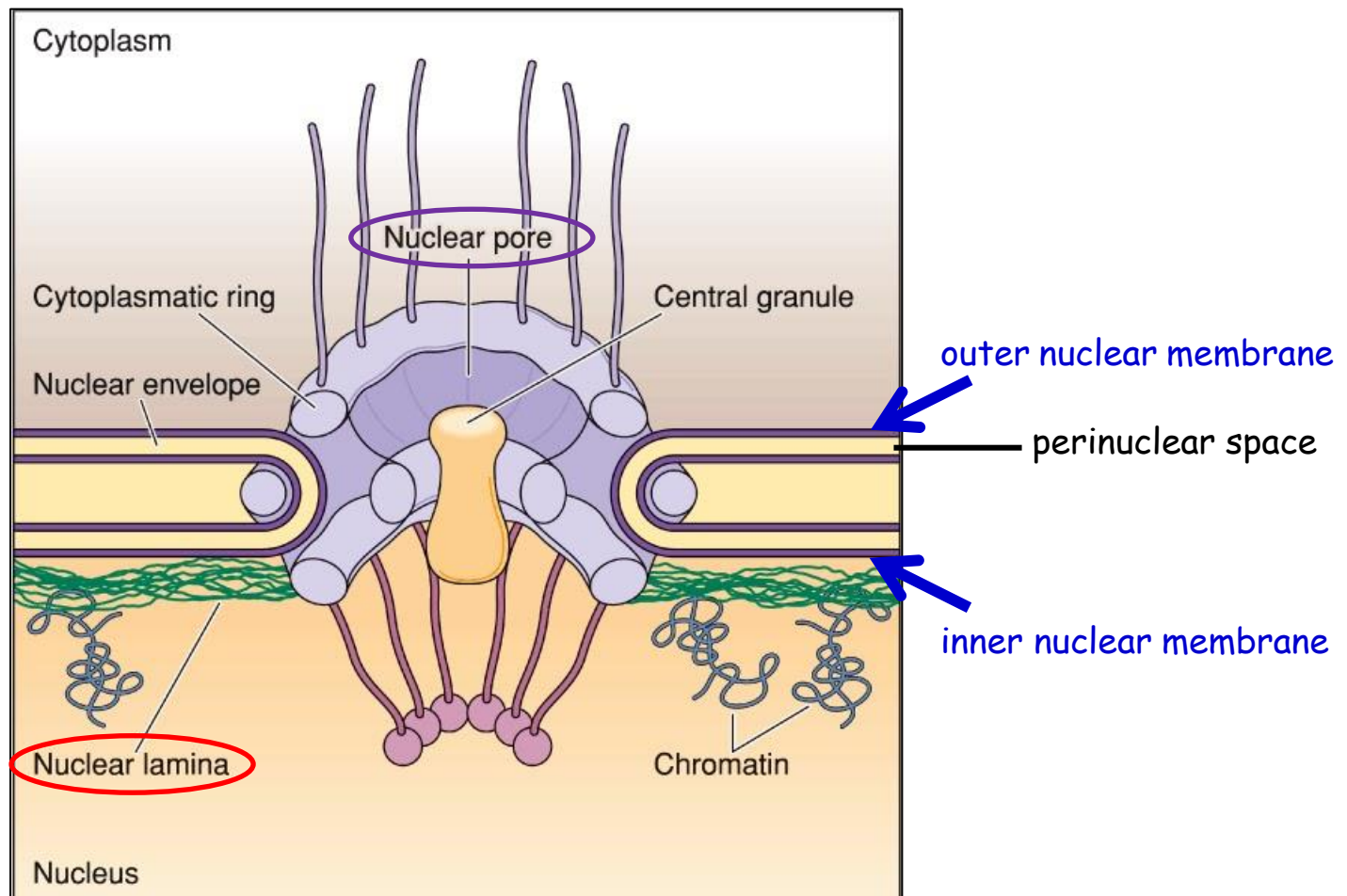
- **Complexity:** Prokaryotes are relatively simple; eukaryotes are more complex in structure and function.
- **Cellular reproduction:** Eukaryotes divide by mitosis; prokaryotes divide by simple fission.
- **Genetic material:**
 - *Packaging:* Prokaryotes have a nucleoid region whereas eukaryotes have a membrane-bound nucleus.
 - *Amount:* Eukaryotes have much more genetic material than prokaryotes.
 - *Form:* Eukaryotes have many chromosomes made of both DNA and protein (**histones**) whereas prokaryotes have a single, circular DNA with no histone proteins.

The *nucleus* is the information store of the cell

The nucleus contains molecules of *DNA* (deoxyribonucleic acid) - extremely long polymers that encode the genetic specification of the organism

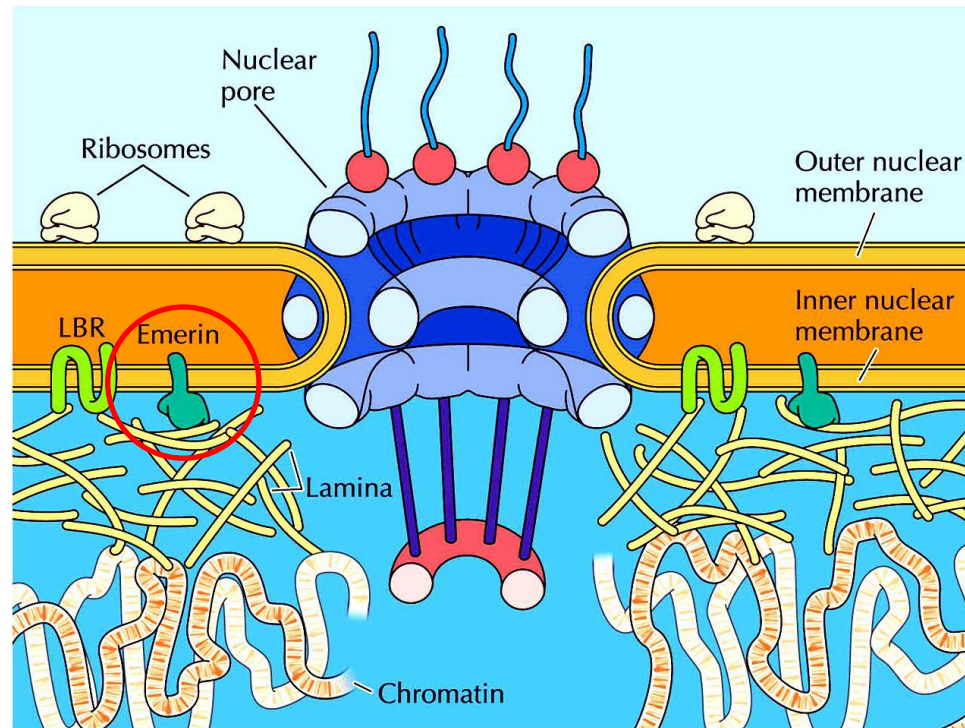


- The nucleus is surrounded by a **double membrane**, called the nuclear envelope
- The nucleus communicates with the cytosol via **nuclear pores** that perforate the envelope



The *nuclear envelope* consists of:

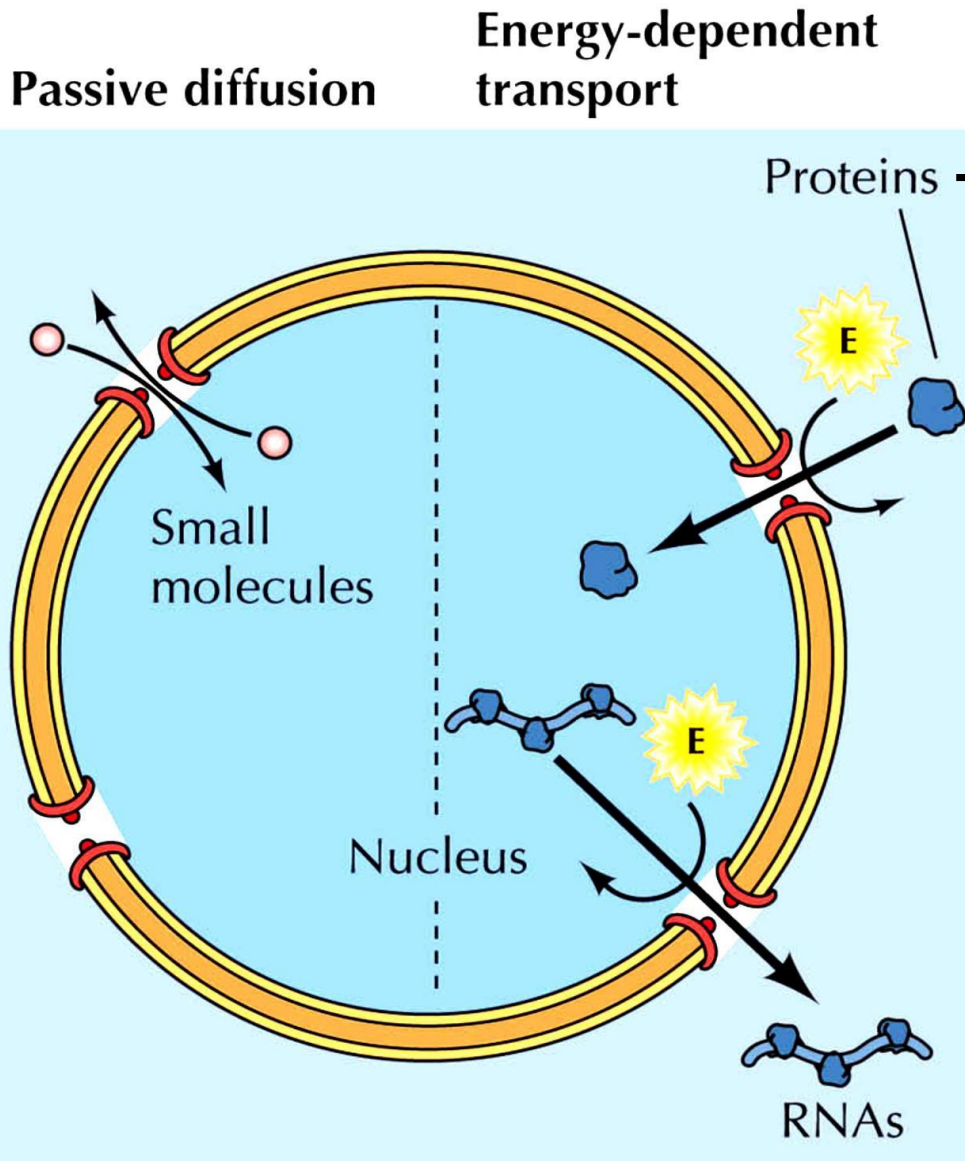
- Two concentric membranes, called the **inner and outer nuclear membranes**
- The **nuclear lamina**, a fibrous network that provides structural support to the nucleus
- The **nuclear pore complexes**, the only channels through which molecules are able to travel between the nucleus and the cytoplasm



The nuclear lamina

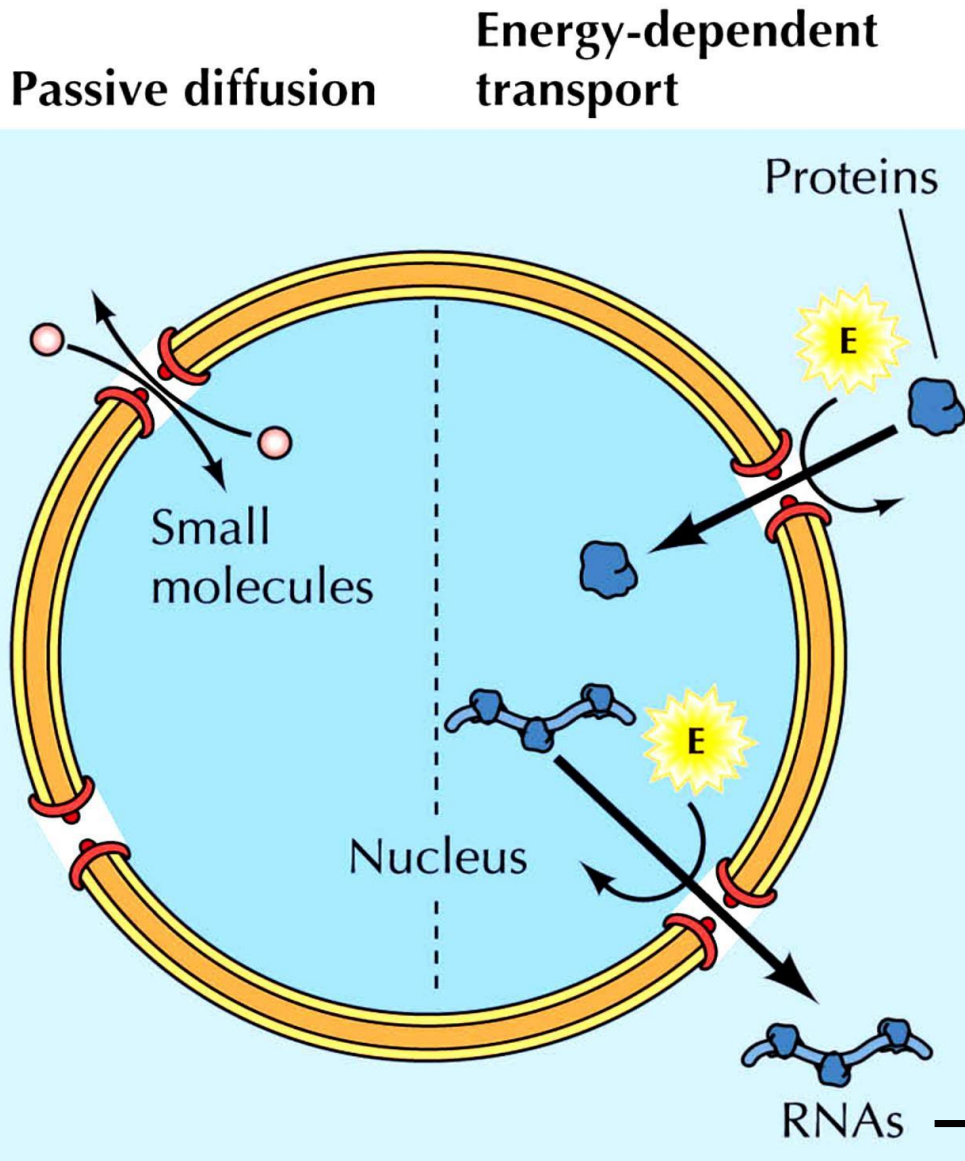
- Supports the nuclear envelope, composed of lamins.
- Integrity of nuclear lamina regulated by phosphorylation/dephosphorylation.
- Human conditions: lamin A/C mutation causes Hutchinson-Gilford Progeria syndrome, lamin B mutation causes leukodystrophy (loss of myelin)
- Mutations in lamin binding protein **emerin** cause Emery-Dreifuss muscular dystrophy (elbows, neck and heels become stiff, heart problems)
 proteins have other functions in other pathways.
 cells could also have other functions than the *main* one its called for

Traffic through nuclear pore complexes (NPCs)



- Proteins →
1. DNA-binding proteins:
- histones, nonhistone proteins, activators and repressors of transcription
 2. Messenger RNA (mRNA)-binding proteins
 3. Components of the nucleus (lamins)
 4. Ribosomal proteins
 5. Shuttling nuclear transport receptors (importins): deliver other proteins to the nucleus
- RNAs

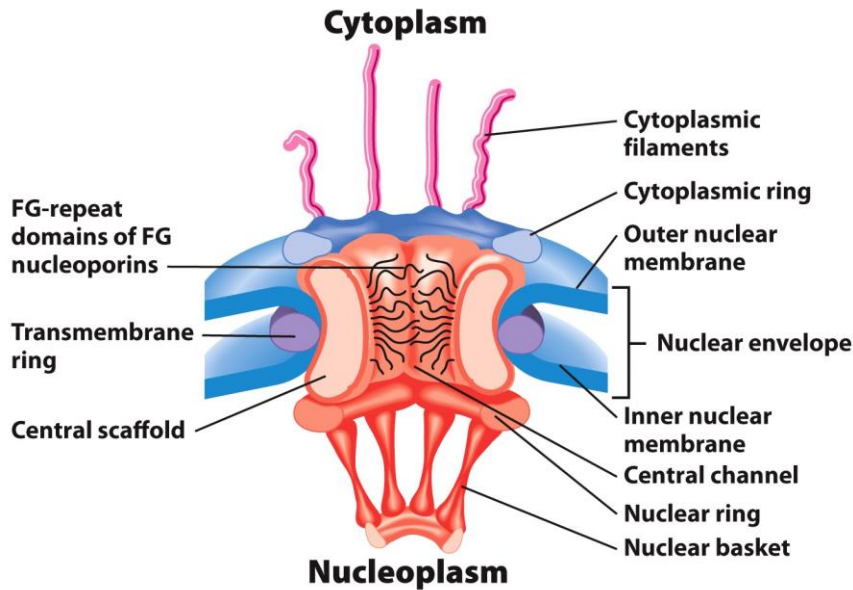
Traffic through nuclear pore complexes (NPCs)



1. mRNAs (together with mRNA-binding proteins)
2. tRNAs (transport RNAs)
3. 40S and 60S ribosomal subunits (complexes of ribosomal RNAs [rRNAs] and ribosomal proteins)

Nuclear pore complex (NPC)

END CLASS WED 9 SEPT

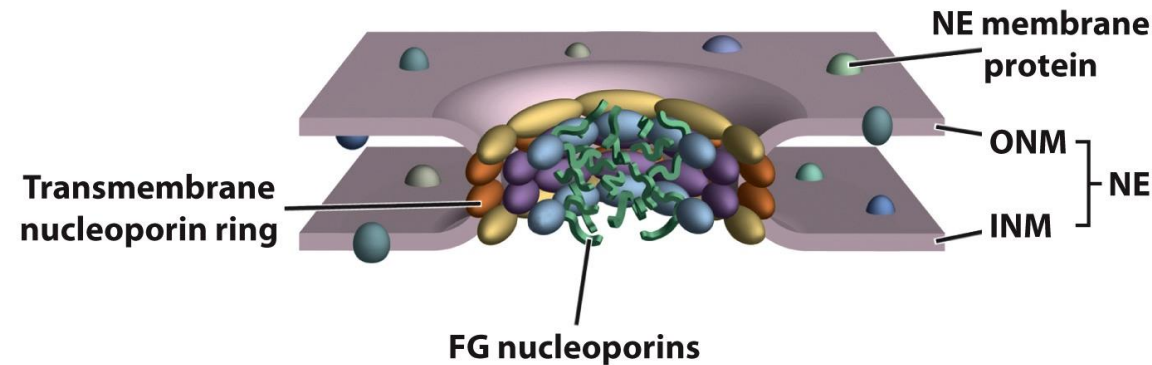


Model of a vertebrate nuclear pore complex (NPC). The structure consists of several parts, including a scaffold that anchors the complex to the nuclear envelope, a cytoplasmic and a nuclear ring, a nuclear basket, and eight cytoplasmic filaments.

Structure of Nuclear Pore Complex and its Role in Nucleocytoplasmic Trafficking

- Huge complex (15-30X mass of a ribosome) that exhibits octagonal symmetry.
- Channel: 20-to 30-nm-wide
- FG (phenylalanine-glycine) domains form a hydrophobic sieve that blocks the diffusion of larger macromolecules (greater than about 40,000 Daltons).

Nuclear pore complex (NPC)

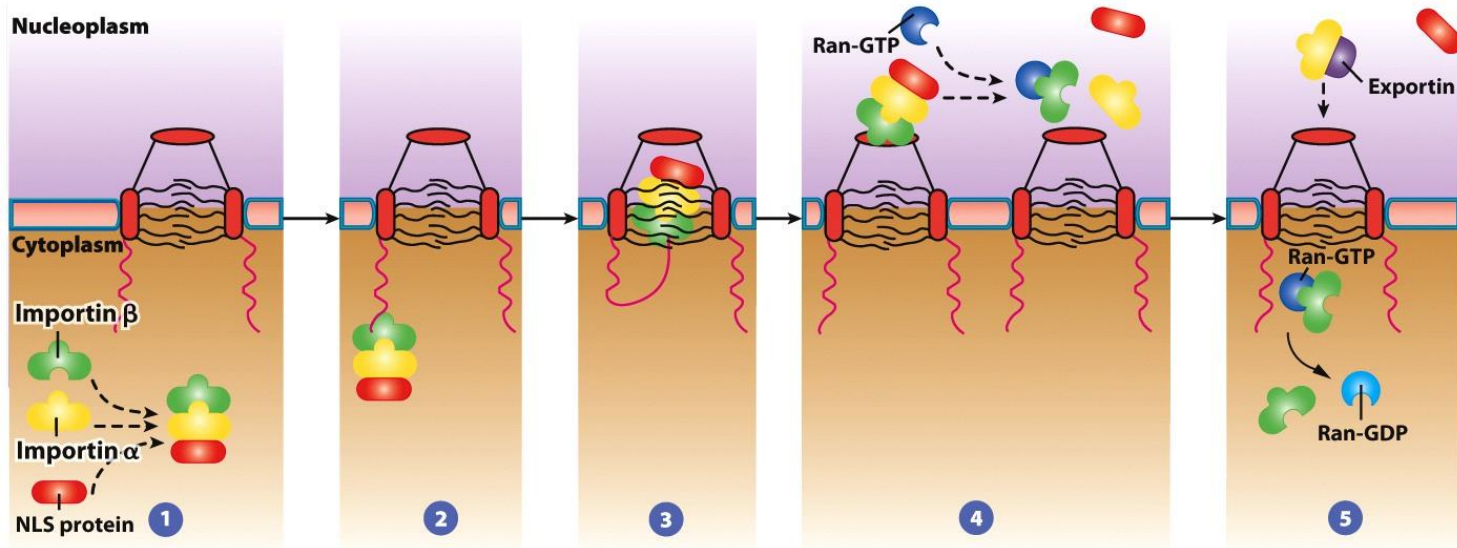


Model of a vertebrate nuclear pore complex (NPC). Three dimensional reconstruction of a portion of a nuclear pore complex showing the localization of individual nucleoporin molecules within the structure

Structure of Nuclear Pore Complex and its Role in Nucleocytoplasmic Trafficking

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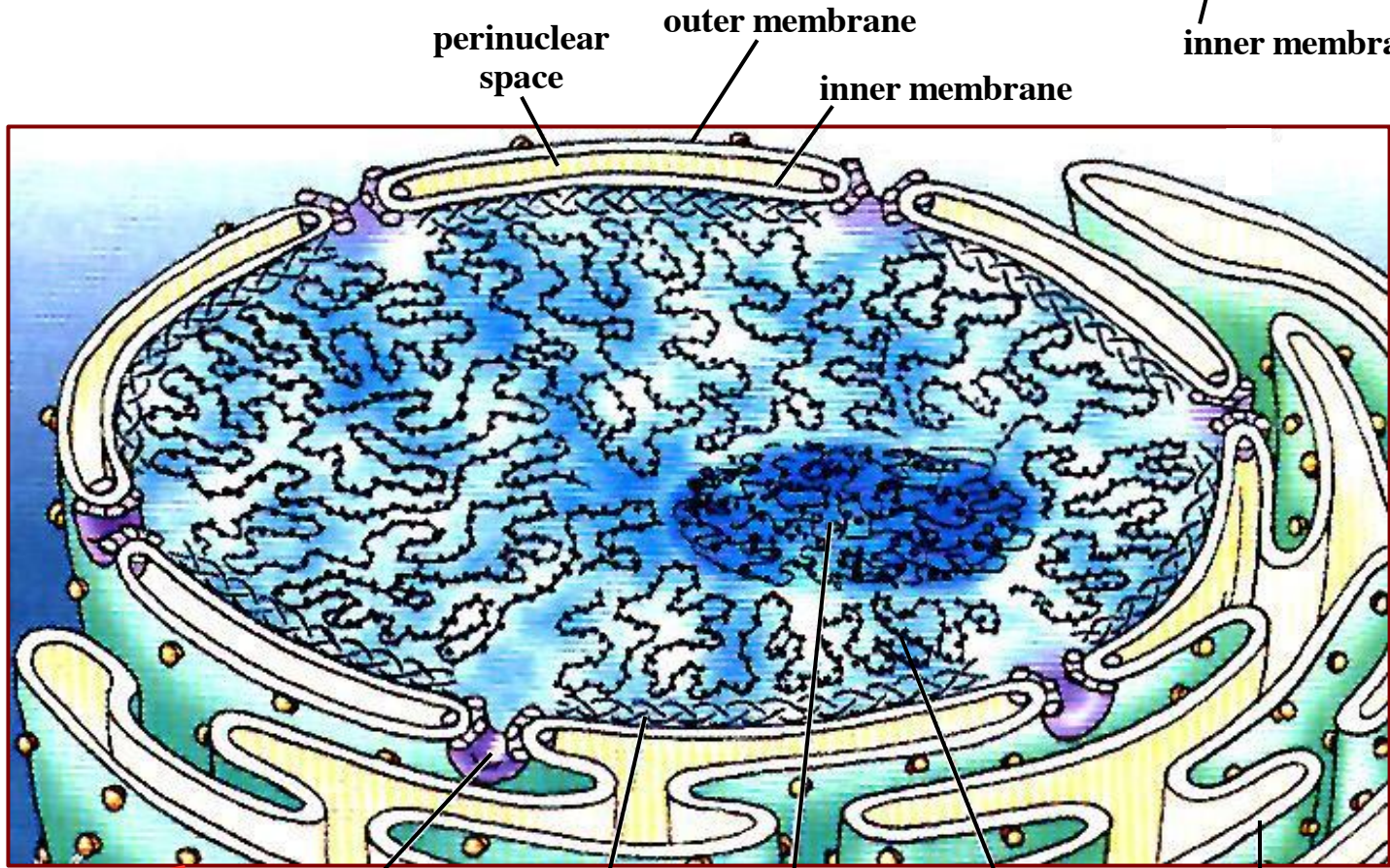
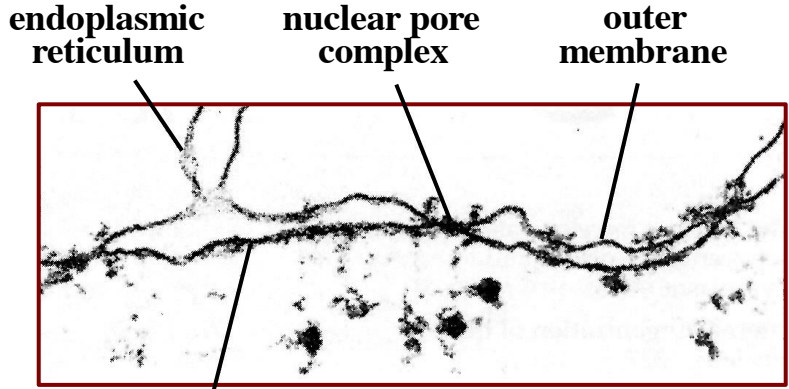
Import of proteins through the NPC



Proteins synthesized in the cytoplasm are targeted for the nucleus by a **nuclear localization signal (NLS)**, e.g. P-K-K-K-R-K-V having basic residues.

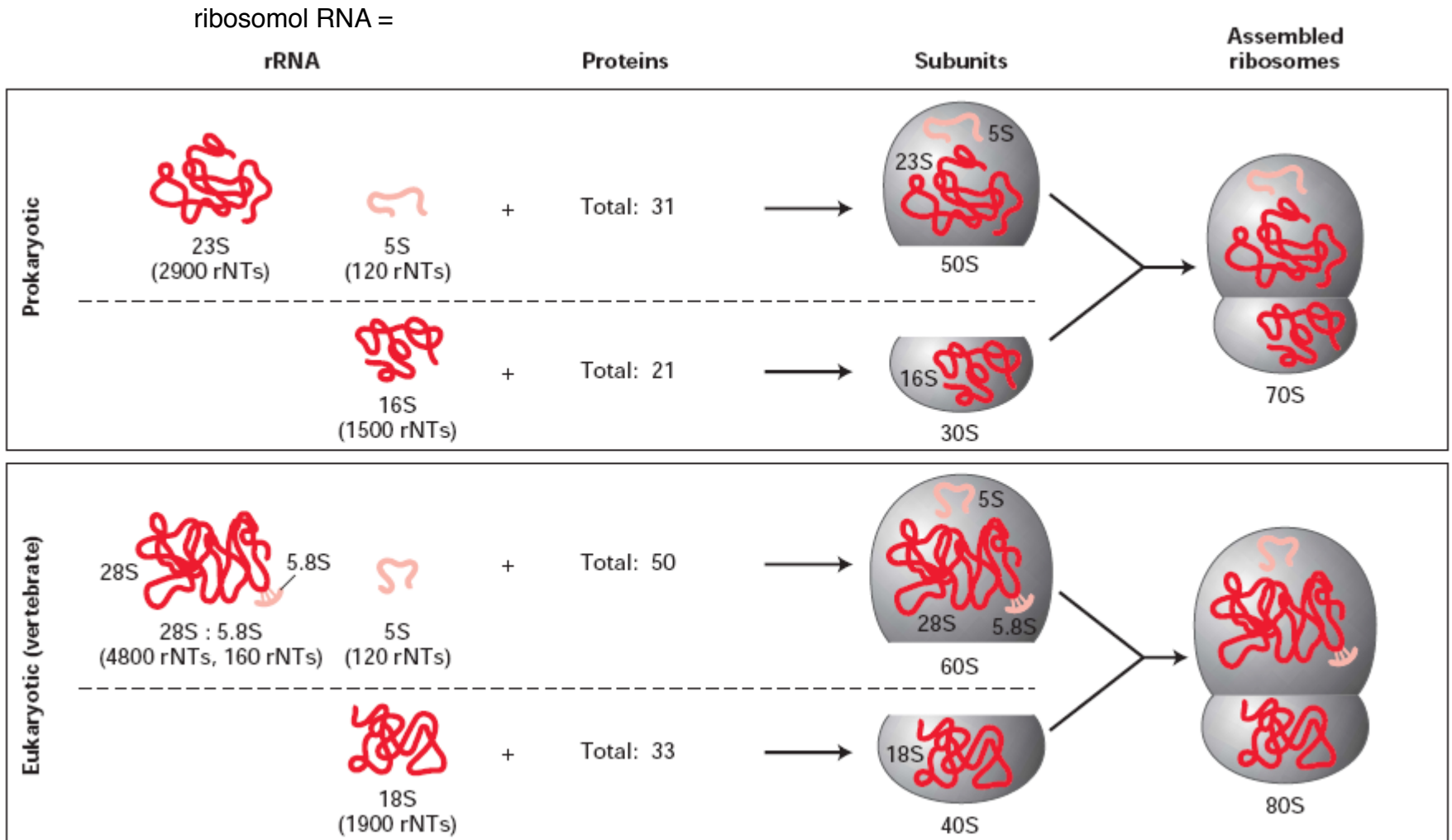
1. Proteins with an NLS bind to an NLS receptor (**importin α/β heterodimer**).
acido amino codes by letters to review
2. The protein/importin complex associates with cytoplasmic filaments.
3. The protein/importin complex passes through the NPC.....
4.and associates with a GTPase called Ran.
5. The Ran•GTP-importin β complex is transported back to the cytoplasm where Ran is converted to Ran•GDP and brought back in to the nucleus. Importin α is returned to the cytoplasm via a protein called exportin.

The outer nuclear membrane is continuous with the rough endoplasmic reticulum (ER), and the space between the inner and outer nuclear membranes is continuous with the lumen of the rough ER



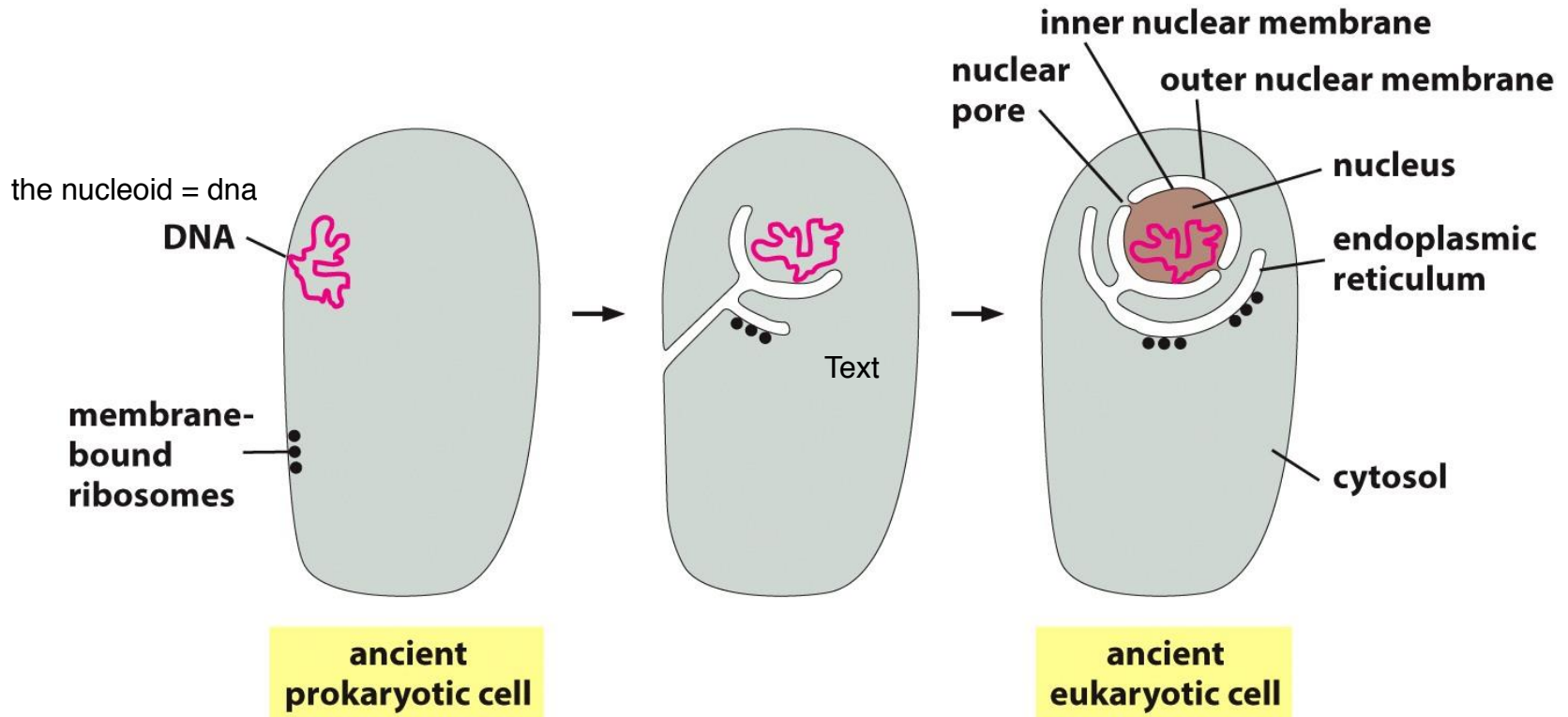
ribosomes nuclear pore complex nuclear lamina nucleolus chromatin rough endoplasmic reticulum

Eukaryotic and prokaryotic ribosomes



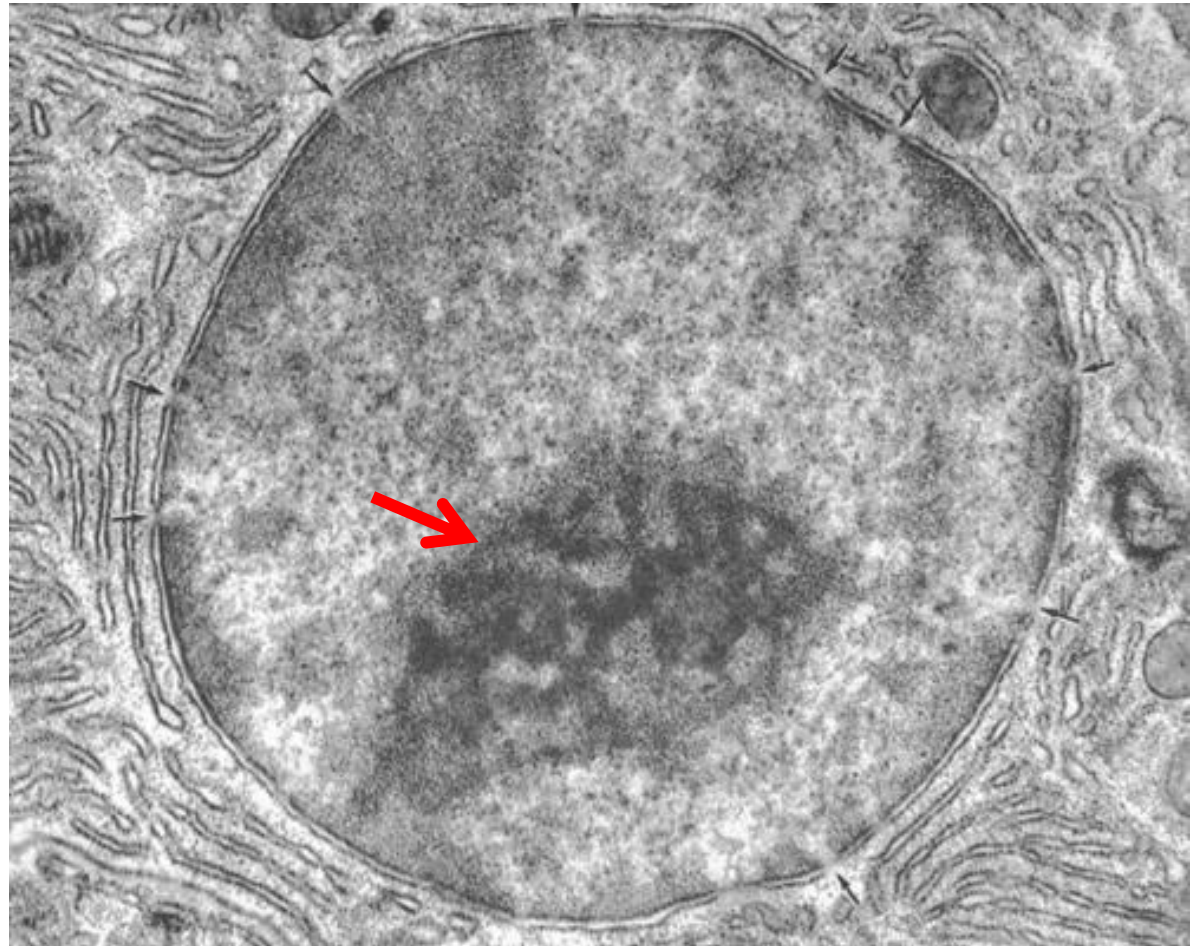
S= unit , it reflects the rate at which the material will travel 10a la -13seconds . the larger the S value= the larger the ribosome

Early origins of the nucleus



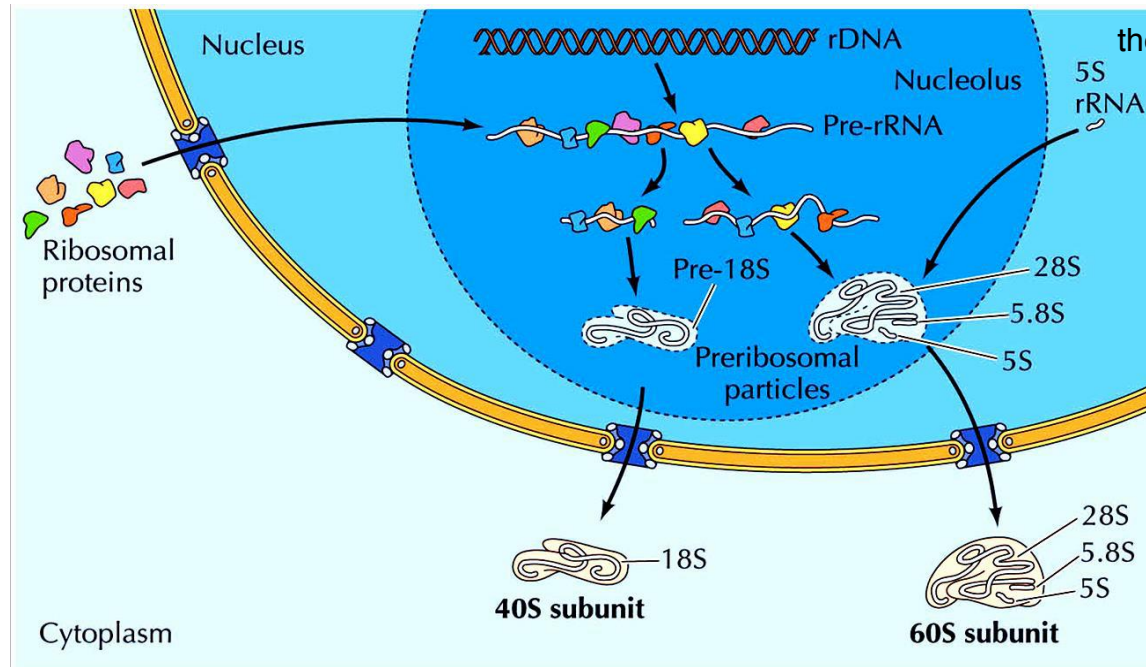
A suborganelle of the nucleus, the **nucleolus**, is a factory where *ribosomes* are assembled

the subunits are assembled in the nucleolus
—> ribosomes created



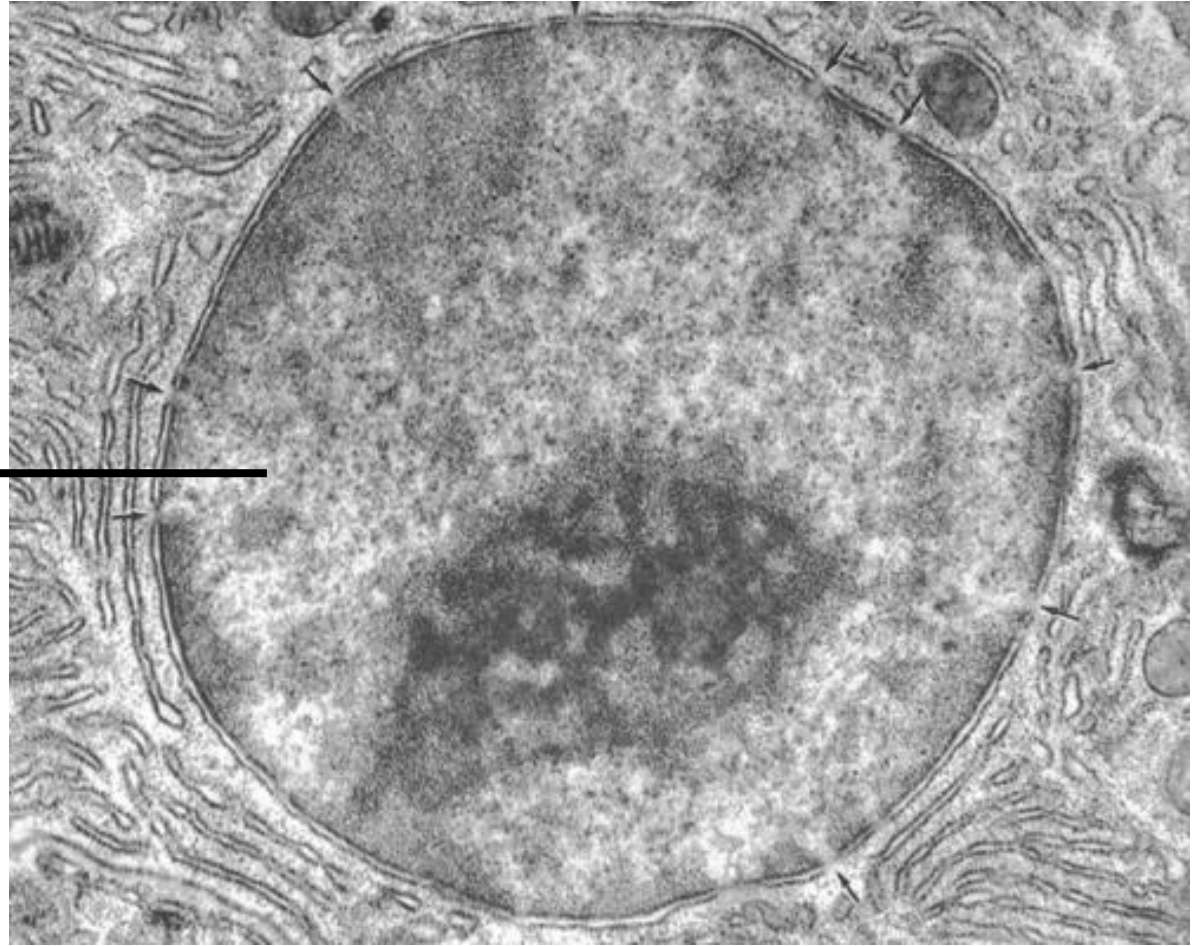
Ribosome assembly in the nucleolus

1. Ribosomal proteins are imported to the nucleus from the cytoplasm
2. These ribosomal proteins are then delivered to the nucleolus and assemble on pre-rRNA (pre-ribosomal RNA)
3. The pre-rRNA is cleaved to form several rRNAs
4. Ribosomal proteins and rRNAs assemble to form the 40S and 60S ribosomal subunits
5. These subunits are exported to the cytoplasm (fully assembled ribosome is too large to fit through pore, ensuring protein synthesis takes place in cytoplasm)



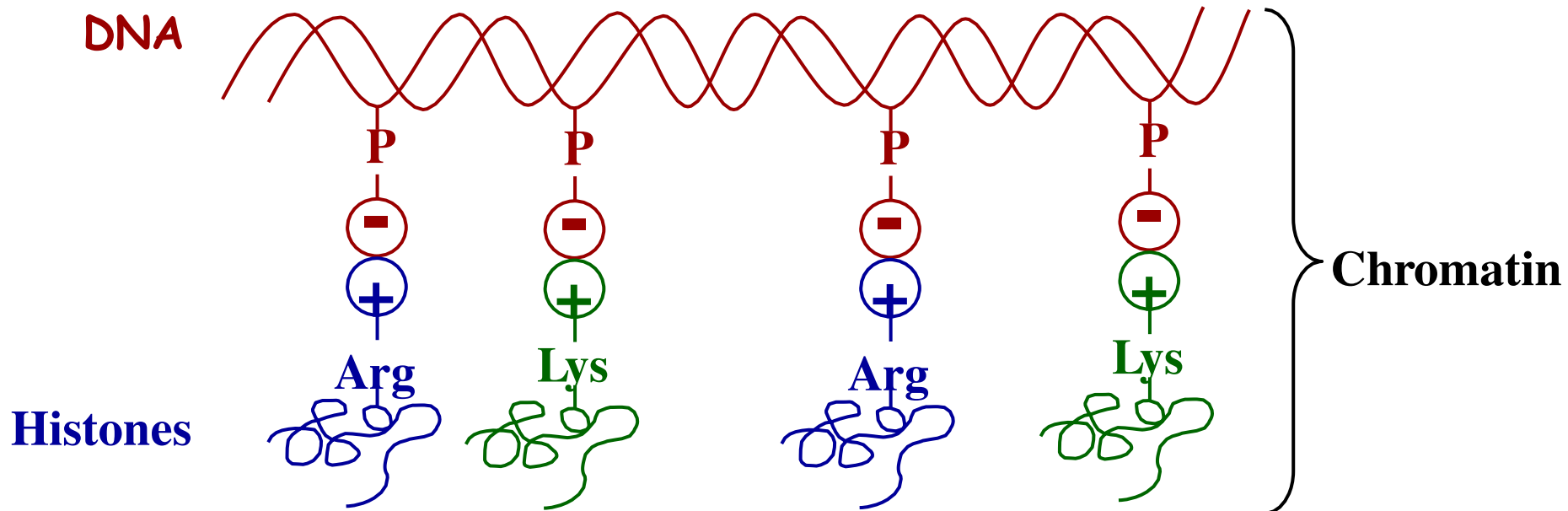
the 40S and 60S subunits are assembled outside of the nucleus because if it was inside it would be too big for them to pass through the pore

The chromosomal DNA is packed into **chromatin** fibers with the aid of specialized proteins



Chromatin

- The complexes composed of eukaryotic DNA and proteins are called **chromatin**
- Chromatin contains about **twice as much** protein as DNA
- The major proteins of chromatin are the **histones**
- Histones are small proteins (11 to 23 kDa) containing a high proportion of **basic amino acids** (arginine and lysine) that facilitate binding to the negatively charged DNA molecule



5 major types of histones

in the proteins

H1

H2A

H2B

H3

H4

Histones are very similar among different species of eukaryotes

Chromatin also contains an approximately equal mass of nonhistone chromosomal proteins (more than a 1000 different types)

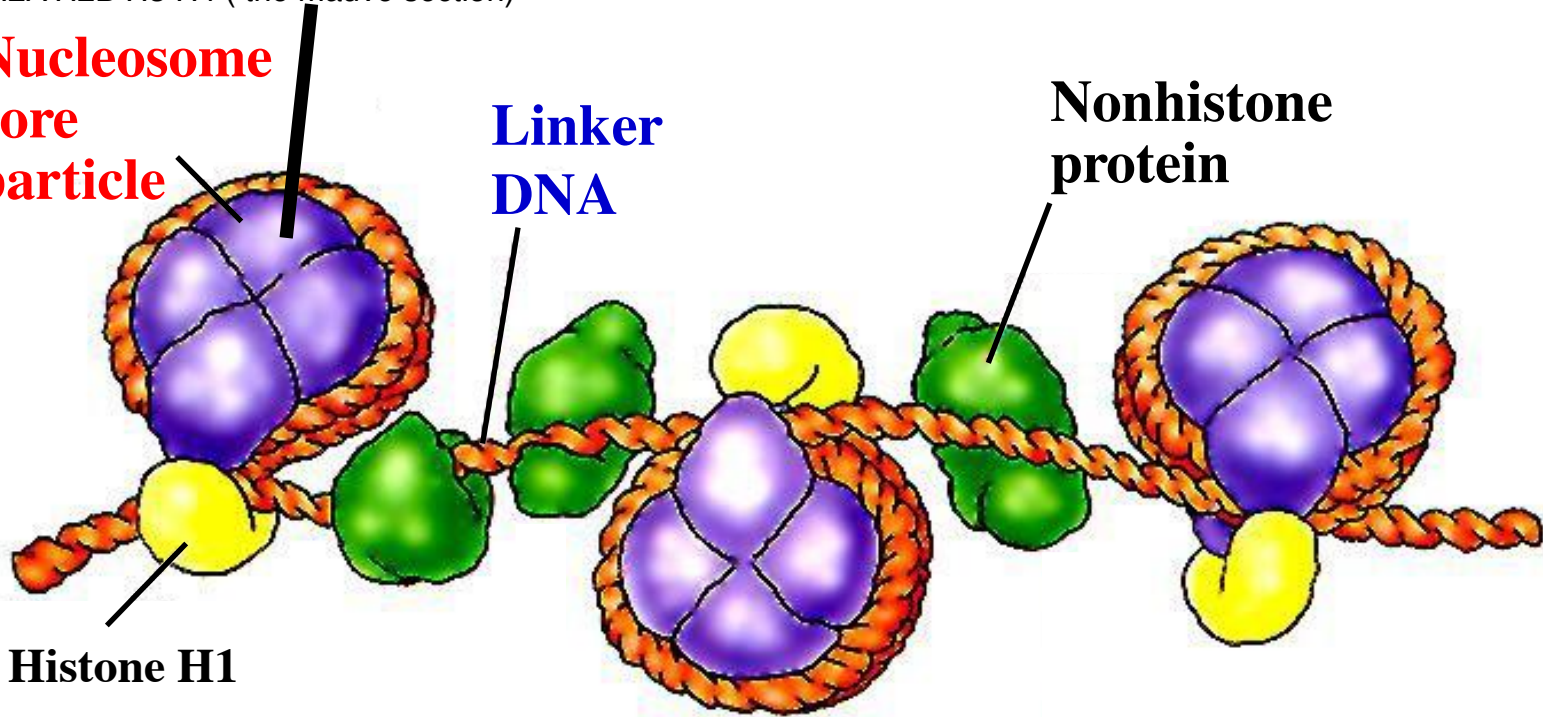
The basic structural unit of chromatin is called the *nucleosome*

8 proteins (2 each) , or the 4 othes histones found
H2A H2B H3 H4 (the mauve section)

**Nucleosome
core
particle**

**Linker
DNA**

**Nonhistone
protein**

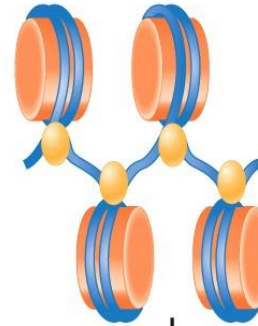


- The DNA is wrapped around an octamer of histones H2A, H2B, H3 and H4 in a **nucleosome core particle** and sealed by histone H1. This produces a 7-fold compaction of the DNA.
- Nonhistone proteins bind to the **linker DNA** between nucleosome core particles

Higher-ordered structures of chromatin

these are other forms how they can be compacted the DNA

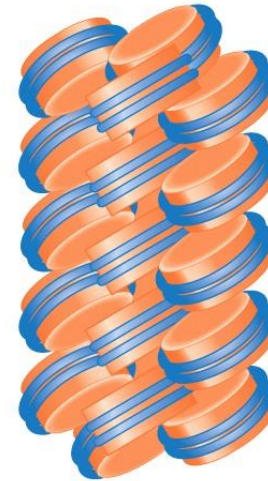
Zig-zag



Solenoid



Formation of 30 nm fibers are dependent upon histone interactions and further increase compaction by ~6 fold



(b)

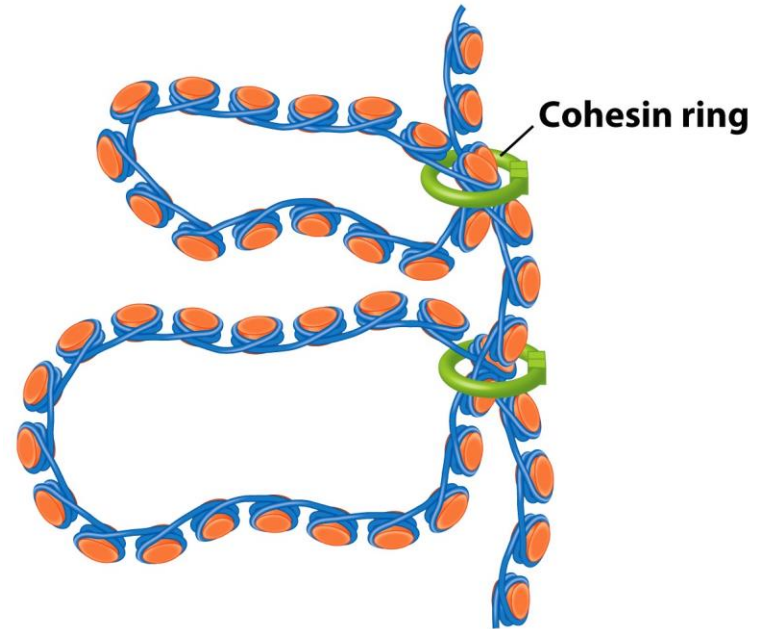


11 nm

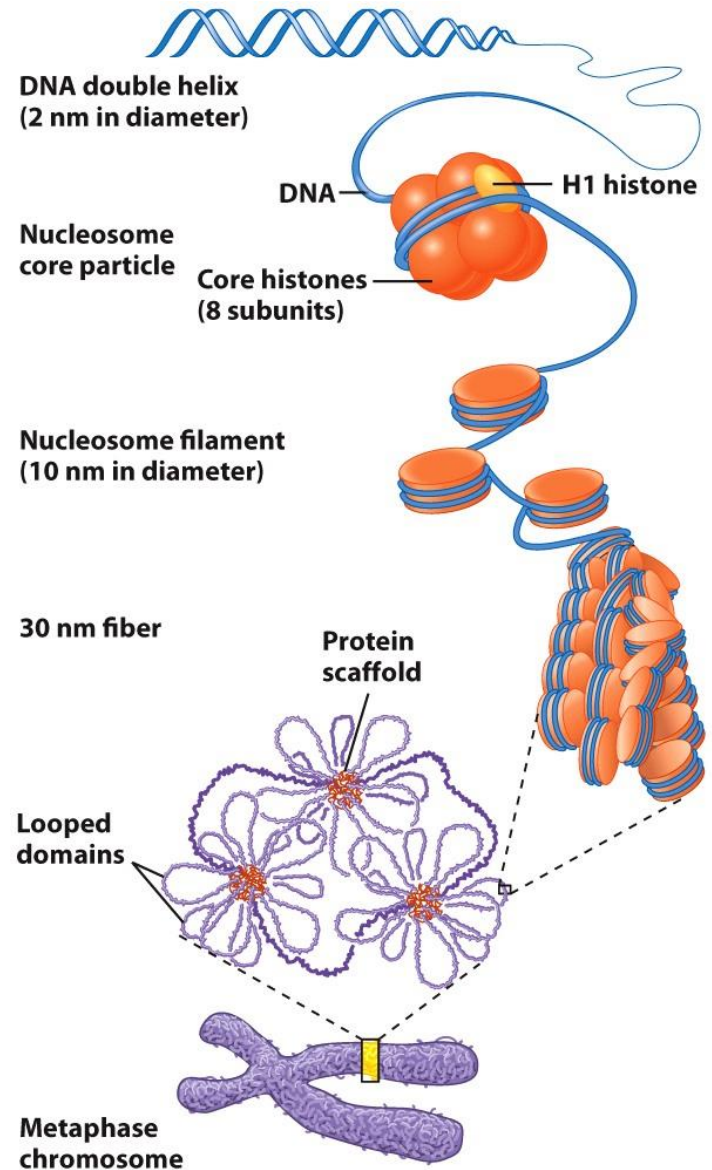
(c)

Higher-ordered structures of chromatin

The 30 nm fibers are then organized into 80-100 nm supercoiled loops, possibly stabilized by a protein called cohesin

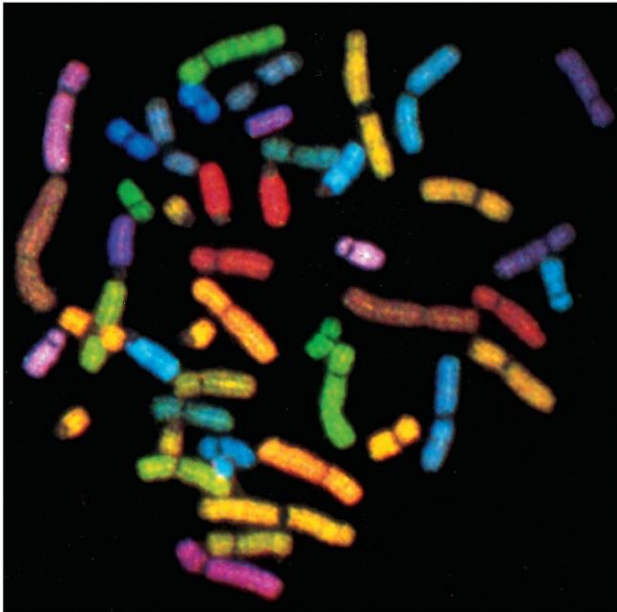


Mitotic chromosomes represent the ultimate in chromatin compactness with a ratio of 10,000:1 (1 μm of mitotic chromosome length contains ~ 1 cm of non-compacted DNA)

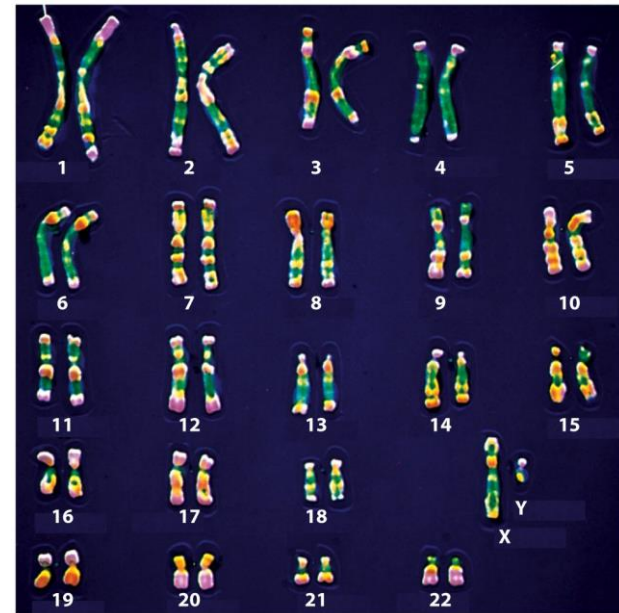


As a cell prepares to divide into two daughter cells, its chromatin condenses into chromosomes that can be distinguished in the light microscope.

centromer = in the middle of the chromosomes



Human mitotic chromosomes labeled with different specific fluorescent dyes.



CNRI/Science Photo Library/Photo Researchers, Inc.

Chromosomes can be arranged in a **karyotype** (a preparation of homologous pairs ordered according to size; may be used to screen chromosomal abnormalities).

Heterochromatin and Euchromatin

transcribed DNA is usually euchromatin

Euchromatin returns to a dispersed state after mitosis.

Heterochromatin is condensed during interphase.

- **Constitutive heterochromatin** remains condensed all the time.
 - Found mostly around centromeres and telomeres. = at the end of the chromosome (at the either end), to protect the chromosomes when they get replicated os they don't get shorter everytime
 - Consists of highly repeated sequences and few genes.
- **Facultative heterochromatin** is inactivated during certain phases of the organism's life (X-inactivation)

Mitochondria play a critical role in the generation of metabolic energy in eukaryotic cells

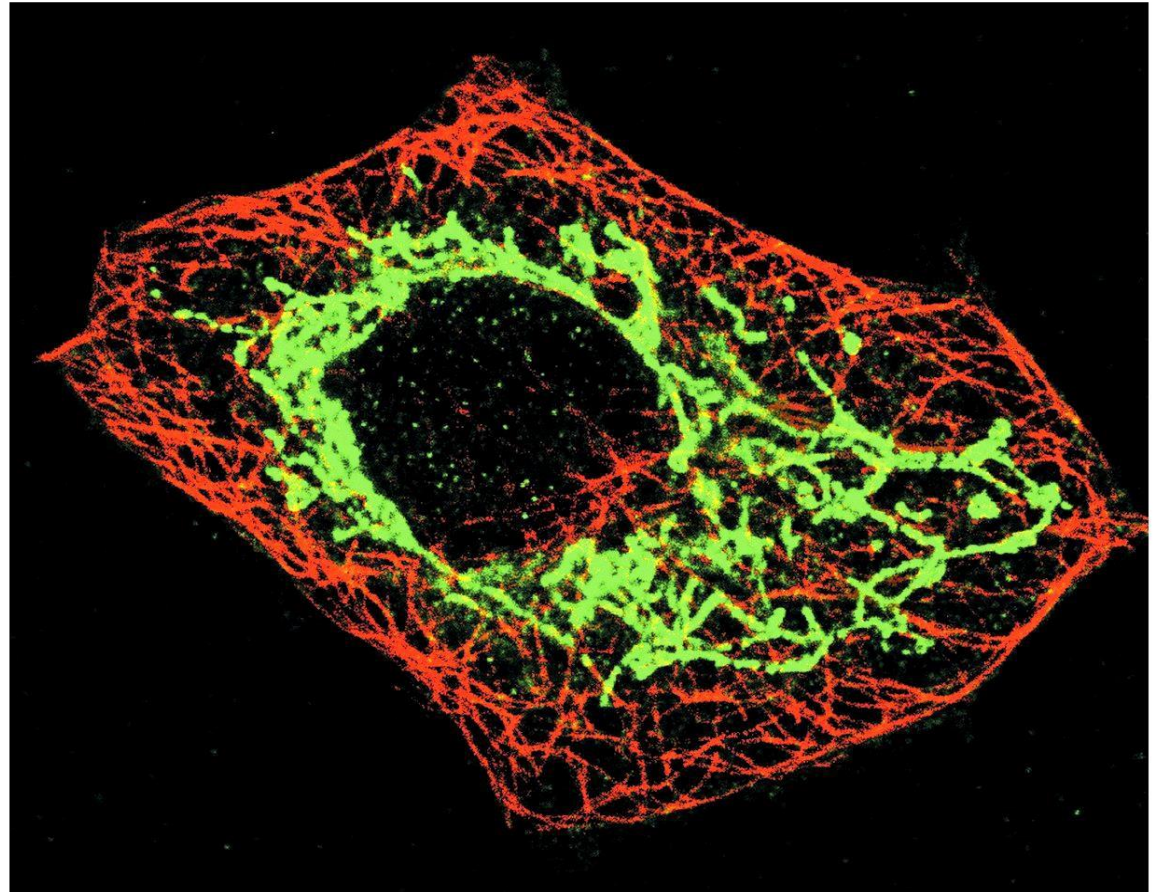
- They oxidize carbohydrates and lipids to produce the basic chemical fuel adenosine triphosphate (ATP) by a process called oxidative phosphorylation
- ATP is used in a variety of energy-requiring reactions within cells
- Because mitochondria consume oxygen and release carbon dioxide in the course of ATP production, the entire process is called cellular respiration, from its similarity to breathing

Morphology

Depending upon the cell type and physiological conditions, mitochondria can have different overall structures

Mitochondria can appear as a highly branched, interconnected **tubular network**.

Micrograph of a mammalian fibroblast that has been fixed and stained with fluorescent antibodies to a mitochondrial (green) and a cytoskeletal (red) protein



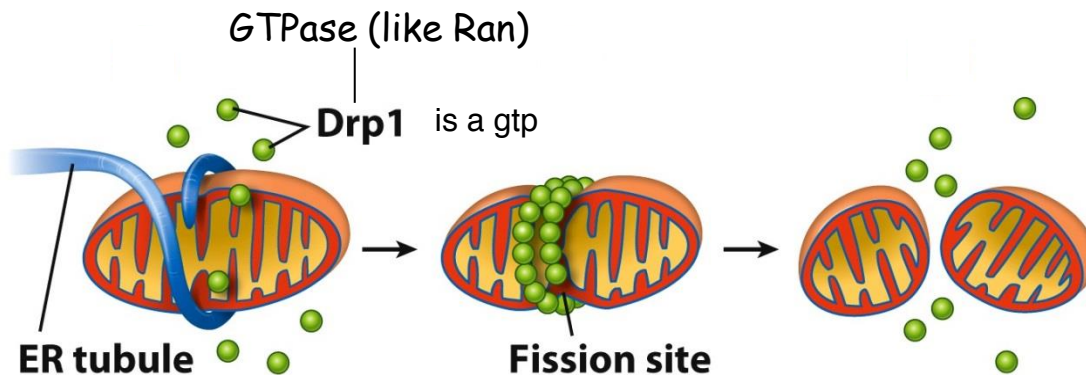
The balance between fusion and fission is a major determinant of mitochondrial morphology

Single mitochondrion: $\sim 4 \mu\text{m}$ length

Observations of fluorescently labeled mitochondria within living cells have shown them to be **dynamic organelles** capable of dramatic changes in shape:

- they can fuse with one another (**fusion**) or split into two (**fission**)

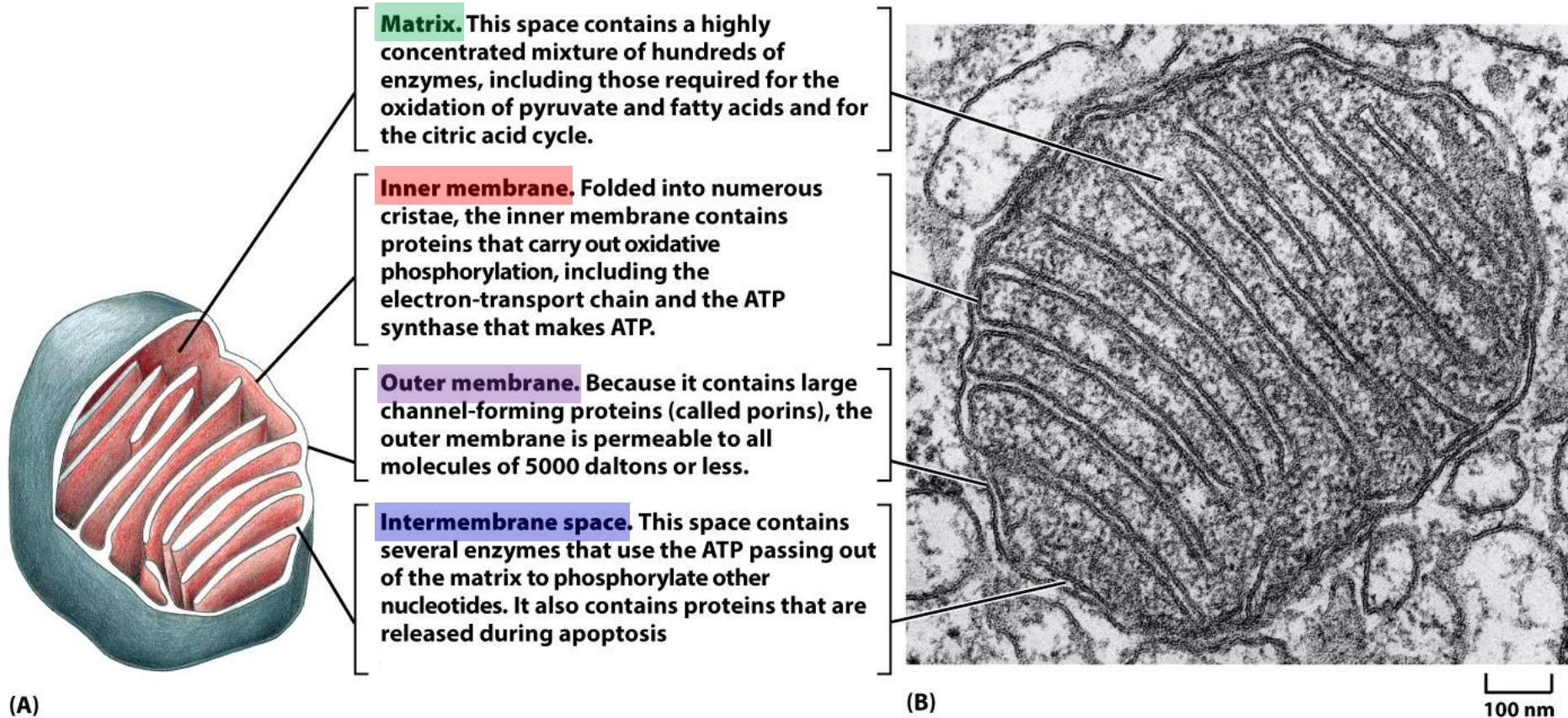
Fission is induced by contact with endoplasmic reticulum (ER) tubules.



Mitochondria arise from preexisting mitochondria by fission

Mitochondria are surrounded by a double-membrane system, consisting of **inner** and **outer** mitochondrial membranes separated by an **intermembrane space**.

The inner membrane forms numerous folds (**cristae**), which extend into the interior (or **matrix**) of the organelle. Its surface area is substantially increased by its folding into cristae.



The mitochondrial **matrix** contains:

- **Enzymes** responsible for the oxidative breakdown of carbohydrates and lipids via the **citric acid cycle**, and enzymes required for the **expression of mitochondrial genes**
- Several identical copies of **circular DNA molecules** (mitochondrial genome)
- Special **mitochondrial ribosomes**

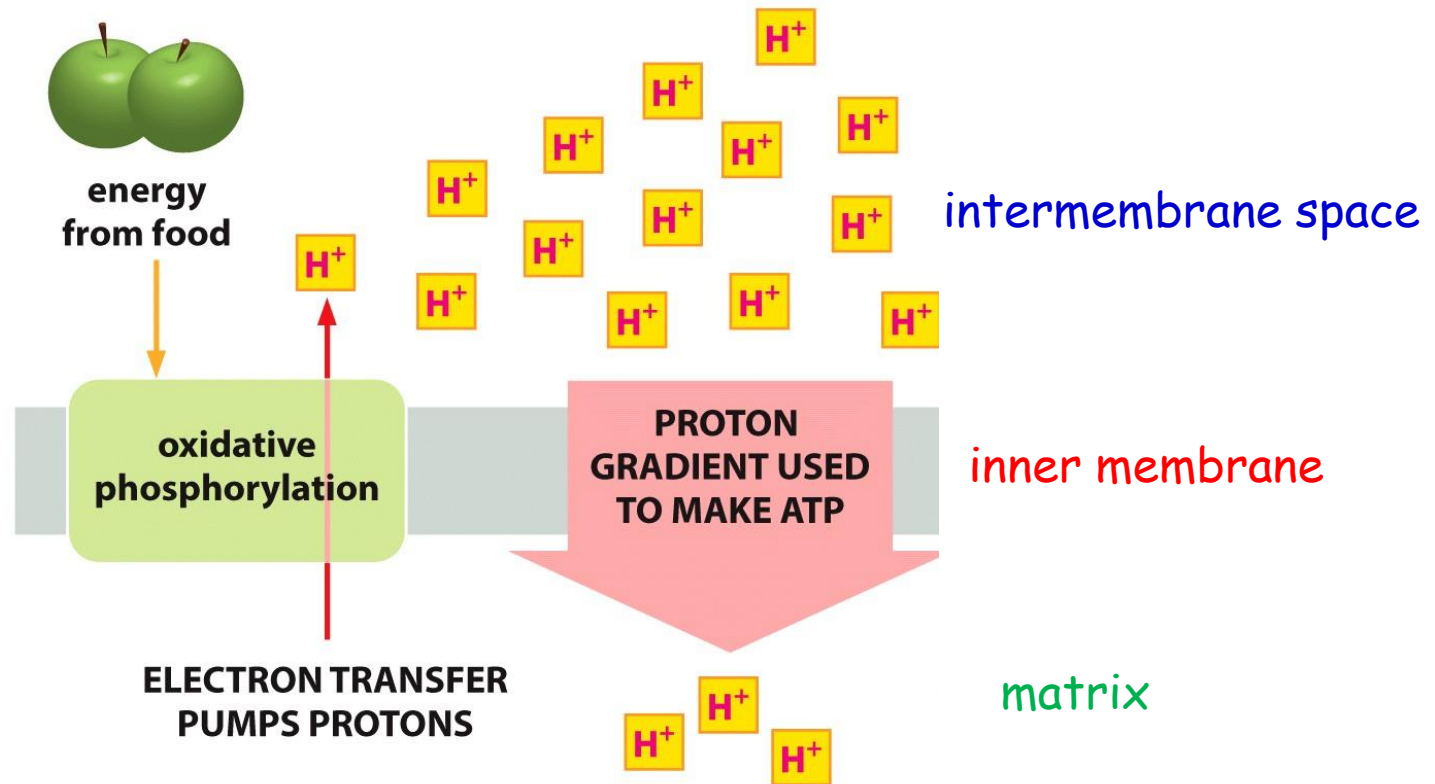
Inner mitochondrial membrane:

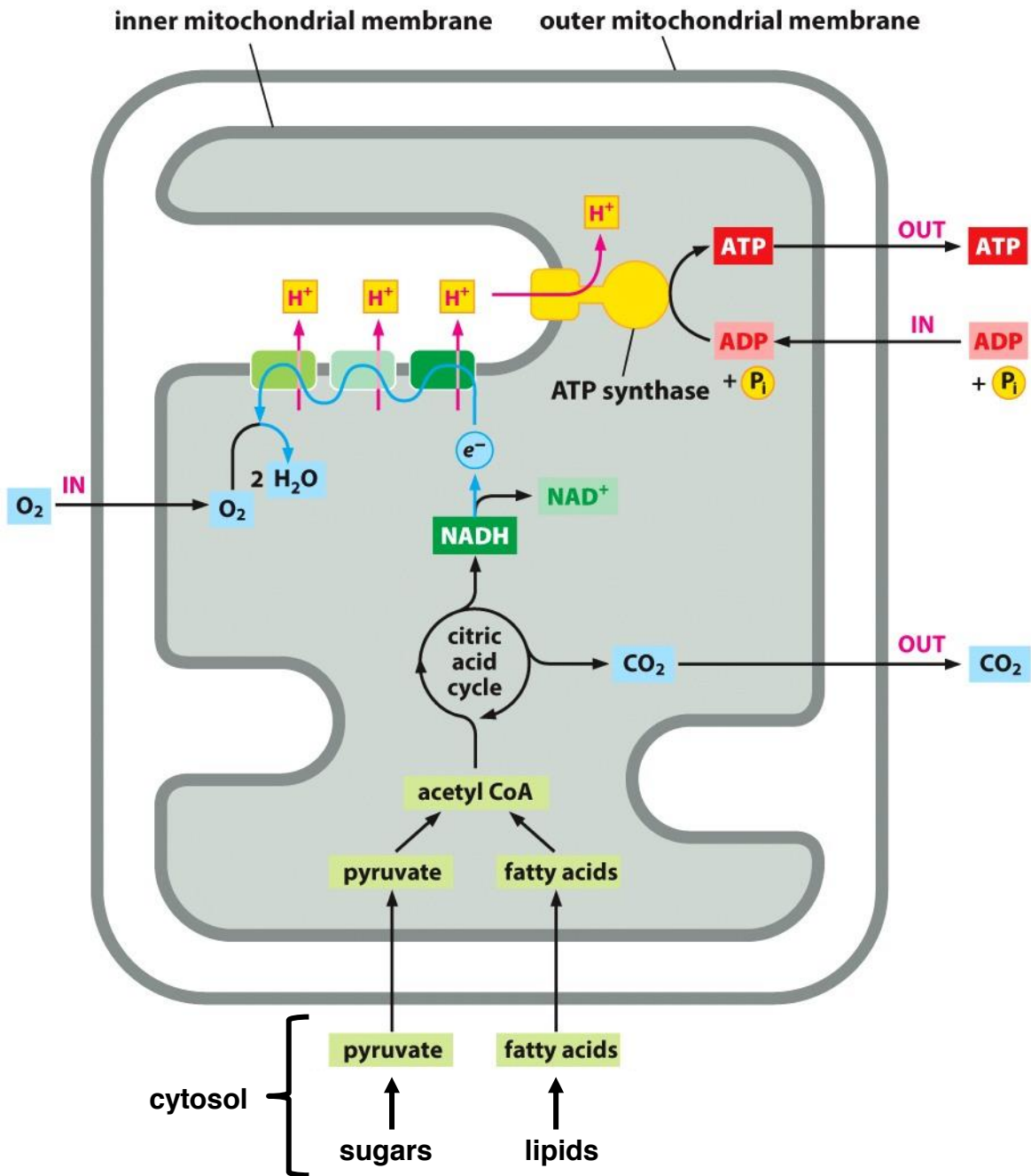
- The principal site of **ATP synthesis**

Outer membrane:

- Contains **enzymes** that **convert lipid substrates** into forms that are subsequently metabolized in the matrix

Energy (ATP) production in the mitochondrion





This electron transport generates a **proton gradient across the inner membrane**, which is used to drive the production of ATP by ATP synthase

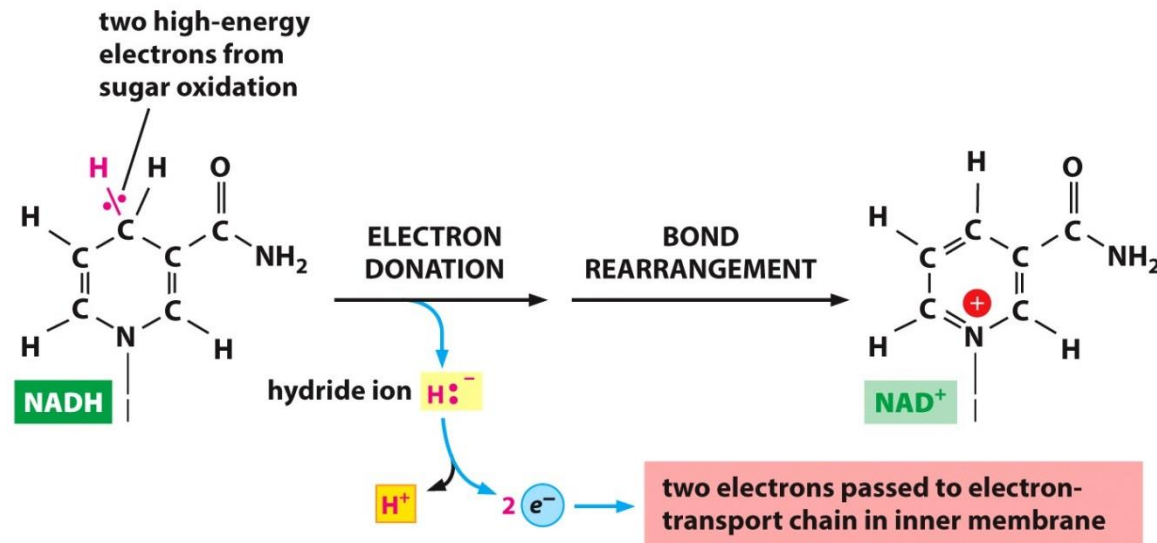
In the process of **oxidative phosphorylation**, high-energy electrons from **NADH** and **FADH₂** are then passed along the electron-transport chain in the inner membrane to oxygen (O₂)

Pyruvate and **fatty acids** enter the mitochondrion, are broken down to acetyl CoA, and are then metabolized by the **citric acid cycle**, which produces NADH and FADH₂

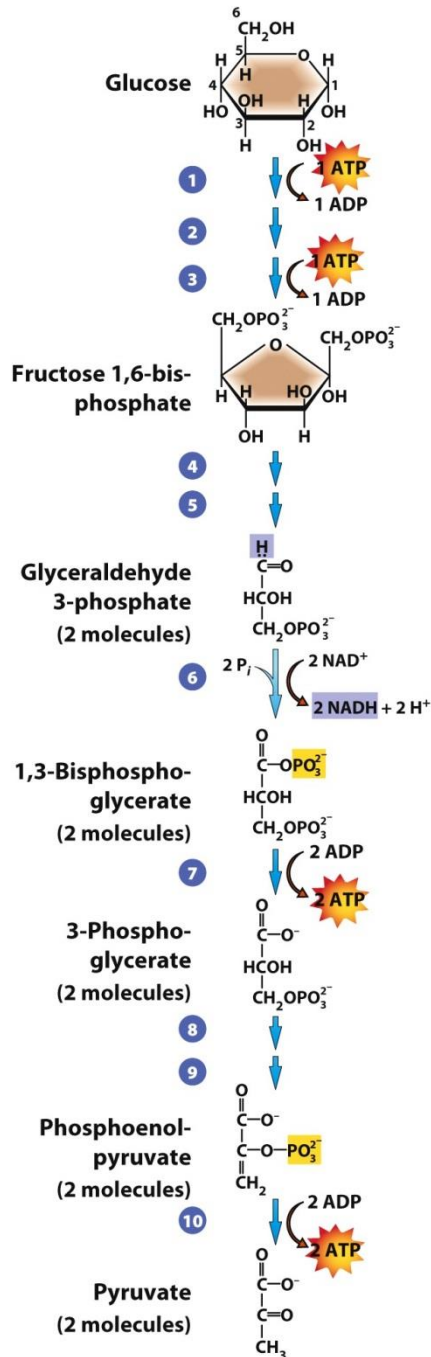
Electron transfer

Types of carriers

1. Flavoproteins, contain NAD^+ , FAD^+ prosthetic groups
2. Cytochromes, contain heme prosthetic groups $\text{Fe}^{3+} \rightarrow \text{Fe}^{2+}$ (e.g. cytochrome c)
3. Copper-containing proteins, $\text{Cu}^{2+} \rightarrow \text{Cu}^{1+}$
4. Ubiquinone (or coenzyme Q), only carrier to not have a prosthetic group
5. Iron-Sulfur proteins



Glycolysis - generation of 2 ATP and 2 NADH



Glucose is phosphorylated at the expense of one ATP, rearranged structurally to form fructose phosphate, and then phosphorylated again at the expense of a second ATP. The two phosphate groups are situated at the two ends (C1, C6) of the fructose chain.

The six-carbon bisphosphate is split into two three-carbon monophosphates.

The three-carbon aldehyde is oxidized to an acid as the electrons removed from the substrate are used to reduce the coenzyme NAD^+ to NADH . In addition, the C1 acid is phosphorylated to form an acyl phosphate, which has a high phosphate group-transfer potential (denoted by the yellow shading).

The phosphate group from C1 is transferred to ADP forming ATP by substrate-level phosphorylation. Two ATPs are formed per glucose oxidized.

These reactions result in the rearrangement and dehydration of the substrate to form an enol phosphate at the C2 position that has a high phosphate group-transfer potential.

The phosphate group is transferred to ADP forming ATP by substrate-level phosphorylation, generating a ketone at the C2 position. Two ATPs are formed per glucose oxidized.

Net reaction:

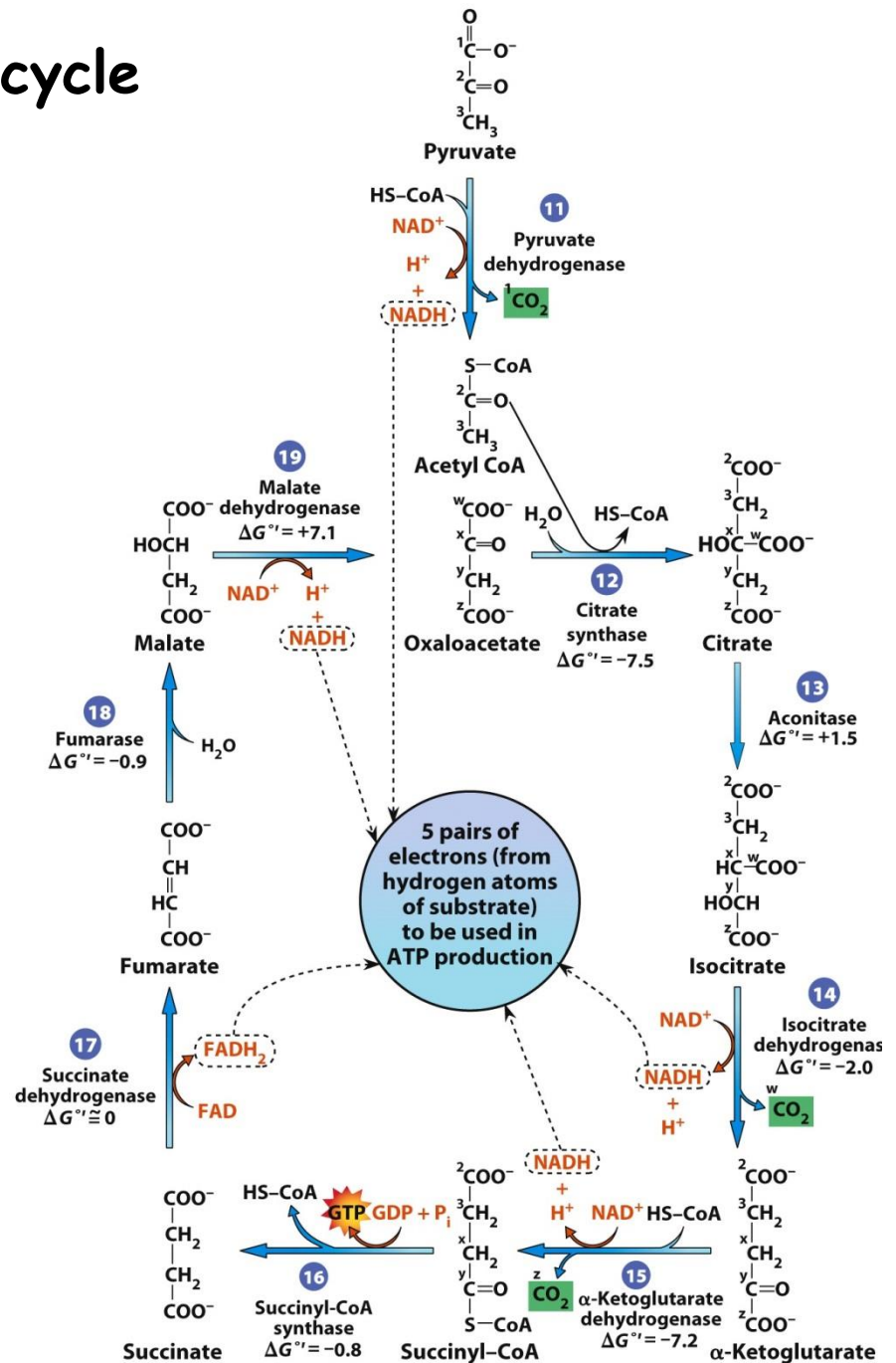


The TCA cycle (aka Krebs cycle or citric acid cycle)

A stepwise cycle where substrate is oxidized and its energy conserved.

The two-carbon acetyl group from acetyl CoA is condensed with the four-carbon oxaloacetate to form a six-carbon citrate.

During the cycle, two carbons are oxidized to CO_2 , regenerating the four-carbon oxaloacetate needed to continue the cycle.



Each pyruvate that enters the mitochondrion generates:

4 NADH (3 from the TCA cycle, 1 from production of Acetyl-CoA)

1 FADH₂

1 GTP double them and the rest is from the glycolysis

So, including glycolysis, after the TCA cycle there is a **TOTAL** of:

10 NADH

2 FADH₂

2 ATP

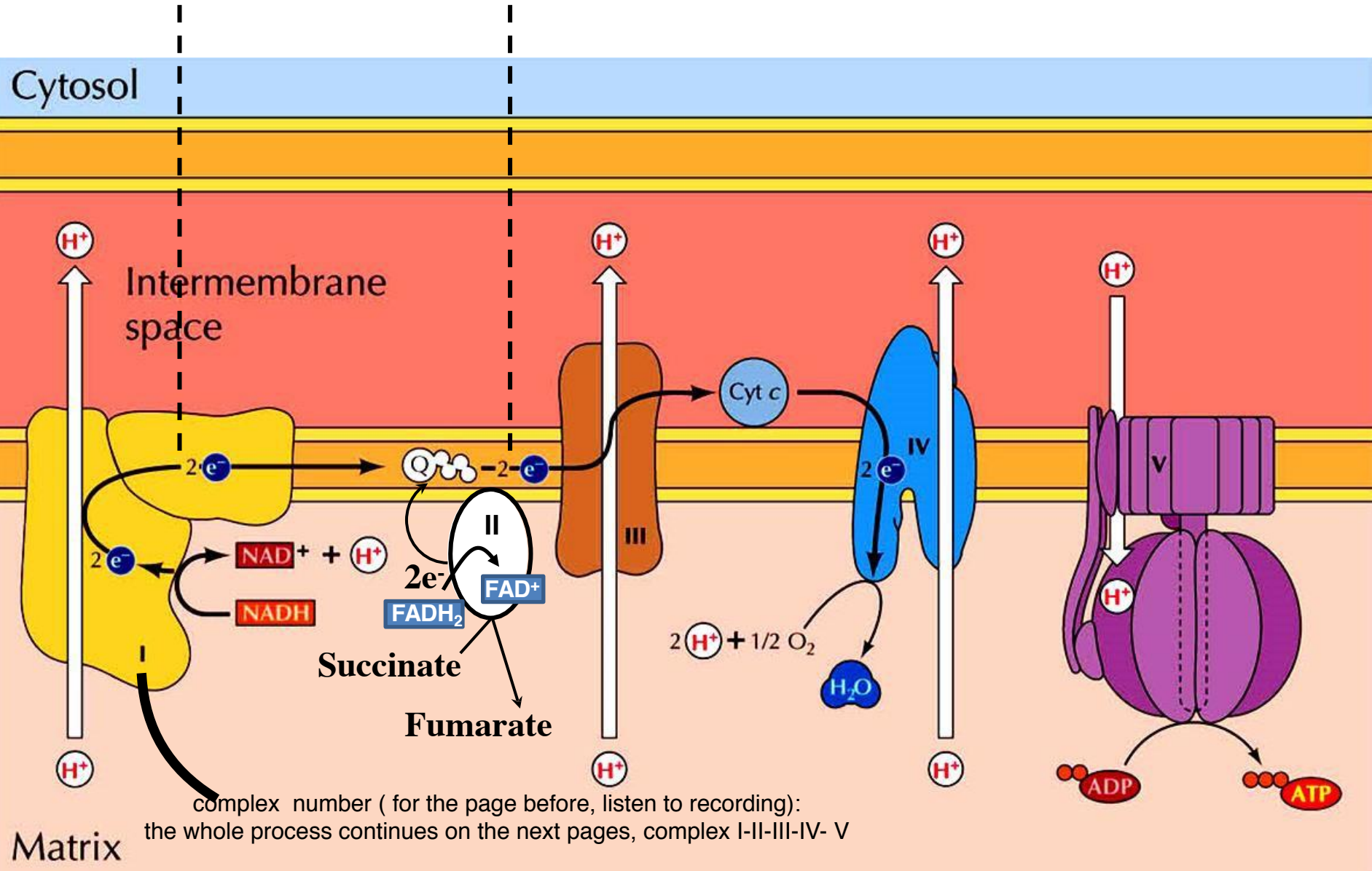
2 GTP

During oxidative phosphorylation, it is estimated that each NADH molecule generates ~2.5 ATP molecules and each FADH₂ molecule generates ~1.5 ATP molecules (enters the electron transport chain further downstream of NADH). Therefore, **the overall yield of ATP molecules from a single glucose molecule is ~30.**

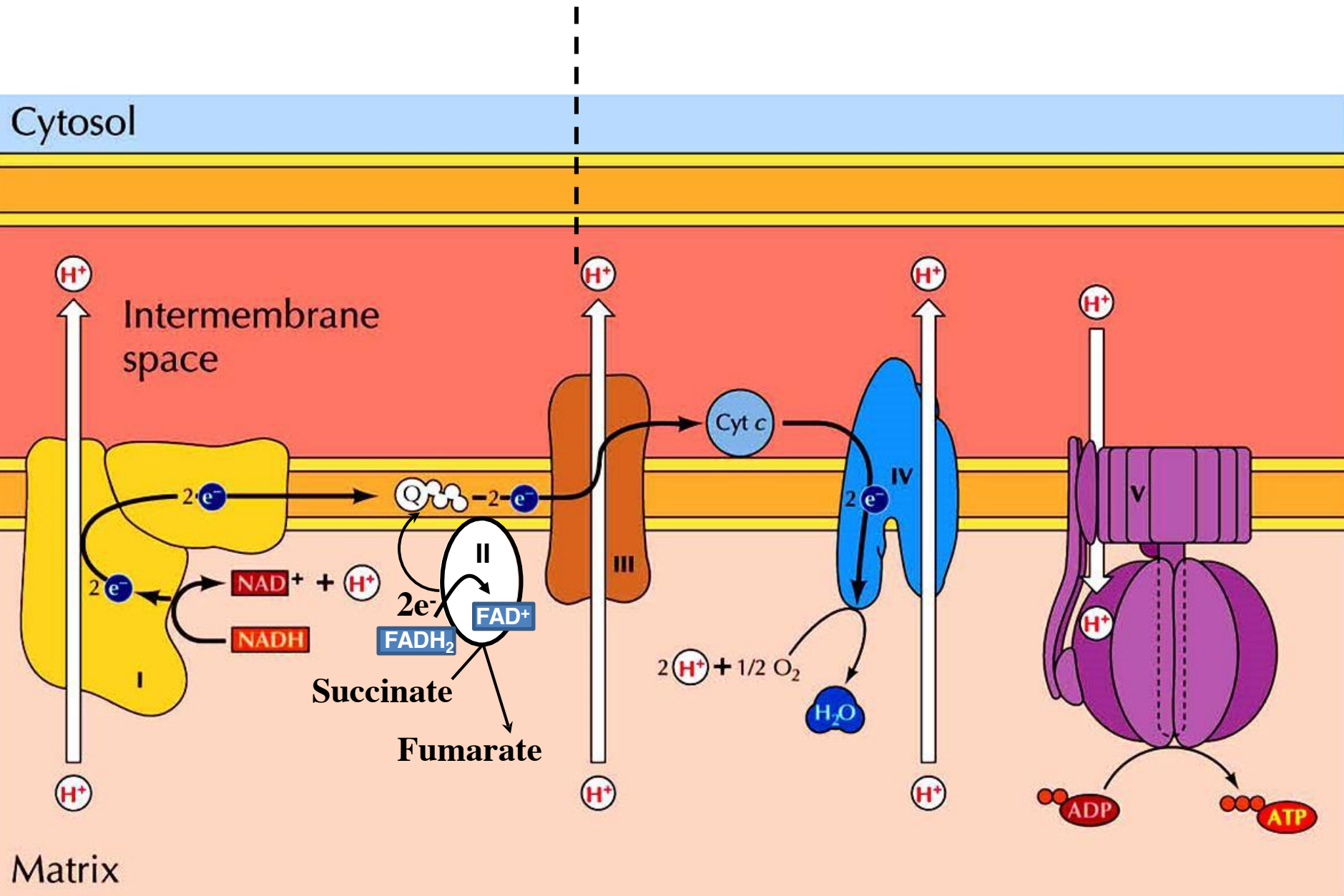
The complexes of the electron transport chain

	Complex I NADH dehydrogenase (Mammalian)	Complex III Cytochrome <i>bc</i> ₁	Complex II Succinate dehydrogenase	Complex IV Cytochrome <i>c</i> oxidase
Subunits				
mtDNA encoded	7	1	0	3
nDNA encoded	38	10	4	10
TOTAL	45	11	4	13
Molecular mass (Da)	~980,000	~240,000	~125,000	~200,000

1) Electrons derived from either NADH (via complex I or NADH dehydrogenase) or FADH₂ (complex II or succinate dehydrogenase) are passed to ubiquinone (Q or UQ), a lipid-soluble molecule



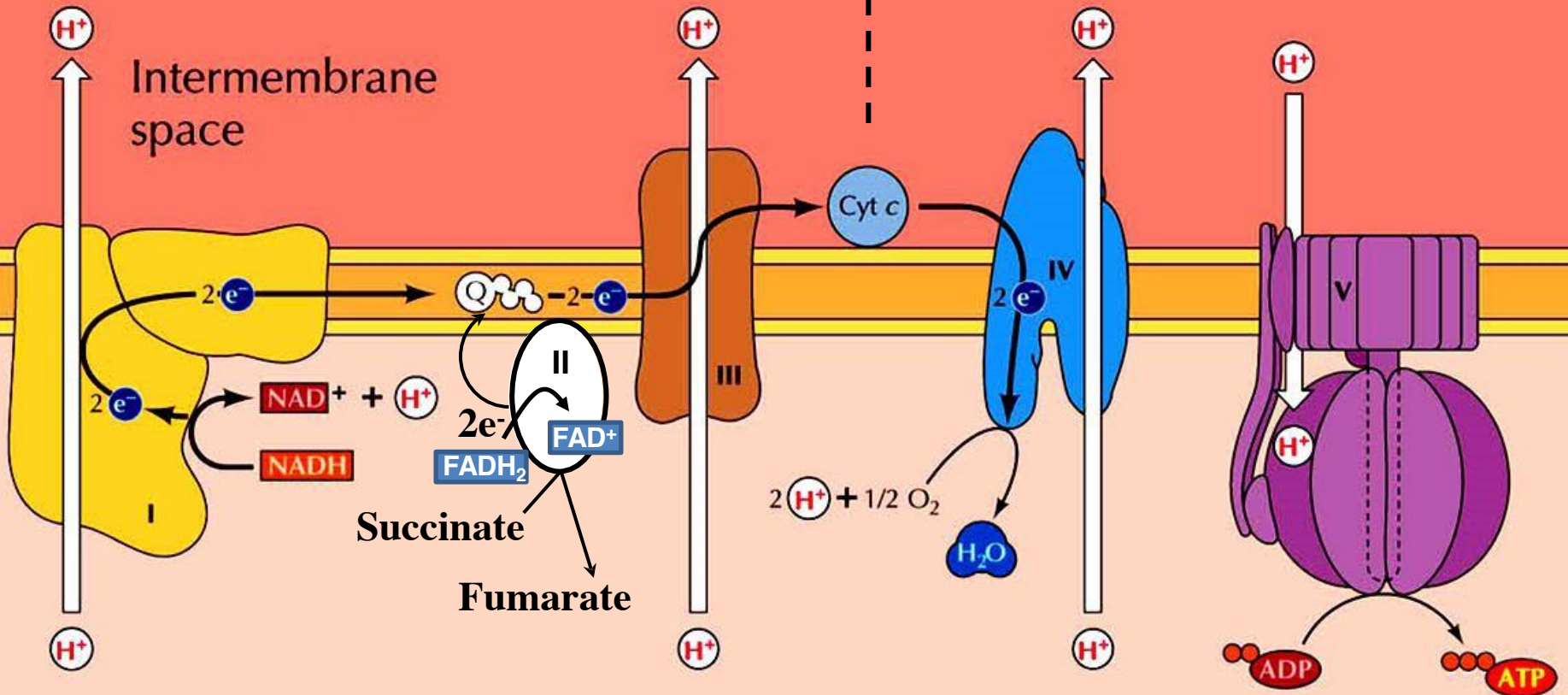
2) The electrons are then passed from coenzyme Q (a.k.a. ubiquinone) to complex III (or. the cytochrome b-c₁ complex)



3) Electrons are then transferred to cytochrome c, a peripheral membrane protein, which carries electrons to complex IV (or cytochrome oxidase)

Cytosol

Intermembrane space

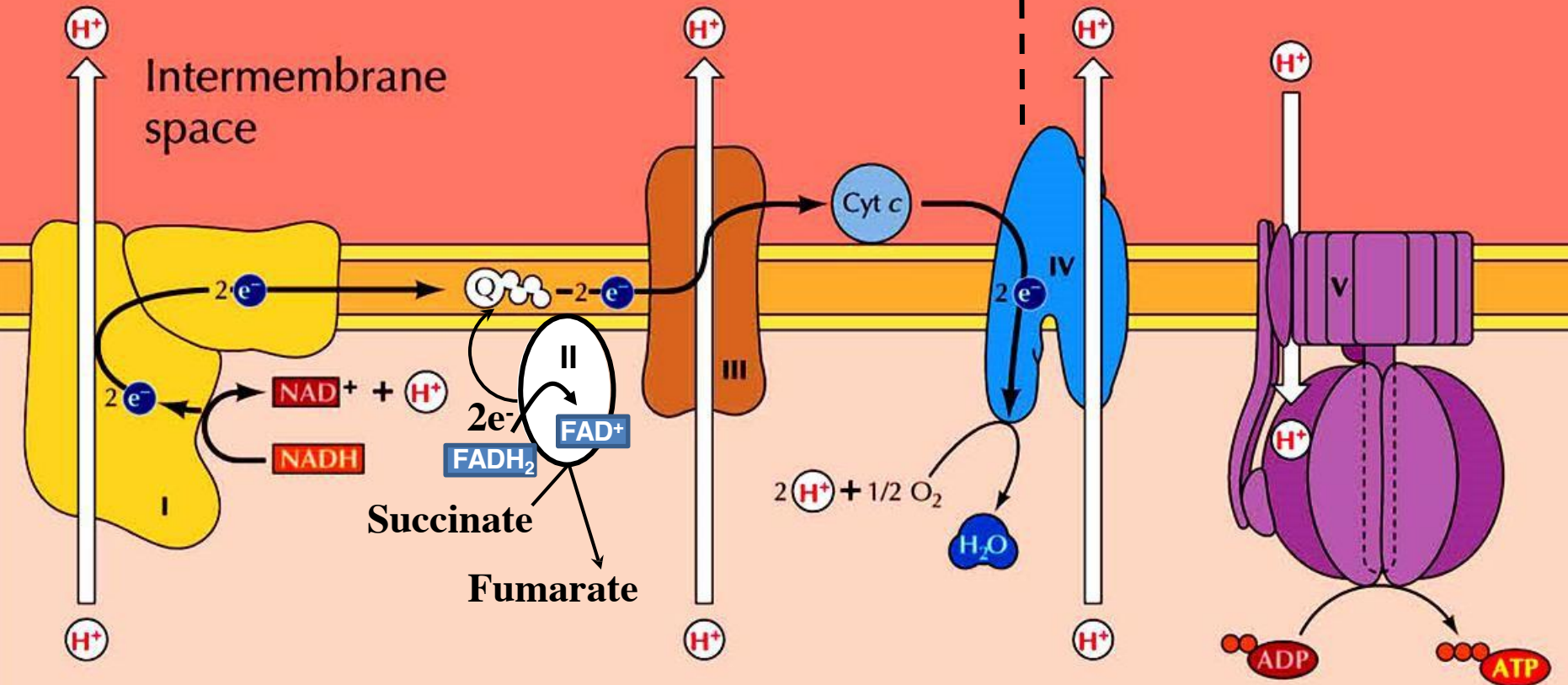


Matrix

4) Complex IV transfers electrons to molecular oxygen to form H_2O within the matrix

Cytosol

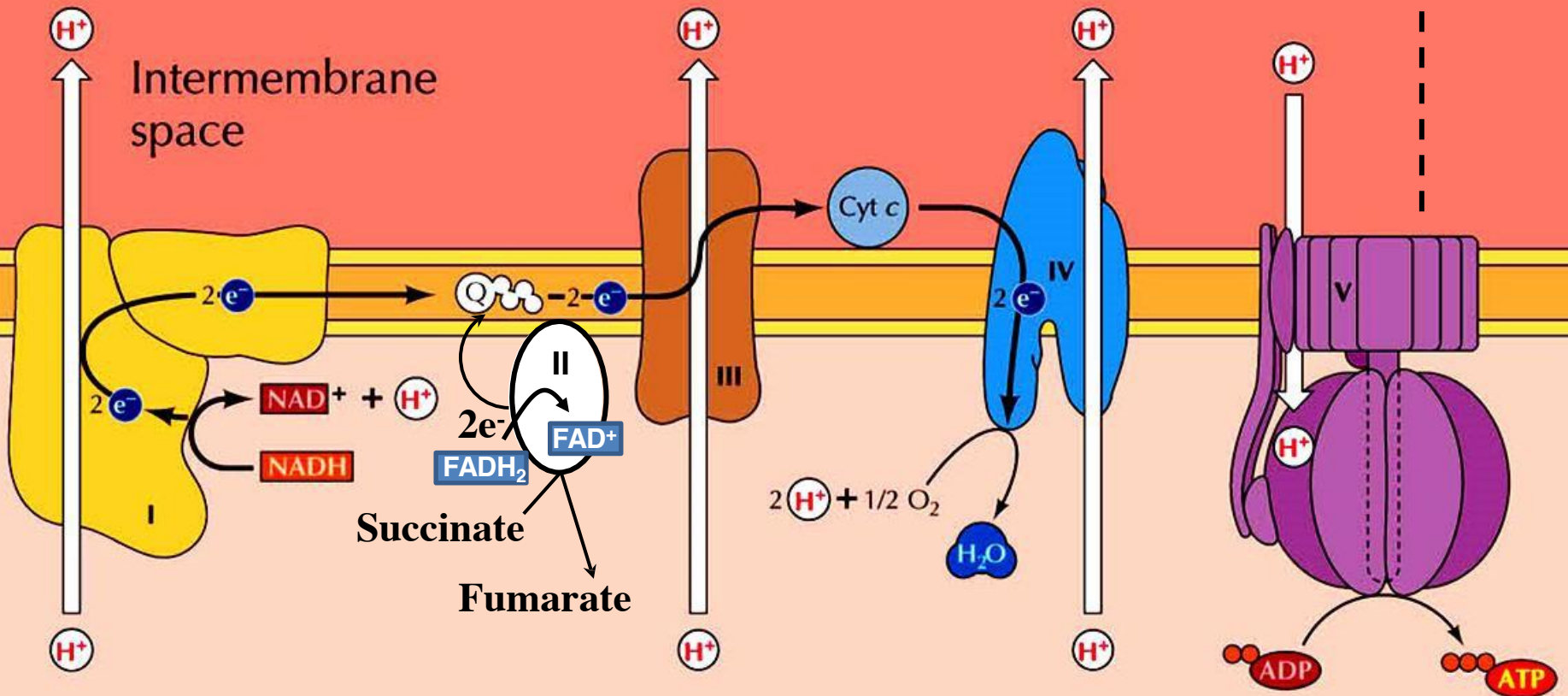
Intermembrane space



Matrix

5) The electron transfers in complexes I, III and IV generate energy, which is used to pump protons from the matrix to the intermembrane space, establishing a proton gradient across the inner membrane. The energy stored in the proton gradient is then used to drive ATP synthesis as the protons flow back to the matrix through complex V (or ATP synthase)

Cytosol



Matrix

ATP production is blocked by metabolic poisons such as cyanide, sodium azide and carbon monoxide - bind to catalytic sites of complex IV. inhibit the complex IV → not generating as much ATP

Electron transport can be "uncoupled" from ATP synthesis by endogenous proteins (uncoupling proteins) such as UCP1 in brown adipose tissue. UCP1 dissipates the H⁺ gradient and the energy of electron transfer is released as heat rather than a high-energy ATP molecule.

Chemicals (e.g. 2,4-dinitrophenol (or DNP)) also dissipate the proton gradient and prevent ATP production.

Therapeutic mechanism:

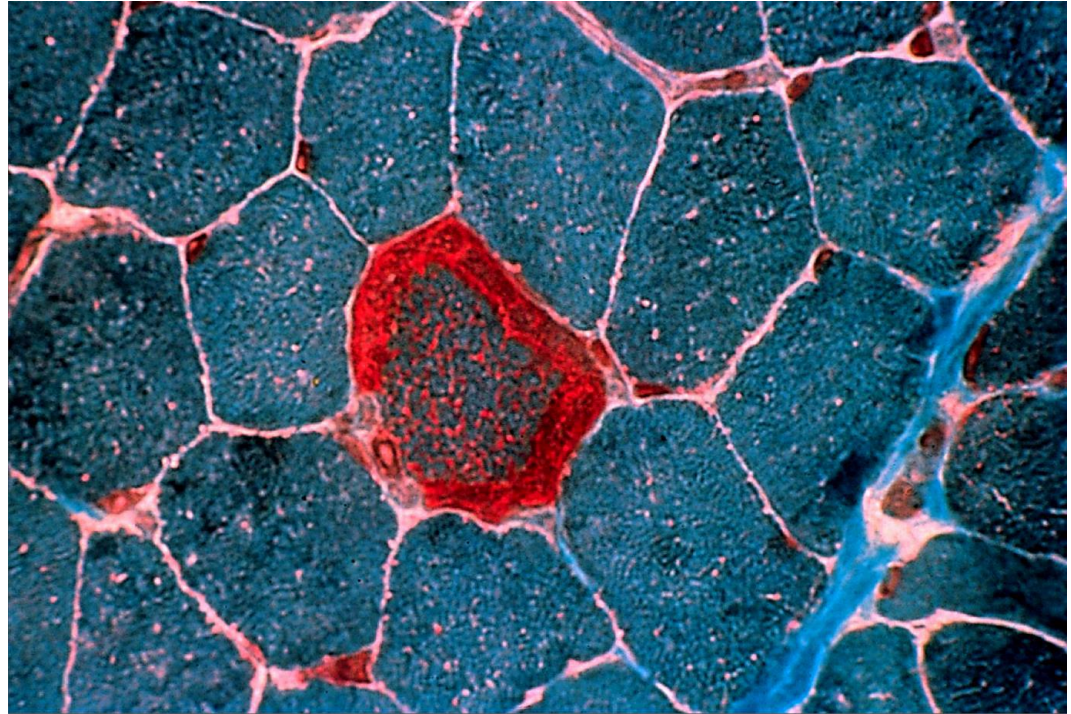
Reduced [ATP] causes the cell to oxidize stores of fat to replenish the [ATP]. Therefore, burn fat resulting in weight loss (in theory). a pill to lose weight not such a good idea

Mitochondrial disorders

Disorders that are due to abnormalities in mitochondrial structure and function most dramatically affect muscle and nerve tissues because of their high demand for ATP.

Ragged-red fibers in skeletal muscle of a patient suffering from the Myoclonic Epilepsy and Ragged Red Fibers (MERRF) disorder.

The red-stained "blotches" just beneath the cells' plasma membrane are due to abnormal proliferation of mitochondria that have decreased cytochrome c oxidase (complex IV) activity.



Mitochondrial disorders

Buildup of ROS in mitochondria cause a 10-fold increase in mutation rate of mitochondrial (mt)DNA compared to nuclear DNA. Thus, long-lived cells (nerve cells, muscle cells) may accumulate undesirable mtDNA mutations that can result in adult-onset neurological disorders (e.g. PD) and contribute to aging.

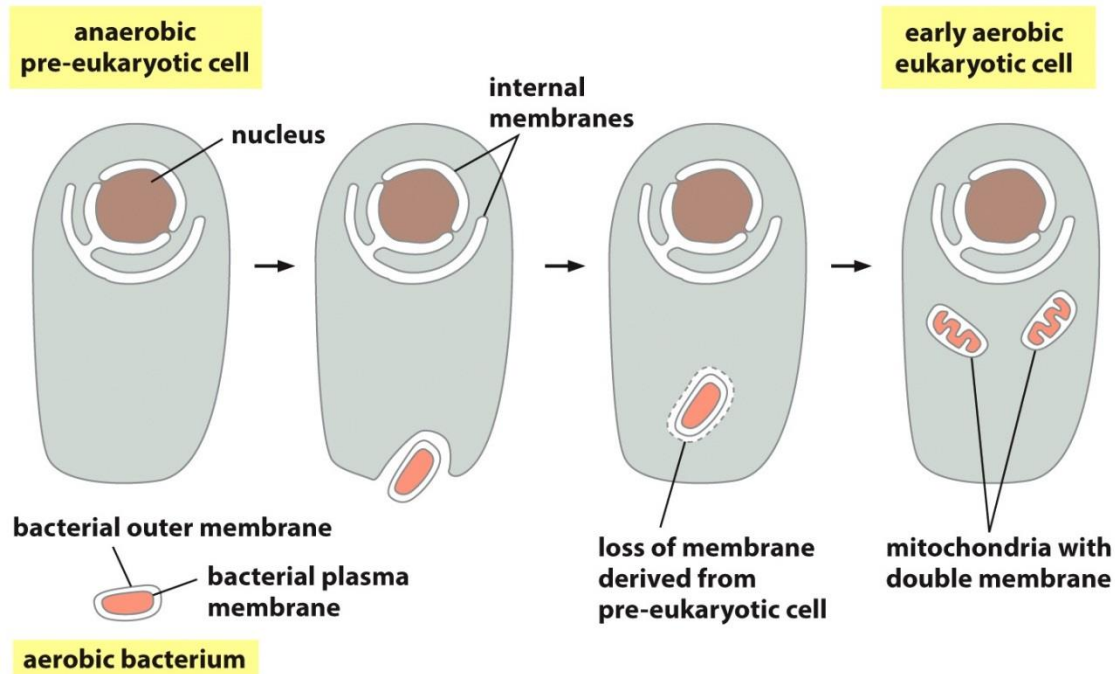
Heroin contaminated with a drug called MPTP caused young adults to present with PD-like tremors. MPTP damages complex I. PD patients have a decrease in complex I activity.

MPTP: not toxic by itself but when it interferes with heroin it attacks complex I

PD: parkinsons disease

Yeast "petite" colonies arise from loss of mitochondrial DNA. They cannot respire and hence can only utilize fermentable carbon sources (e.g. glucose) but not non-fermentable carbon sources (e.g. glycerol, ethanol).

Origins of mitochondria



Endosymbiont theory: mitochondria (and chloroplasts) are derived from smaller prokaryotic cells that took up residence in a eukaryotic cell.

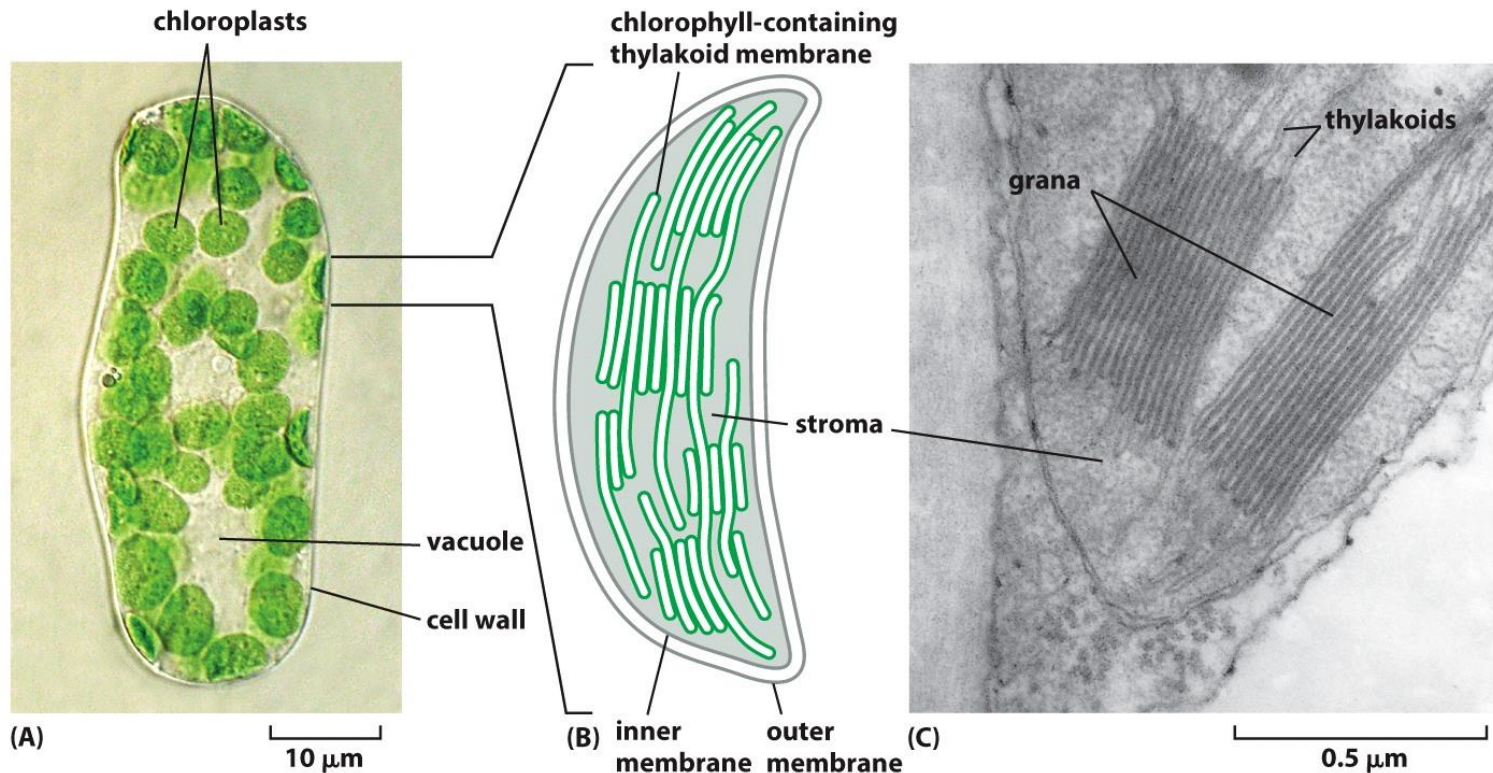
Support for the theory:

1. Outer membrane of bacteria and mitochondria contain porins
2. Inner membrane of bacteria and mitochondria contain the lipid cardiolipin
3. Mitochondria arise from pre-existing mitochondria via fission
4. Mitochondria and bacteria contain a single, circular DNA
5. Mitochondrial ribosomes are similar to those of bacteria (70S)

Chloroplasts resemble mitochondria in that both contain a permeable outer membrane and a relatively impermeable inner membrane

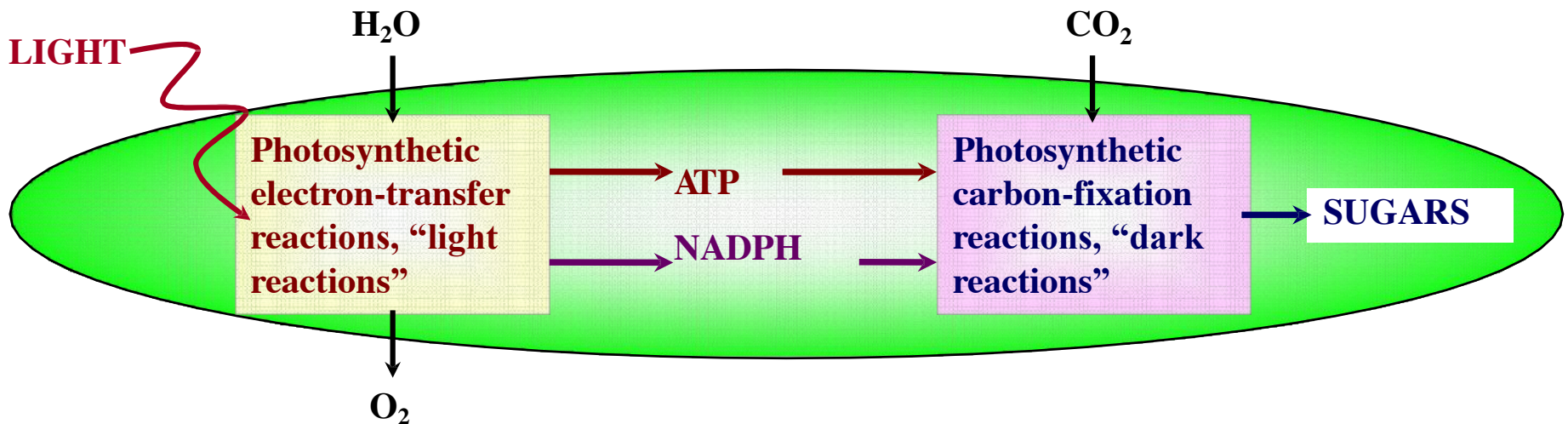
Stroma is analogous to the mitochondrial matrix.

A third membrane is formed by the **thylakoids** (orderly stacks are called **grana**).



Chloroplasts:

- are the largest and most characteristic organelles in the cells of plants
- are the sites of **photosynthesis** - a series of light-driven reactions that creates organic molecules from atmospheric carbon dioxide (CO_2)
- perform photosynthesis during the day light hours and thereby produce **ATP** and **NADPH**, which in turn are used to convert CO_2 into sugars inside the chloroplast

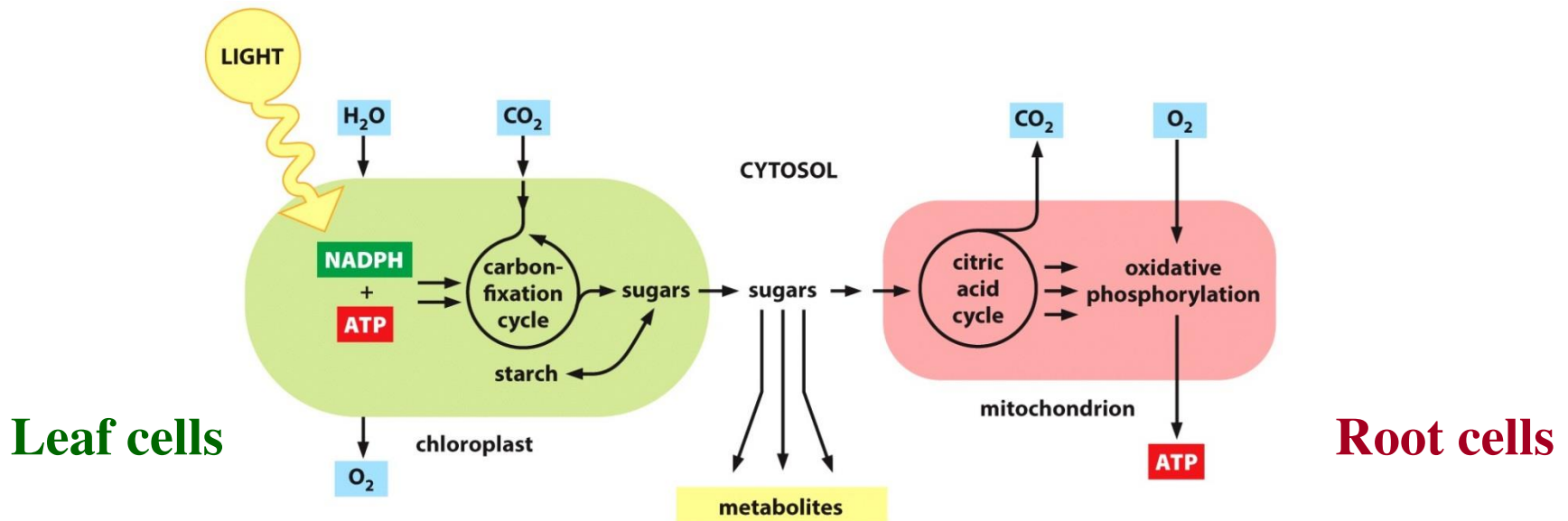


In plants, the chloroplasts and mitochondria collaborate to supply cells with metabolites and ATP

The plant contains many cells that lack chloroplasts and therefore cannot produce their own sugars and ATP.

Therefore for most of its ATP production, the plant relies on an export of sugars from its chloroplasts to the mitochondria that are located in all cells of the plants.

Most of the ATP needed by the plant is synthesized in these mitochondria.



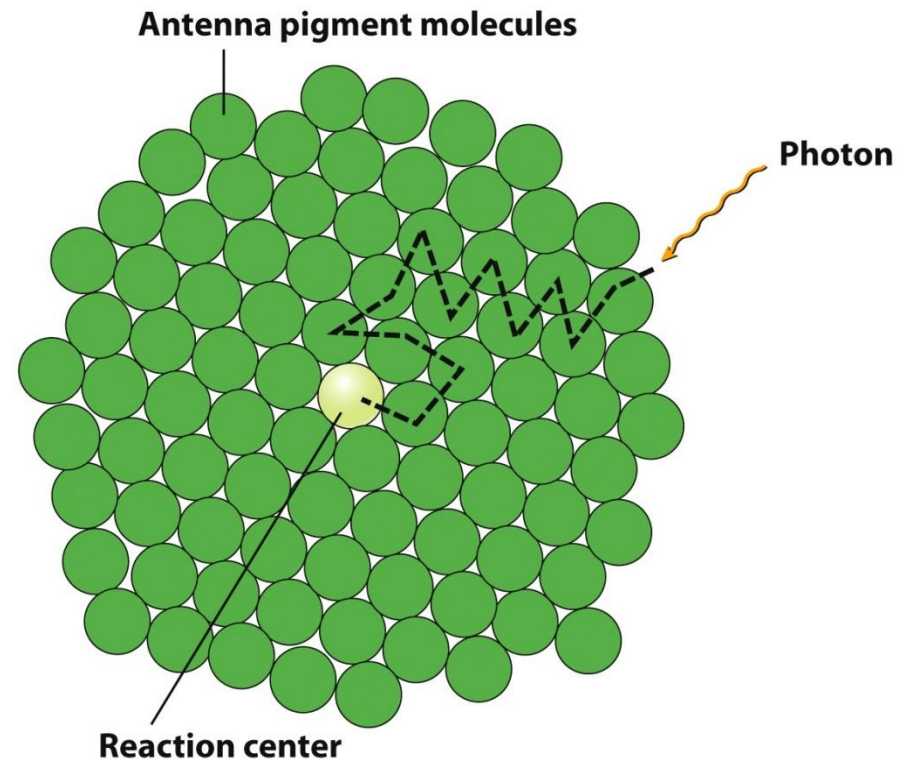
Three of four stages in photosynthesis (the “light reactions”) take place in the thylakoid membranes:

1. Absorption of light by green pigments (chlorophylls) attached to proteins
2. Electron transport to generate a H^+ gradient
3. Synthesis of ATP and NADPH
- 4.

Each photosynthetic unit contains several hundred chlorophyll molecules.

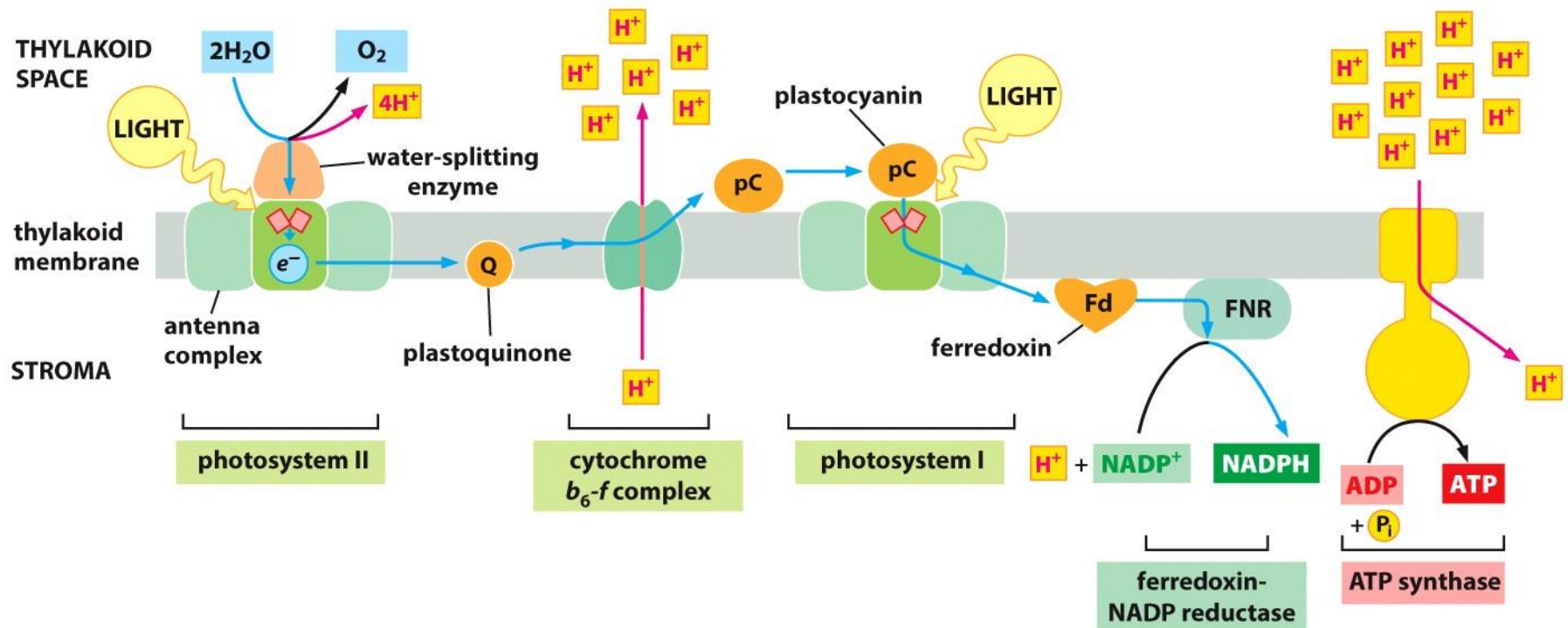
One member of the group—the reaction-center chlorophyll—transfers electrons to an electron acceptor.

The other pigments act as harvesting antennae and rapidly transfer photons to the reaction center (antenna pigments).

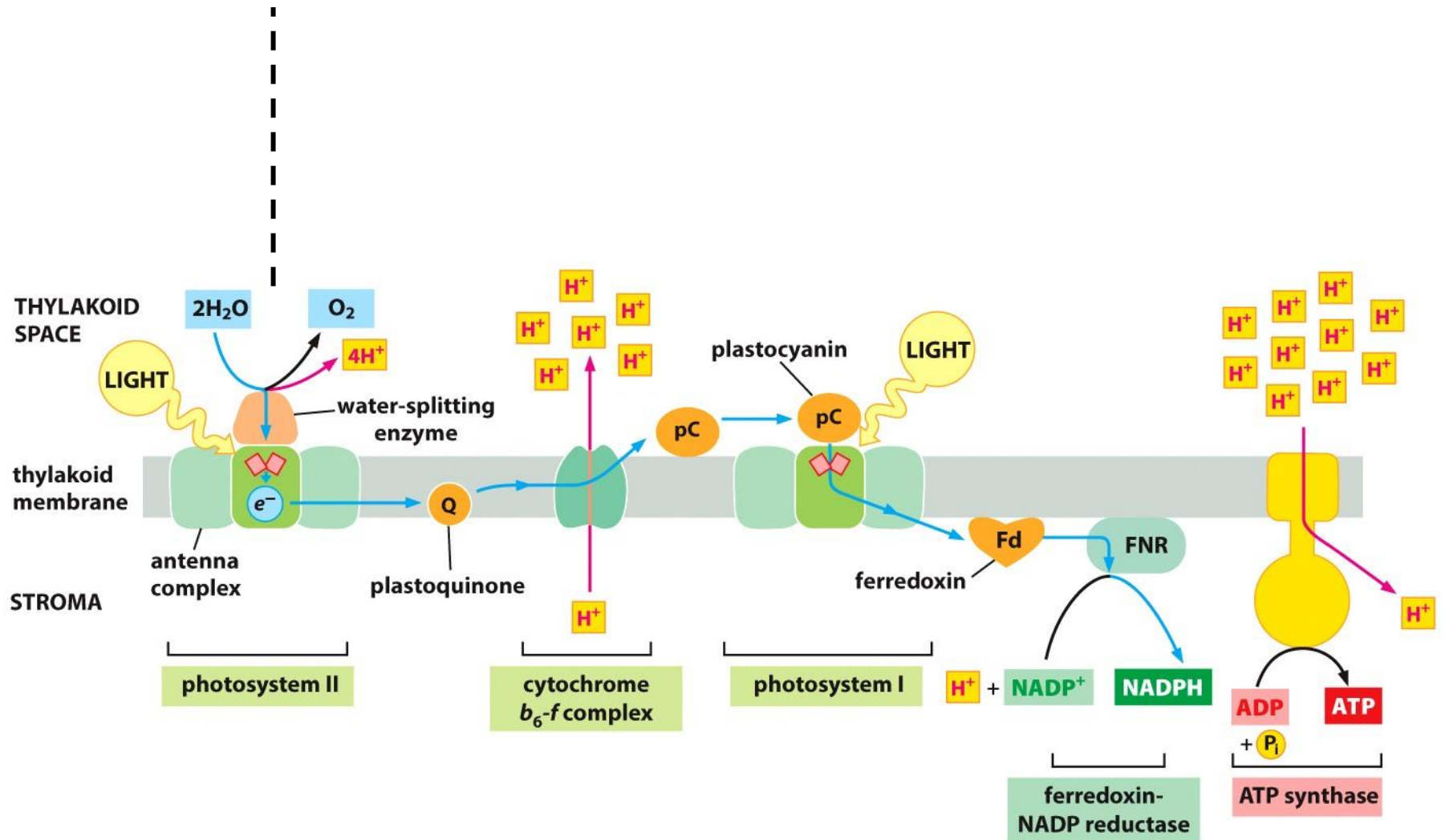


Electron transport generates a H^+ gradient across the thylakoid membrane with the lumen containing a higher concentration of protons compared to the stroma.

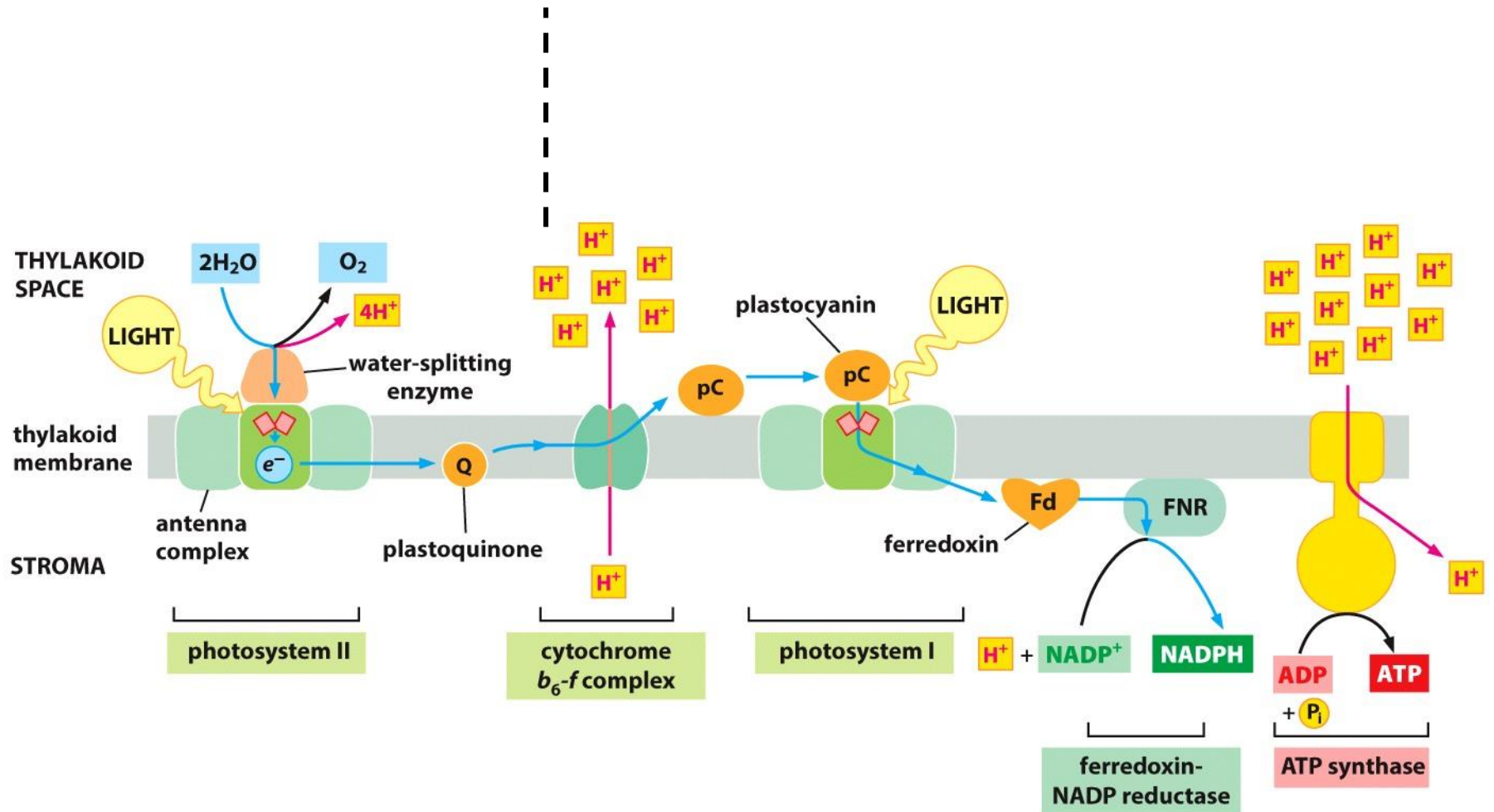
Photosynthetic units are found in two large protein complexes called Photosystems I and II (PSI and PSII). These complexes are embedded in the thylakoid membrane.



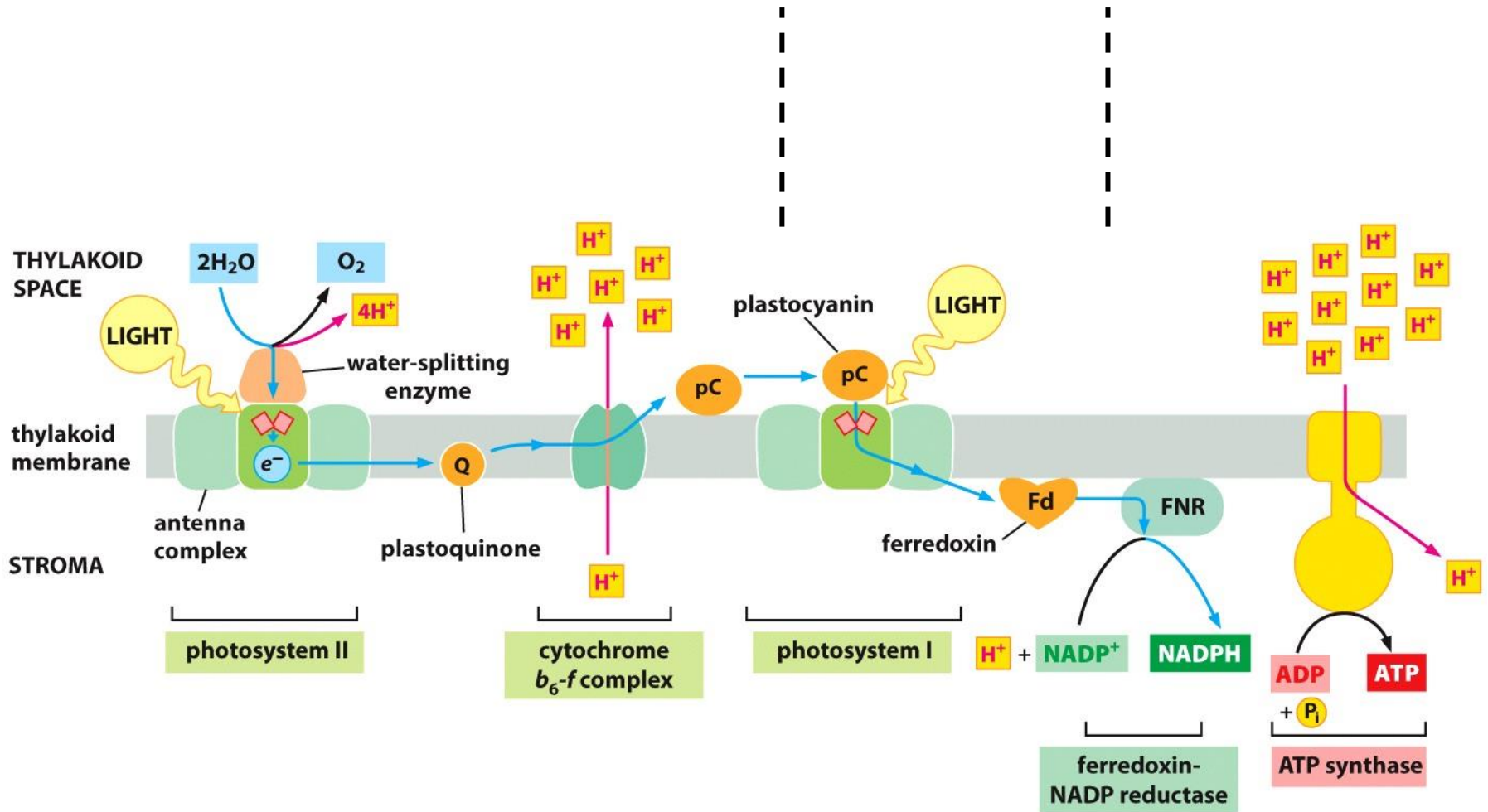
When the reaction center of PSII is excited by a photon, water is split into O_2 , protons are released and the electrons enter the transfer chain.



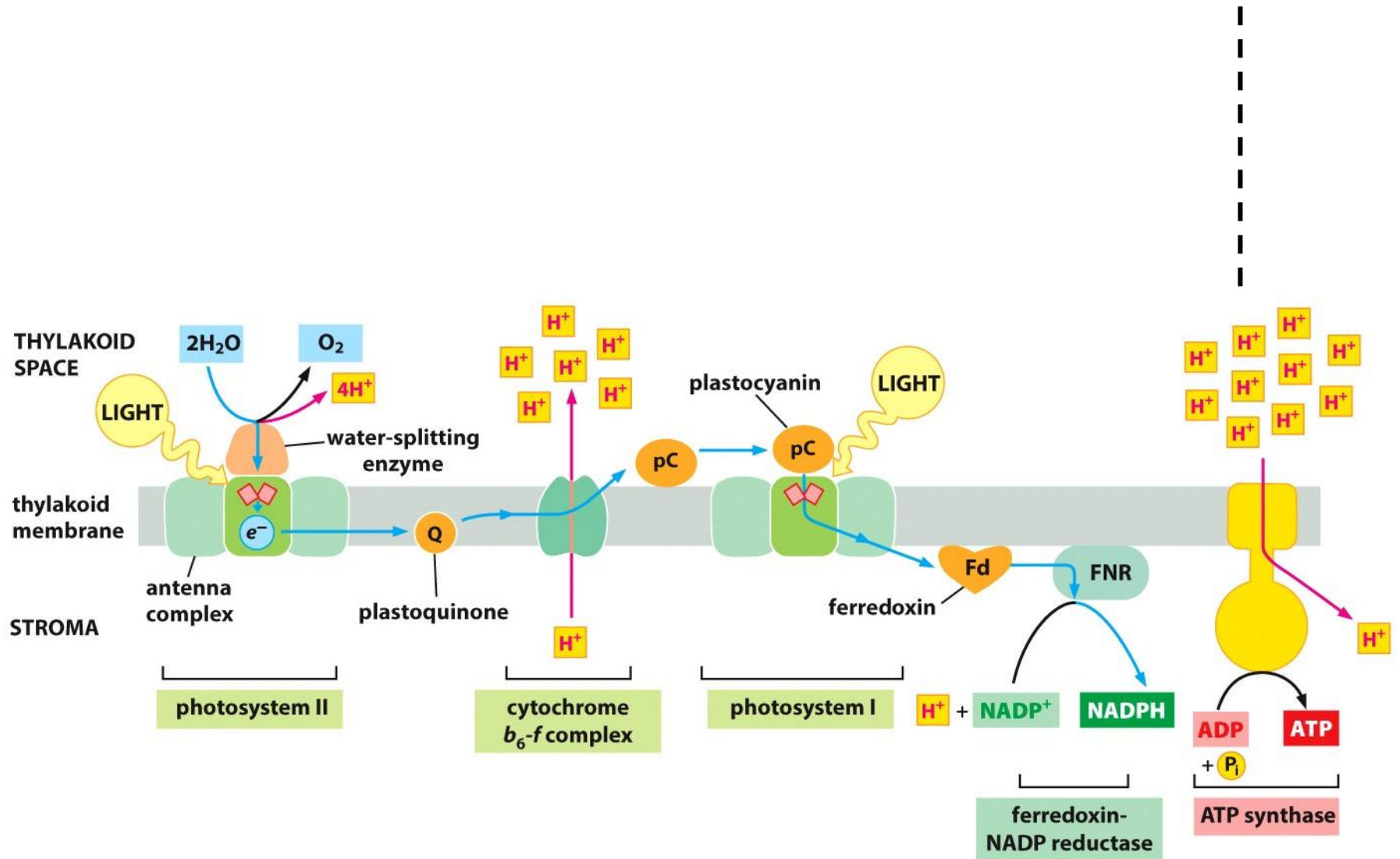
The electrons are transferred from PSII to the cytochrome b_6 -f complex by the lipid-soluble **plastoquinone (Q)**. Electron transfer through cytochrome b_6 -f allows for the entry of more protons into the lumen of the thylakoid.



Plastocyanin, a luminal protein of the thylakoid, transfers the electrons to PSI, which in turn passes the electrons to a water-soluble molecule called **ferredoxin**. This Fe-S protein associates with **ferredoxin-NADP⁺ reductase (FNR)** to produce **NADPH**.



The **ATP synthase** of the thylakoid membranes then couples proton movement into the stroma to **ATP** synthesis.



Herbicides target:

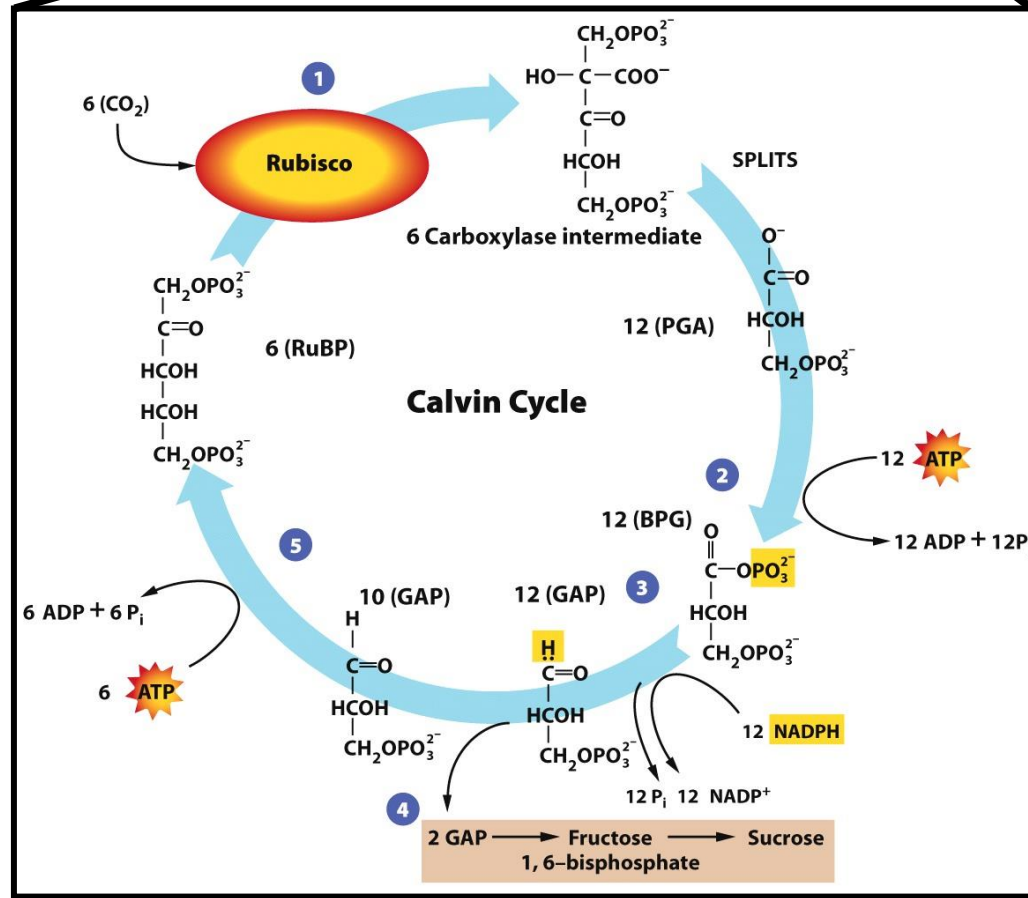
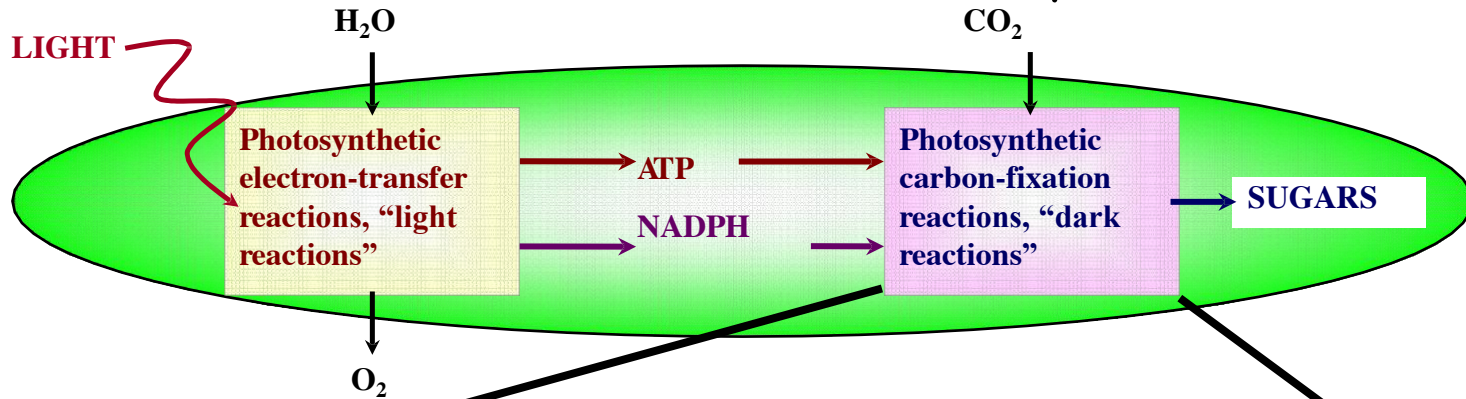
PSII (diuron, atrazine, terbutryn) by blocking electron transport through this complex

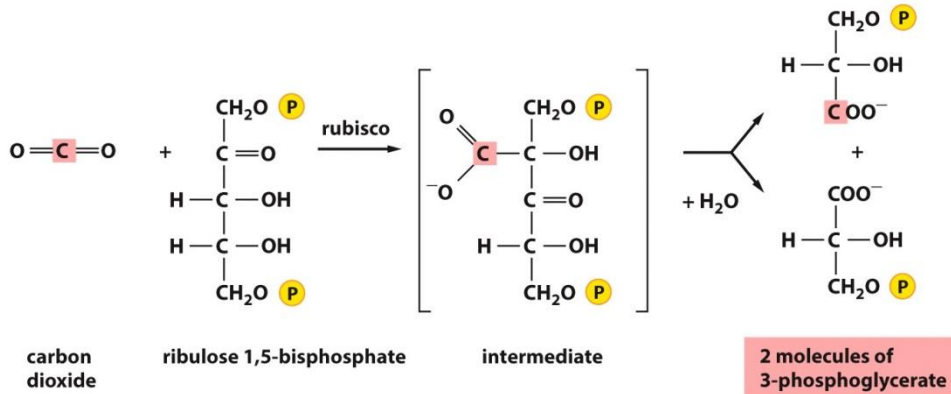
PSI (paraquat) by competing with ferredoxin for electrons, which are transferred to O_2 to create reactive oxygen that damages chloroplasts and kills the plant. It also diverts electrons from complex I in humans with similar effects.

Comparison between chloroplasts/photosynthesis light reactions (PSLR) and mitochondria/oxidative phosphorylation (OP)

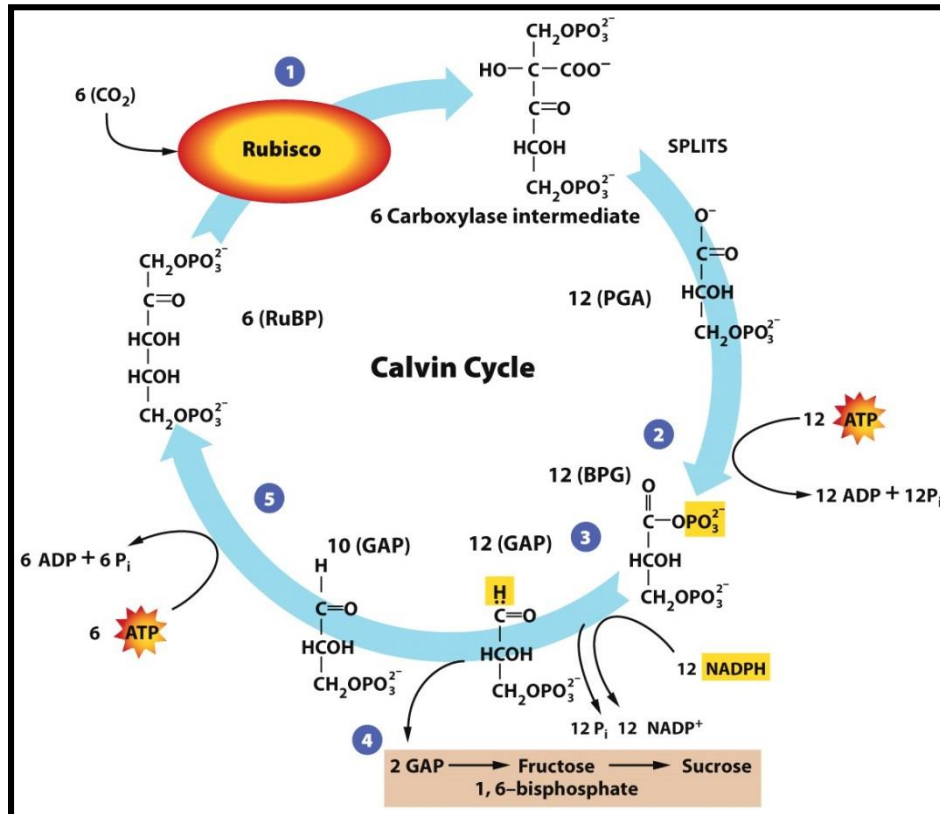
- Both generate ATP, and both use a proton pump to do so.
- Both contain DNA and ribosomes.
- Both are surrounded by a double membrane.
- Chloroplasts contain an additional third membrane (thylakoid) while the inner mitochondrial membrane forms cristae
- Mitochondria rely on both a proton gradient and a charge gradient across the inner membrane to generate ATP, while chloroplasts rely on a proton gradient (the charge is neutralized by the permeability of the thylakoid membrane to ions such as Cl^- and Mg^{2+}).
- The electron transfer chain of both organelles is composed of a number of large protein complexes.
- The terminal electron acceptor in OP is O_2 and in PSLR it is NADPH.
- OP requires O_2 and produces CO_2 as a byproduct while PSLR produce O_2 and (in the Calvin cycle) utilize CO_2 .

Carbon fixation and the Calvin cycle





Rubisco is highly inefficient (fixes only 3 CO_2/sec). Therefore, cells need abundant amounts (50% of leaf protein). Hence, given the number of plants on earth, it is the most abundant protein on the planet (5-10kg of rubisco for every human).



Consumes 18 ATP/glucose molecule. Oxidative phosphorylation of that glucose molecule results in ~30 ATP, therefore net gain.