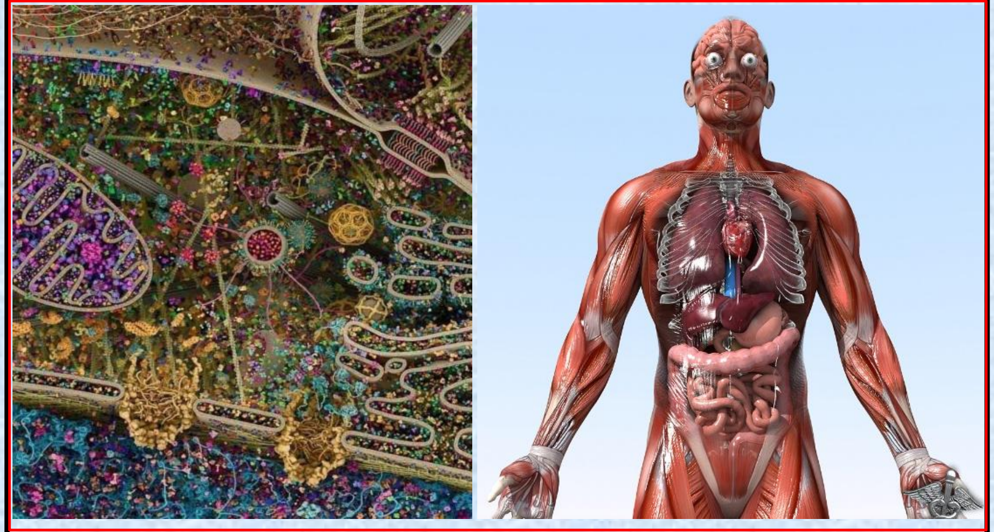
General Animal Biology

Zoo-109

علم الأحياء

109- حيـن



For Pre-Medical Students

Common First Year

السنة الأولى المشتركة - المسار الصحي

1447-H - 2026

Reference: *Campbell, N. A. and Reece, J. B. (2014). Biology (10th edition). Pearson Education. Inc. USA.*

عمادة التعليم الإلكتروني والتعلم عن بعد
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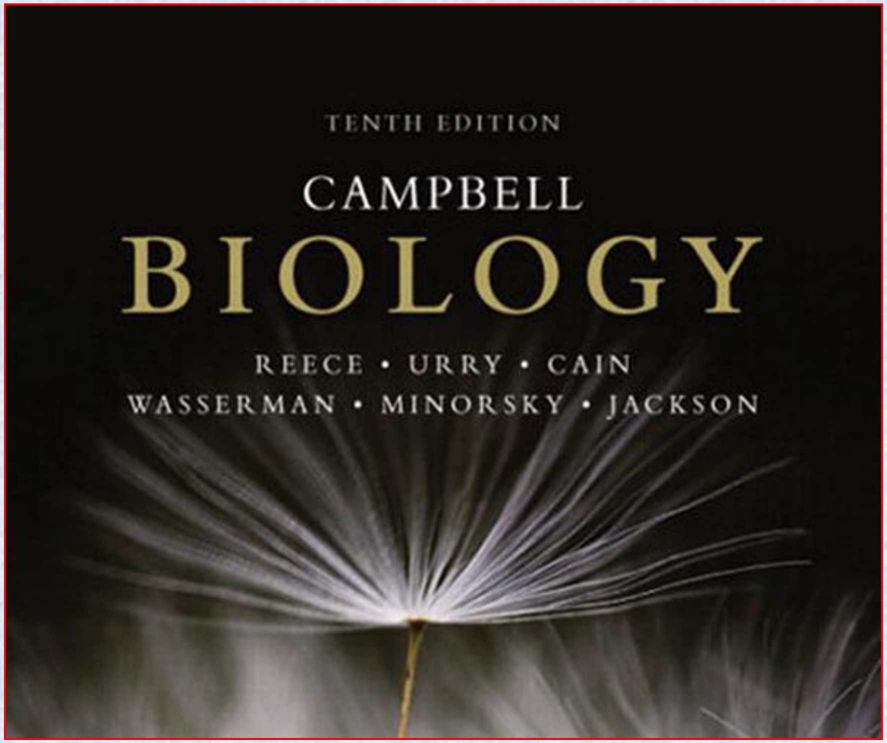

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BIOLOGY

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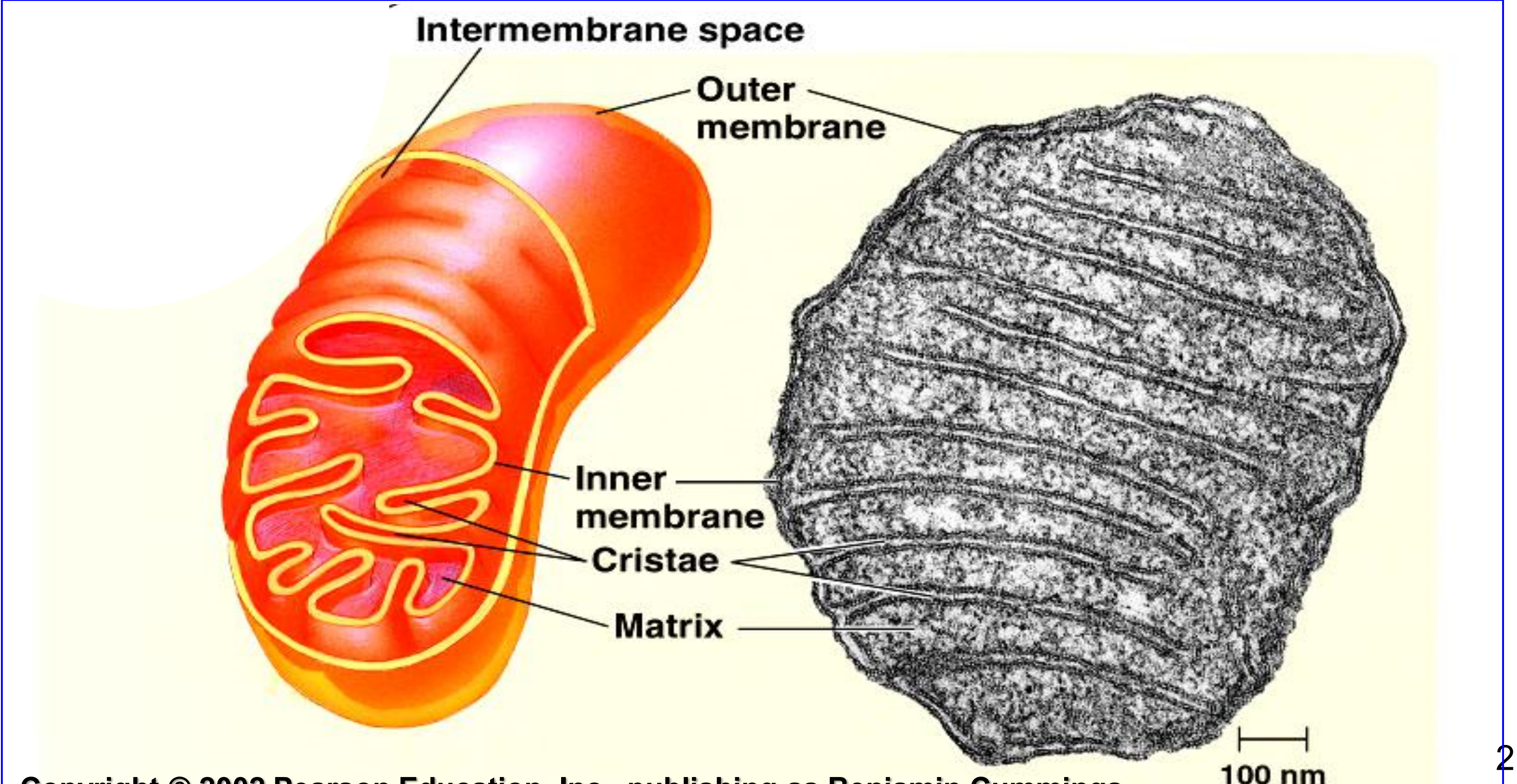
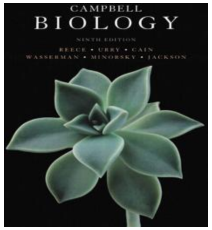
بسم الله الرحمن الرحيم

CELLULAR RESPIRATION: Harvesting chemical energy

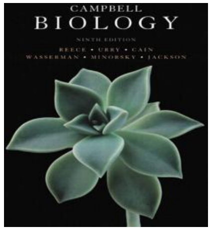




Objectives

The Principles of Energy Harvest.

- **Cellular respiration and fermentation are catabolic, energy-yielding pathways.**
- **Production of Adenosine Tri-Phosphate (ATP).**
  - Redox reactions release energy when electrons move closer to electronegative atoms.
  - Electrons "fall" from **organic molecules** to **oxygen** during cellular respiration.



Overall process

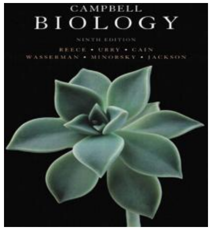
a) Organic compounds + O_2 → CO_2 + H_2O + energy

b) Food is the fuel for cellular respiration.

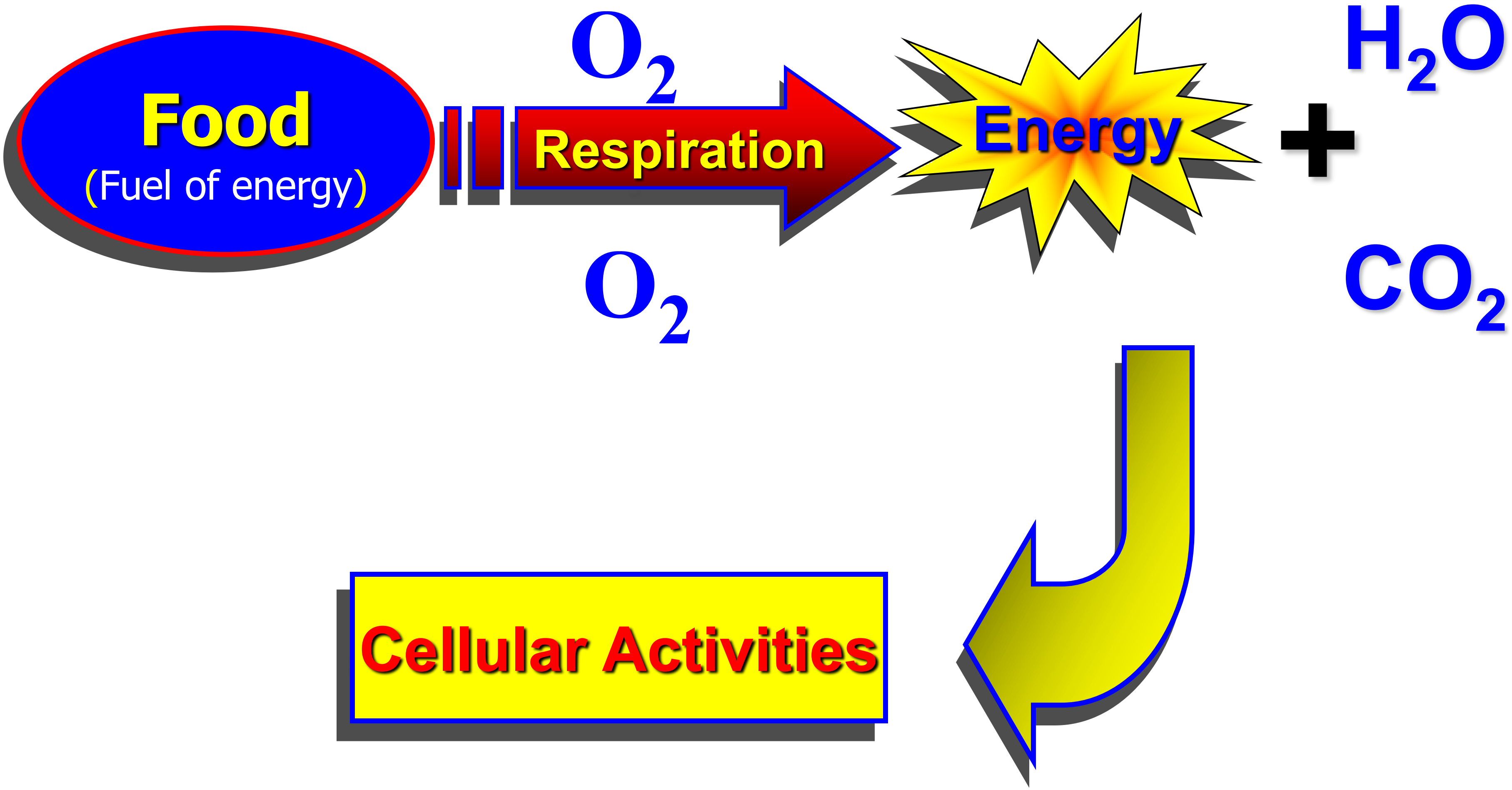
c) Cellular respiration is a catabolic pathway: it releases energy by breaking down complex molecules.

d) Cellular respiration involves movement of electrons (gain or loss).

e) We will study the breakdown of glucose as an example.



Cellular Respiration



Food

(Fuel of energy)

O_2

Respiration

O_2

Energy

+

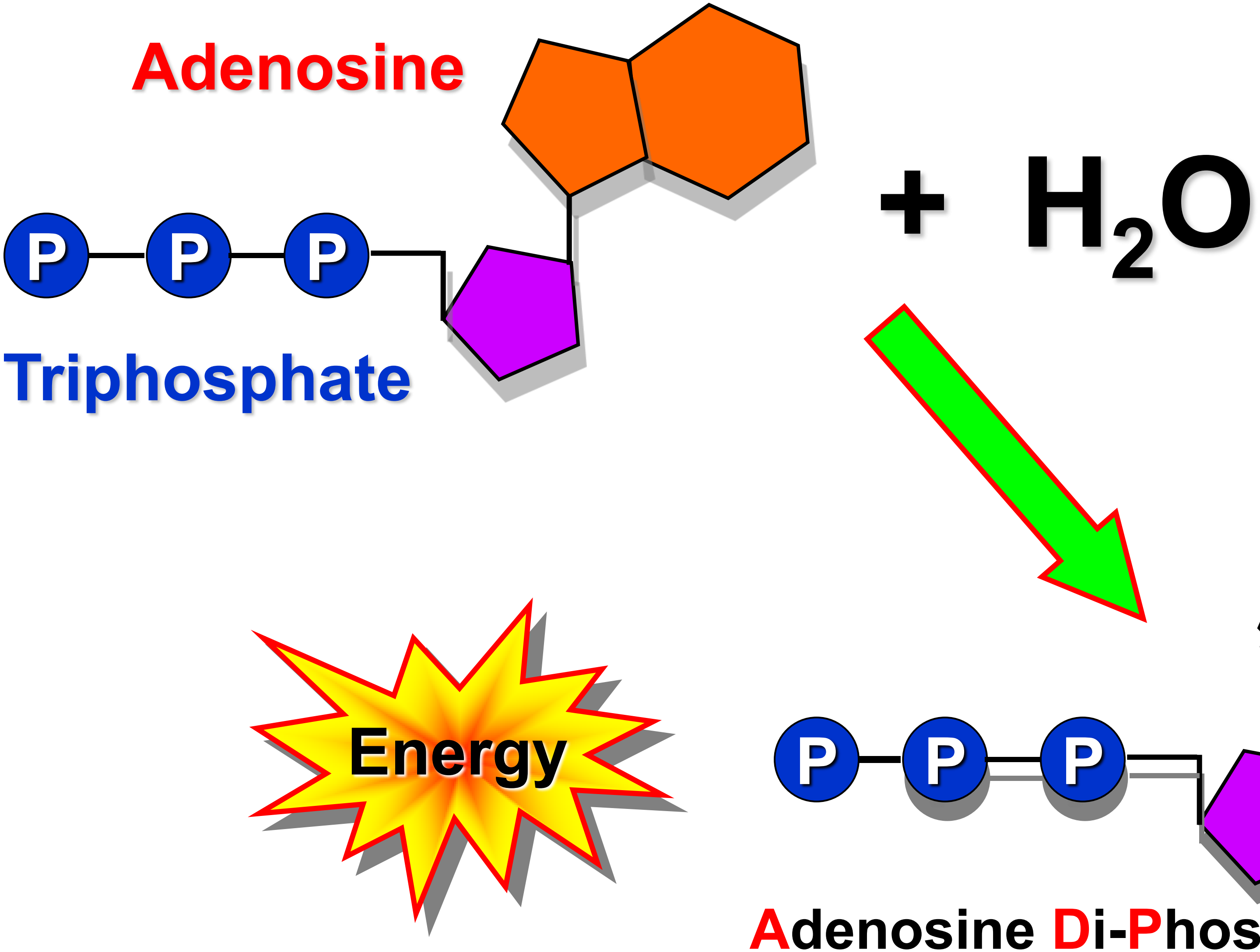
H_2O

CO_2

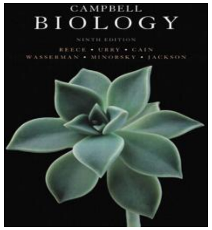
Cellular Activities

Organic compounds + O_2 $\longrightarrow$ Energy + CO_2 + H_2O

Adenosine Tri-Phosphate (ATP)



Adenosine Di-Phosphate

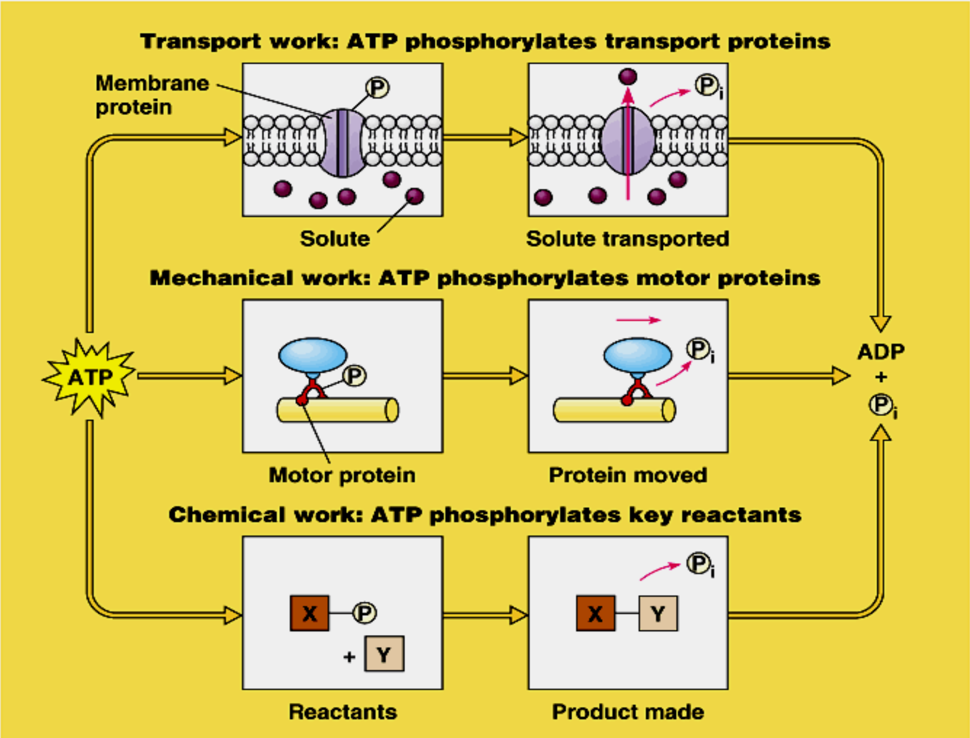


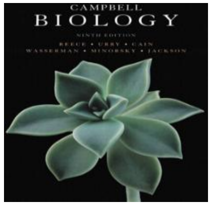
Importance of ATP

The transfer of the terminal phosphate group from ATP to another molecule is phosphorylation فَسْفَرَة.

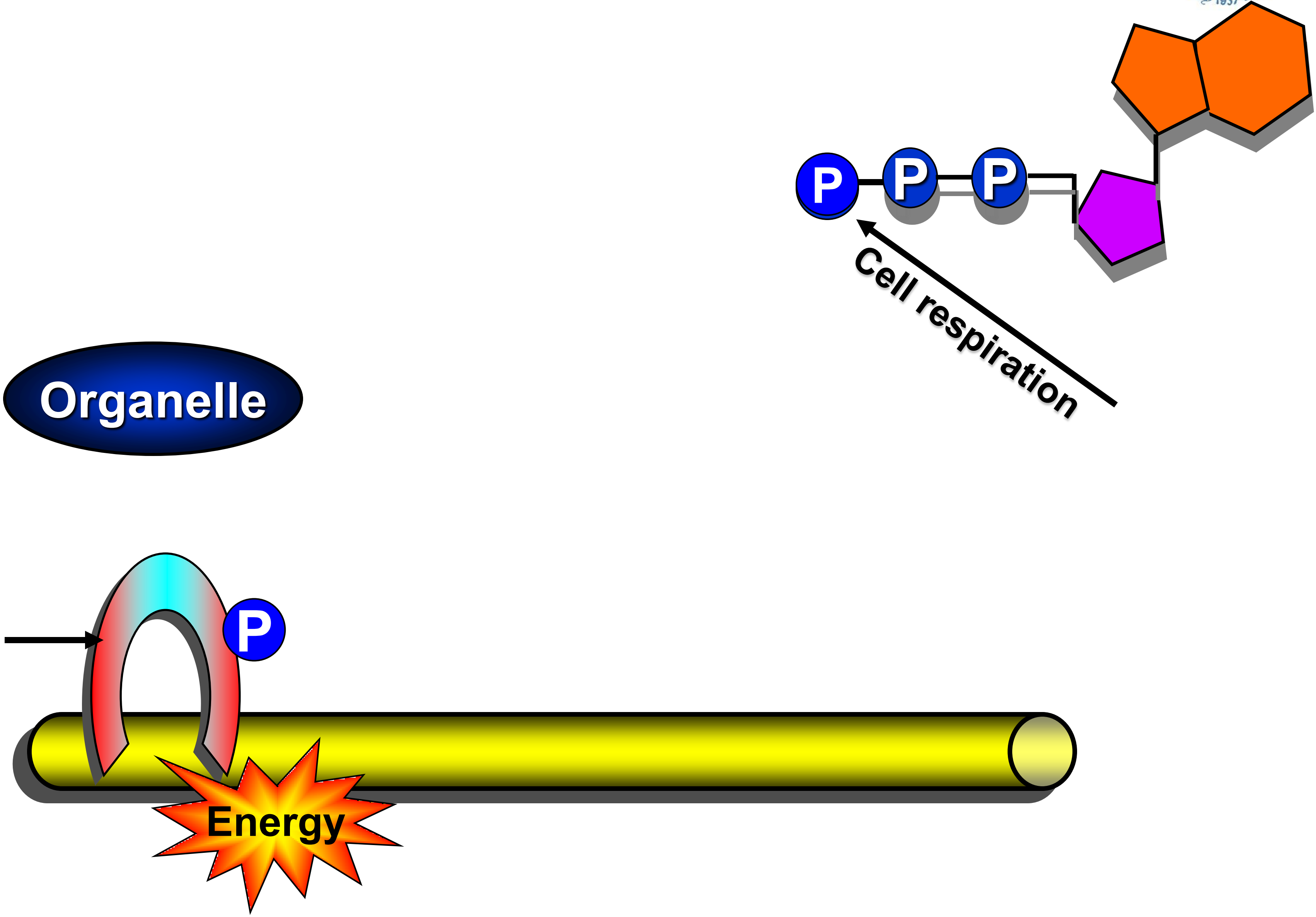
This changes the shape of the receiving molecule in order to work (transport, mechanical, or chemical).

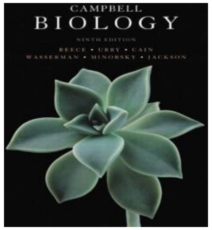
- When the phosphate group leaves the protein molecule, it returns to its original shape.





How dose ATP drive cellular work ?



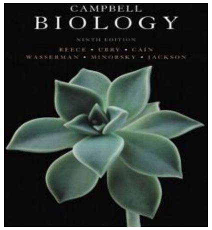


Cells recycle the ATP they use for work

- **ATP (Adenosine Tri-Phosphate) is the important molecule in cellular energetics عمليات إنتاج الطاقة.**
  - **The attachment of three negatively-charged phosphate groups (P) is an unstable غير مستقر, energy-storing مخزن للطاقة arrangement.**
  - **Loss of the end phosphate group release energy.**
  - **Thus, it can diffuse to any part of the cell and release energy.**

The price of most cellular work is the conversion of ATP to ADP and phosphate (P).

An animal cell regenerates تعيد إنتاج ATP from ADP by adding P *via* the catabolism هدم of organic molecules (e.g. glucose).



Redox reactions release energy when electrons move closer to electronegative atoms

- Catabolic pathways relocate يبدل أماكن the electrons stored in food molecules, releasing energy that is used to synthesize لتخليق ATP.
- **Reduction-Oxidation reactions (Redox reactions):**

  Are reactions that result in the transfer of one or more electrons from one reactant to another.
- **Reduction:** Is the addition إكتساب of electrons.
- **Oxidation:** Is the loss فقد of electrons.

Redox reactions require both a donor and acceptor of (*e*).

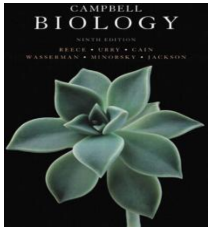
Oxidation	Reduction
Lose electrons	Gain electrons
Lose hydrogen (H)	Gain hydrogen (H)

$$Xe^{-} \quad + \quad Y \longrightarrow X^{+} \quad + \quad Y$$

Oxidation   Reduction   Reducing agent   Oxidizing agent

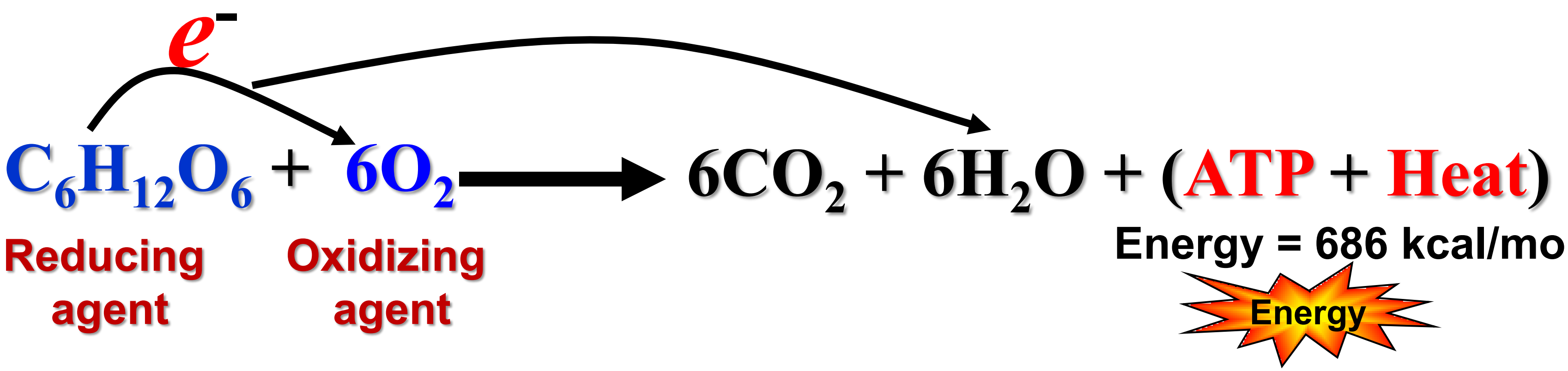
$$Na + Cl \longrightarrow Na^{+} + Cl^{-}$$

Energy



Electrons "fall" *from organic molecules* to *oxygen* during cellular respiration

- In cellular respiration, glucose and other fuel molecules are oxidized, releasing energy.



e^-

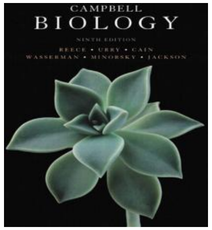
$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + (ATP + Heat)$$

Reducing agent

Oxidizing agent

Energy = 686 kcal/mol

- <u>Glucose is oxidized, oxygen is reduced</u>, and electrons lose potential energy.
- H is the source of electrons that transfers to O.
- Thus, molecules that have an abundance of وفرة من H are excellent fuels because their bonds are a source of electrons that "fall" closer to O.
- Enzymes lower the barrier of activation energy, allowing these fuels to be oxidized slowly.
- When H moves to O, it leaves bonds which degenerated to release energy.
- The resulting energy is used by the cell to synthesis ATP .

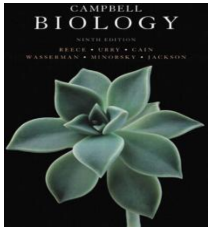


The “fall” of electrons الإنحدار الإليكتروني during respiration is stepwise مرحلي, by NAD⁺ and an electron transport chain

- Cellular respiration does not oxidize glucose in a single step that transfers all the H in glucose to O at one time.
- Rather, glucose and other fuels are broken down gradually تدريجيا in a series of steps, each catalyzed by a specific enzyme.
- At key steps فى الخطوات الأساسية, H atoms move from glucose and passed first to the coenzyme NAD^+ (*Nicotinamide Adenine Dinucleotide*).
- **Dehydrogenase enzymes** strip two H atoms from the fuel (e.g., glucose), pass two electrons to NAD^+ and release H^+.
- This changes the oxidized form, NAD^+, to the reduced form NADH. Thus, NAD^+ is oxidizing agent as it accepts electrons.
  - NAD^+ functions as the oxidizing agent in many of the redox steps during the catabolism of glucose.

$$\text{H-C-OH} + NAD^+ \xrightarrow{\text{Dehydrogenase}} \text{C=O} + NADH + H^+$$

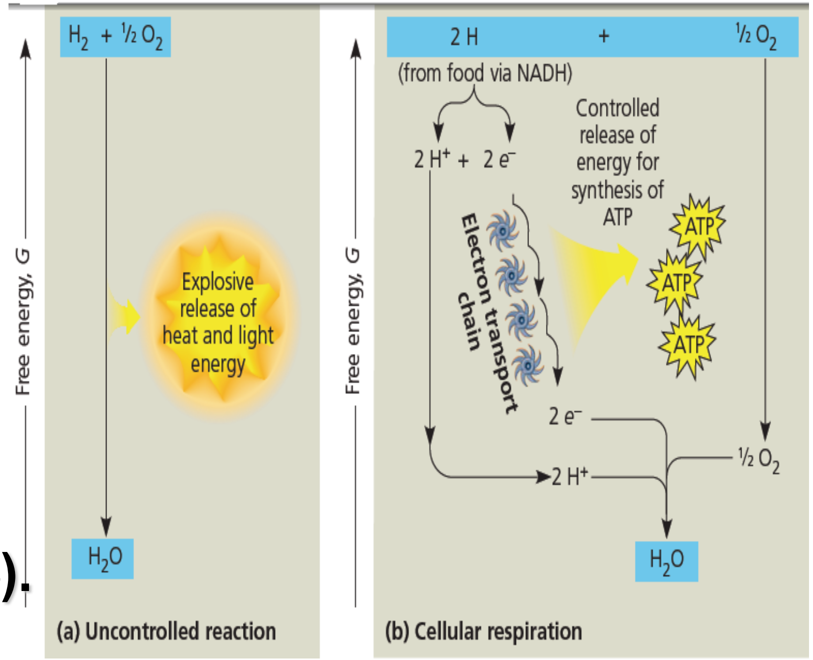
- **As electrons “fall” from NADH to O, their energy is used to synthesize ATP.**



Electron transport chain

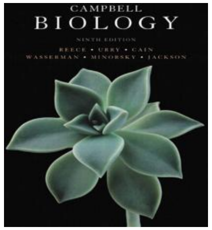
- Cellular respiration uses an electron transport chain سلسلة نقل الإليكترونات to break يُقسّم the fall of electrons to O into several steps عدة خطوات.

- The electron transport chain, consisting of several molecules (primarily proteins), is built into the inner membrane of a mitochondrion.
- NADH takes electrons from food to the "top" of the chain.
- At the "bottom", O captures the electrons and H^+ to form water.
- Electrons are passed by the chain until they are caught by O (*the most electronegative*).



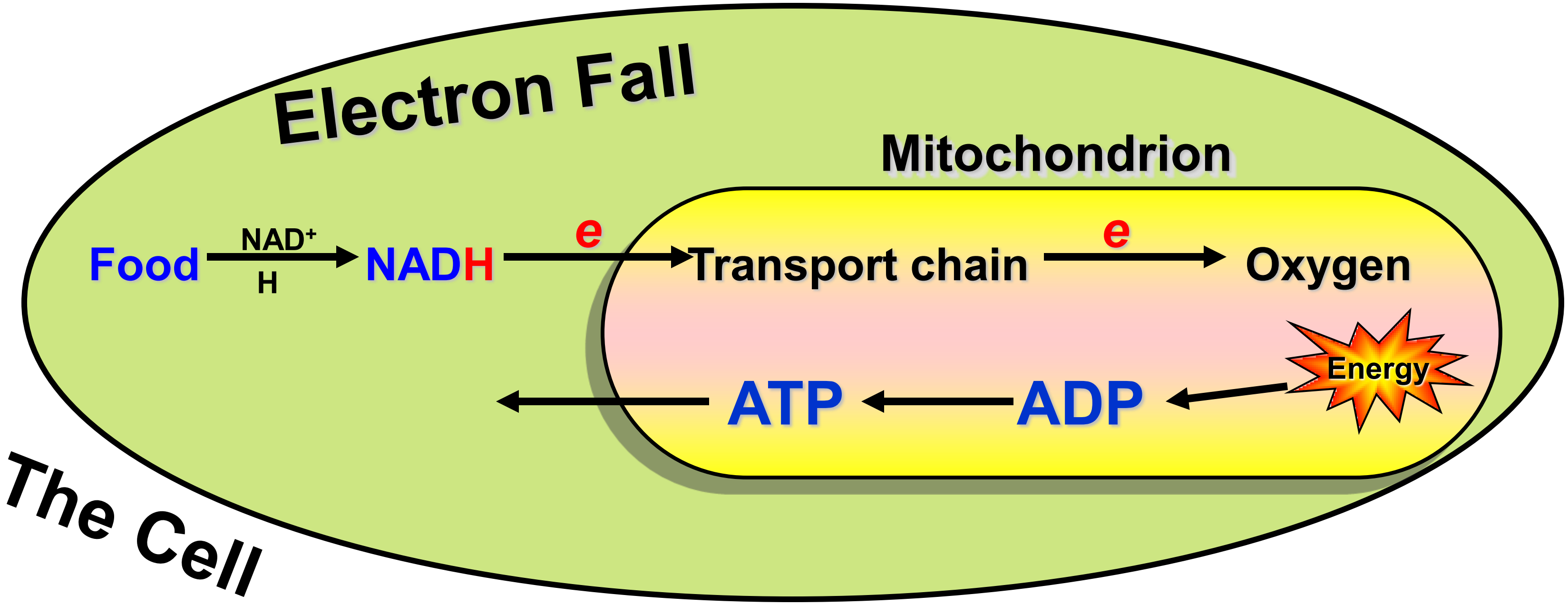
(a) Uncontrolled reaction

(b) Cellular respiration



Summary of electron “Fall” steps

- Falling of all H atoms from glucose to O is gradually not at once.
- It occurs in steps, each step is catalysed by an enzyme.
- H atoms of glucose pass first to the co-enzyme NAD^+ to form NADH
- Then from NADH to electron transport chain, and finally to O and releases energy to form ATP.



Electron Fall

Mitochondrion

Food $\xrightarrow[H]{NAD^+}$ NADH $\xrightarrow{e}$ Transport chain $\xrightarrow{e}$ Oxygen

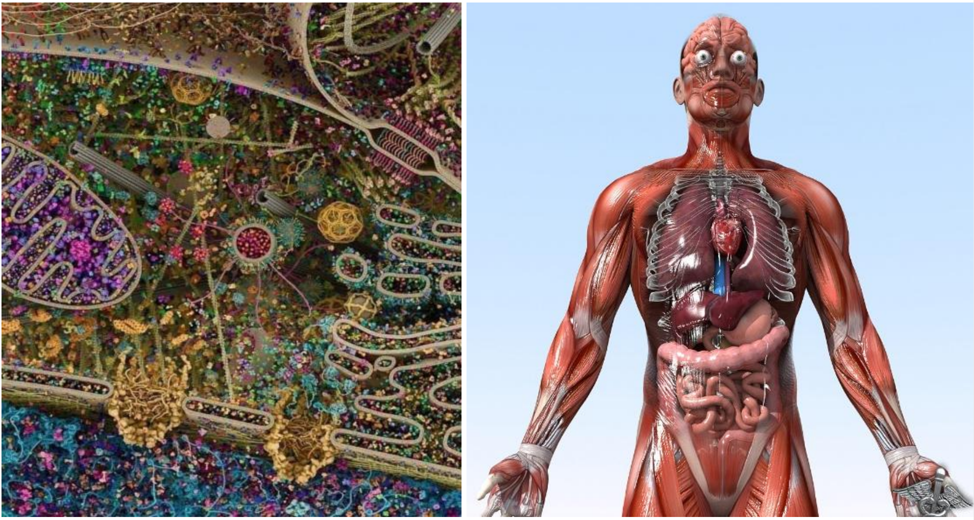
Energy

ATP ← ADP ←

The Cell

General Animal Biology

Zoo-109 علم الأحياء 109- حـيـن



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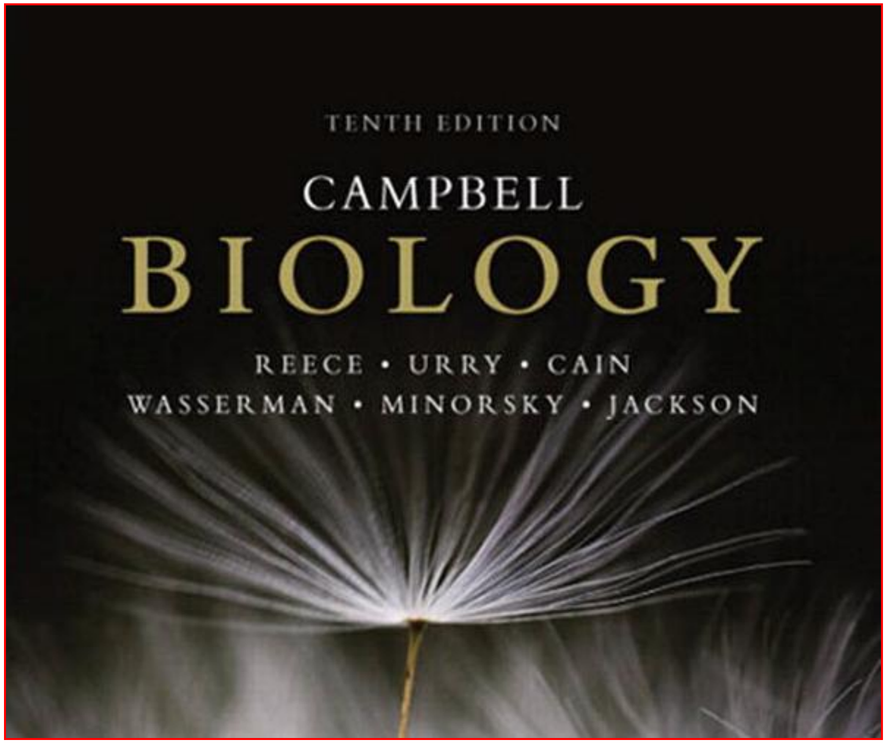

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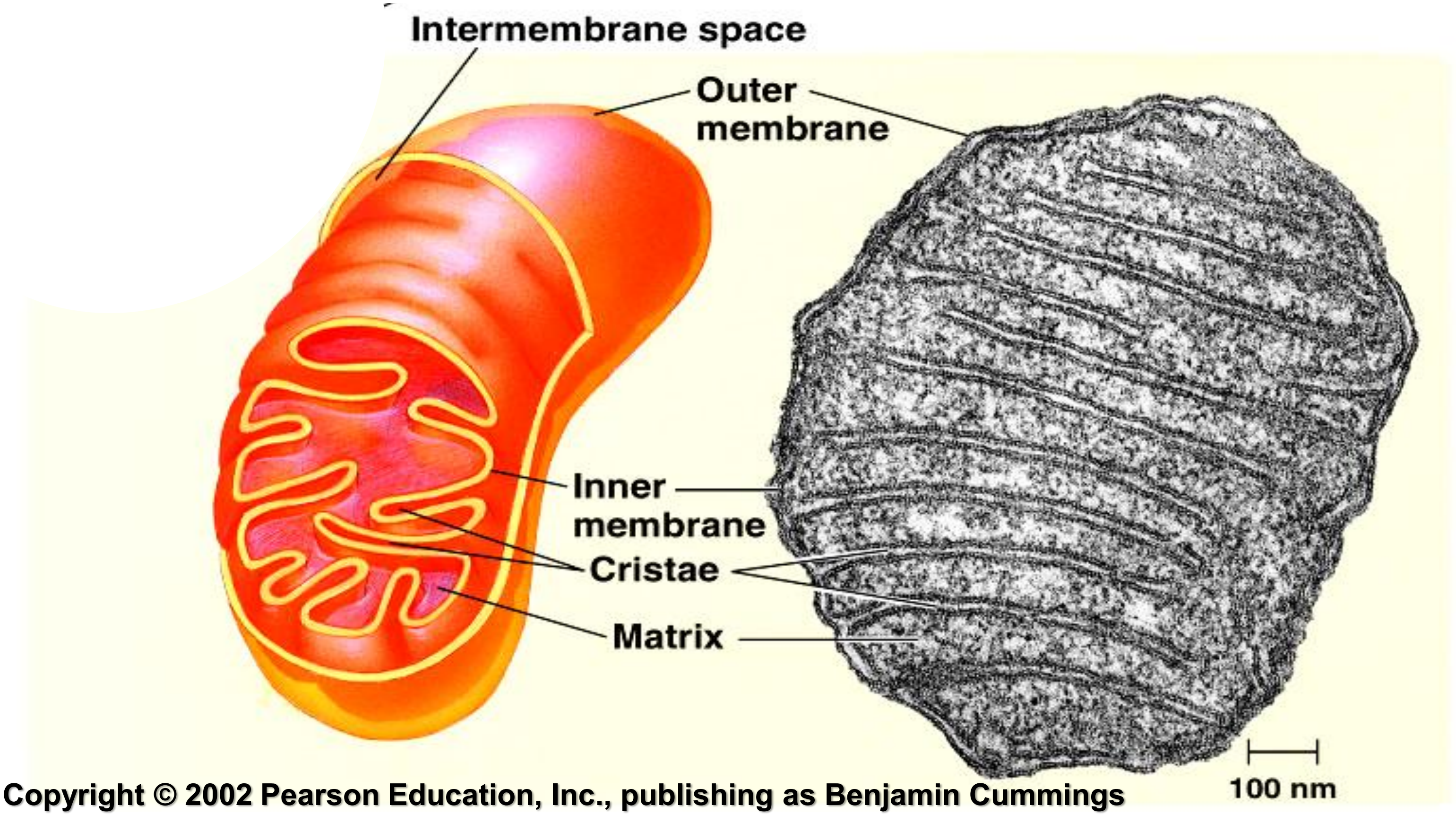
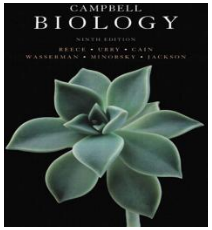
CELLULAR RESPIRATION: Harvesting chemical energy



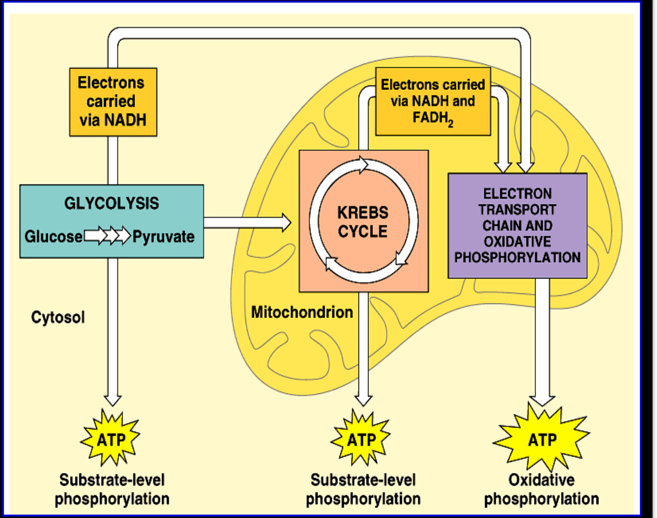


Objectives

Cellular Respiration: involves three stages:

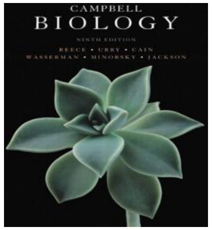
1. **Glycolysis** harvests chemical energy by oxidizing glucose into two pyruvates produces about 5% of ATP (in the cytoplasm).

2. **Krebs cycle** completes the energy-yielding oxidation of organic molecules and produces another 5% of ATP (in the mitochondrial matrix).



3. **Electron transport chain** to synthesis ATP and produces about 90% of ATP (inner mitochondrial membrane).

Cellular respiration generates many ATP molecules. From each glucose molecule, it produces (38 ATP molecules).



Phosphorylation

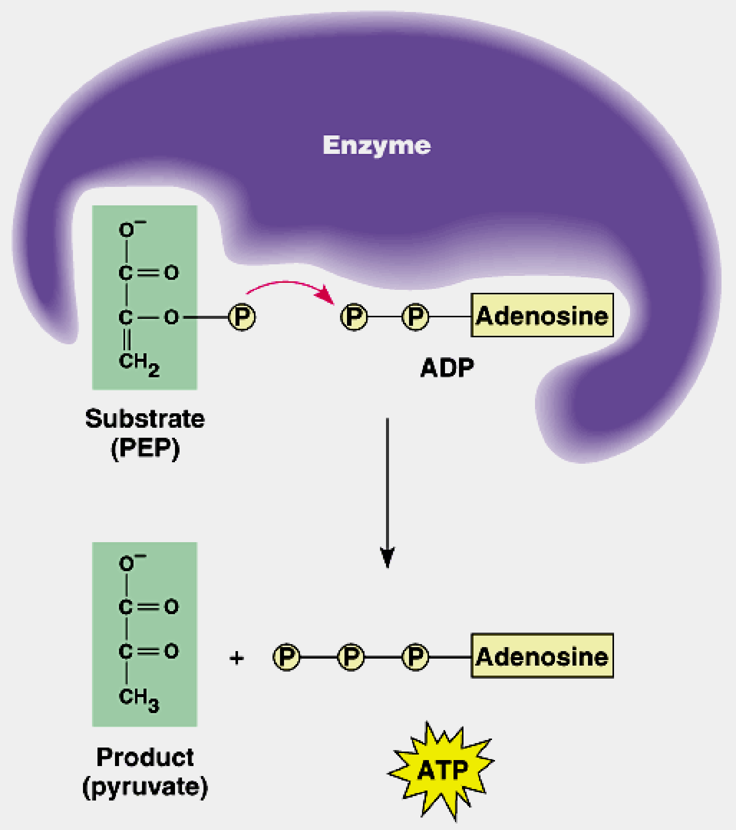
I- Substrate-level phosphorylation:

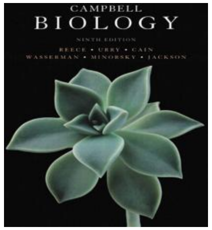
- **Some ATP is generated in glycolysis and Krebs cycle by *Substrate-level phosphorylation*. Phosphate group is transferred from an organic molecule (the substrate) to ADP, forming 10% of the total ATP (4 ATP).**

II- Oxidative phosphorylation:

- **As electrons passed along the Electron transport chain, their energy stored in the mitochondria in a form that can be used to synthesize the rest 90% of the ATP (34 ATP).**

Ultimately, 38 ATP are produced per each one glucose molecule that is degraded to CO_2 and H_2O by respiration.





1- Glycolysis (splitting glucose): harvests chemical energy by oxidizing glucose into 2-pyruvate molecules

- During glycolysis, glucose (a six carbon-sugar) is split into two molecules (each is three-carbon sugar).
- These smaller sugars are oxidized and rearranged to form two molecules of pyruvate.
- Each of the 10 steps in glycolysis is catalyzed by a specific enzyme.
- These steps can be divided into two phases:

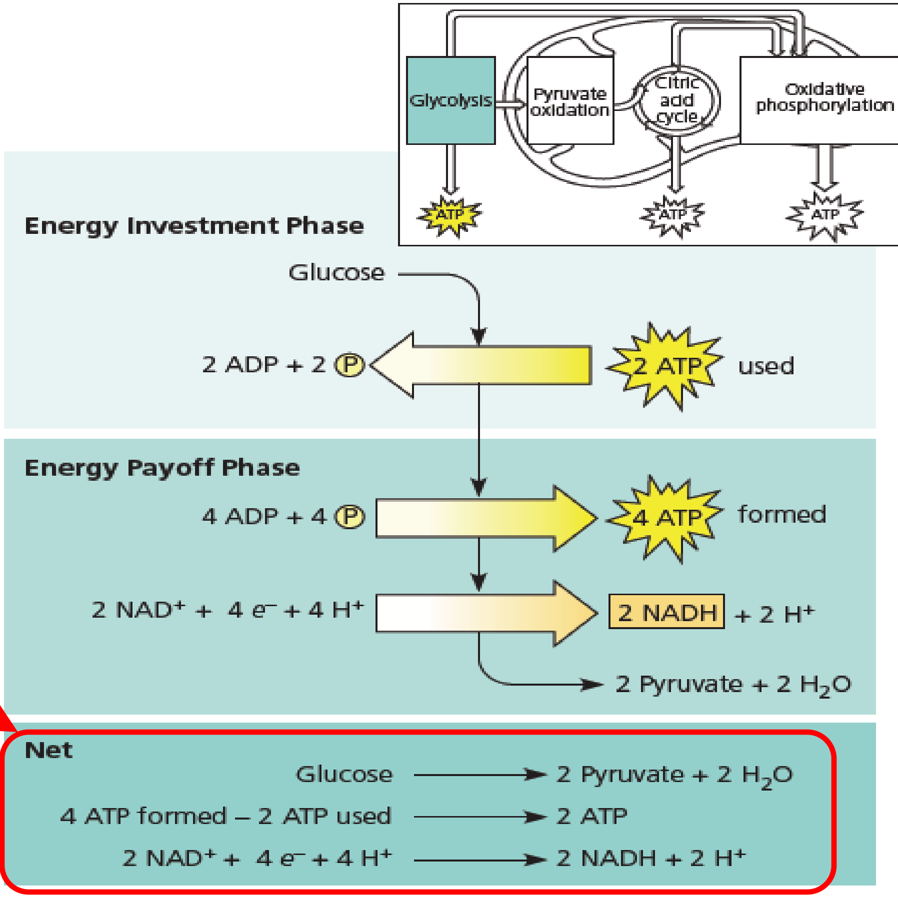
1)- Energy investment phase: إستهلاك طاقة

ATP is consumed to provide activation energy by phosphorylating glucose (this requires 2 ATP per glucose).

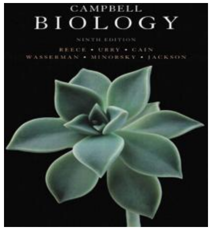
2)- Energy payoff phase: إنتاج طاقة

ATP is produced by substrate-level phosphorylation and NAD^+ is reduced to NADH.

- 4 ATP and 2NADH are produced per one glucose molecule.
- Thus, the net yield from glycolysis is 2 ATP + 2 NADH + 2 Pyruvate molecules per one glucose molecule.



Oxygen is not required for glycolysis



Summary of Glycolysis (Splitting of glucose)

It is the process of breaking a glucose into 2 Pyruvates.

It is a source for some ATP & NADH.

It occurs in the CYTOSOL (cytoplasm).

It has two phases

A)- Energy investment phase

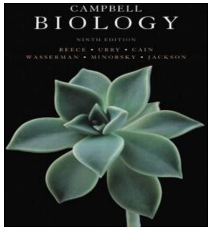
1)- Glucose is phosphorylated twice by adding 2 P coming from 2 ATP (substrate-level-phosphorylation).

2)- Thus, Glucose (6-C) splits into two small sugar molecules (each with 3-C).

B)- Energy pay-off phase

4ATP are formed by adding 4P to 4ADP molecules.

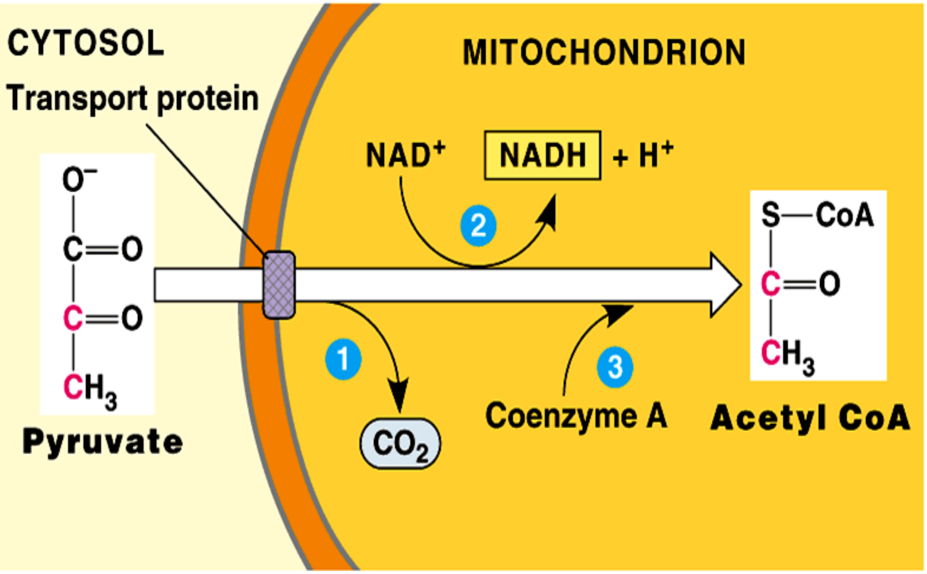
The net yield of this process is the formation of 2 NADH, 2 ATP and 2 Pyruvate molecules.



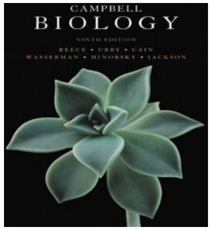
2. The Krebs cycle completes the energy-yielding oxidation of organic molecules (*in mitochondrial matrix*)

It is the process of producing some of the remaining energy (ATP) from the Pyruvate molecules. It occurs mainly in mitochondrial matrix if oxygen is present.

- **If O_2 is present, pyruvate enters the mitochondrion where enzymes of the Krebs cycle complete the oxidation of this organic fuel to CO_2.**
- **As pyruvate enters the mitochondrion which modifies to acetyl-CoA which enters the Krebs cycle in the matrix.**
  - **A carboxyl group is removed as CO_2.**
  - **A pair of electrons is transferred from the remaining two-carbon fragments to NAD^+ to form NADH.**
  - **The oxidized fragment, acetate, combines with the Coenzyme A to form acetyl-CoA.**



This cycle is called Pre-Krebs cycle الدورة التحضيرية لدورة كريبس



2. The Krebs cycle completes the energy-yielding oxidation of organic molecules (*in mitochondrial matrix*)

It is the main source for preparing most of the cellular NADH (storing energy molecule), **and for producing some more of the cellular ATP.**

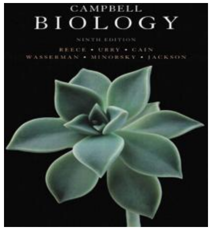
It includes two cycles :

Pre-Krebs cycle المرحلة التحضيرية

The Pyruvate is the substrate for this cycle

Krebs cycle

The acetyl-CoA is the substrate for this cycle



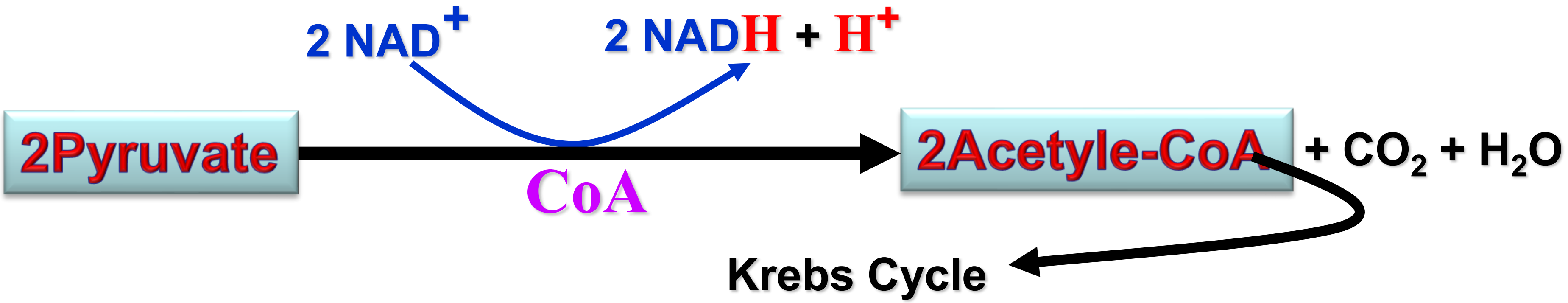
A)- Pre-Krebs cycle

Pyruvate is converted into acetyle-CoA in the presence of O_2 through 3 steps.

a)- $C{=}O^-$ group of pyruvate is released as CO_2.

b)- The remaining two-C fragments are oxidized (releasing e^-) into acetate and the resulting e^- transform NAD^+ into NADH.

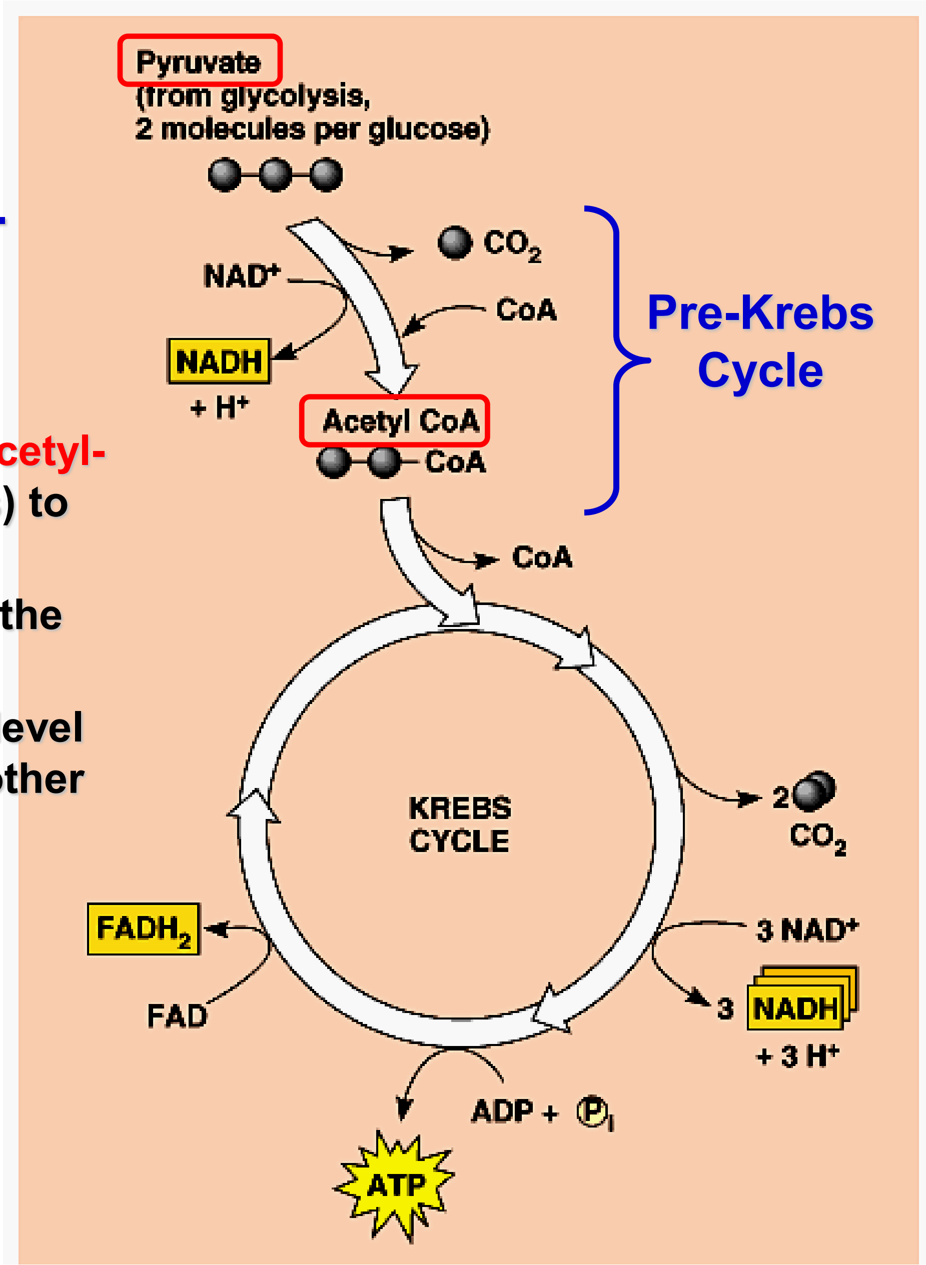
c)- The coenzyme-A (CoA) transform acetate compound into acetyl-CoA, which will be ready for Krebs Cycle for further oxidation.



B)- Krebs cycle

It has eight steps starting with 2 acetyle-CoA compounds. They are summarized as shown in the figure:

- This cycle begins when acetate from each acetyl-CoA combines with oxaloacetate (4 C atoms) to form citrate (citric acid).
- Ultimately, the oxaloacetate is recycled and the acetate is broken down to CO_2.
- Each cycle produces one ATP by substrate-level phosphorylation, 3 NADH, and 1 $FADH_2$ (another electron carrier) per acetyl CoA.



Thus, the outcome of the two cycles (for the 2 Acetyle-CoA molecules) is:

Output

2 ATP

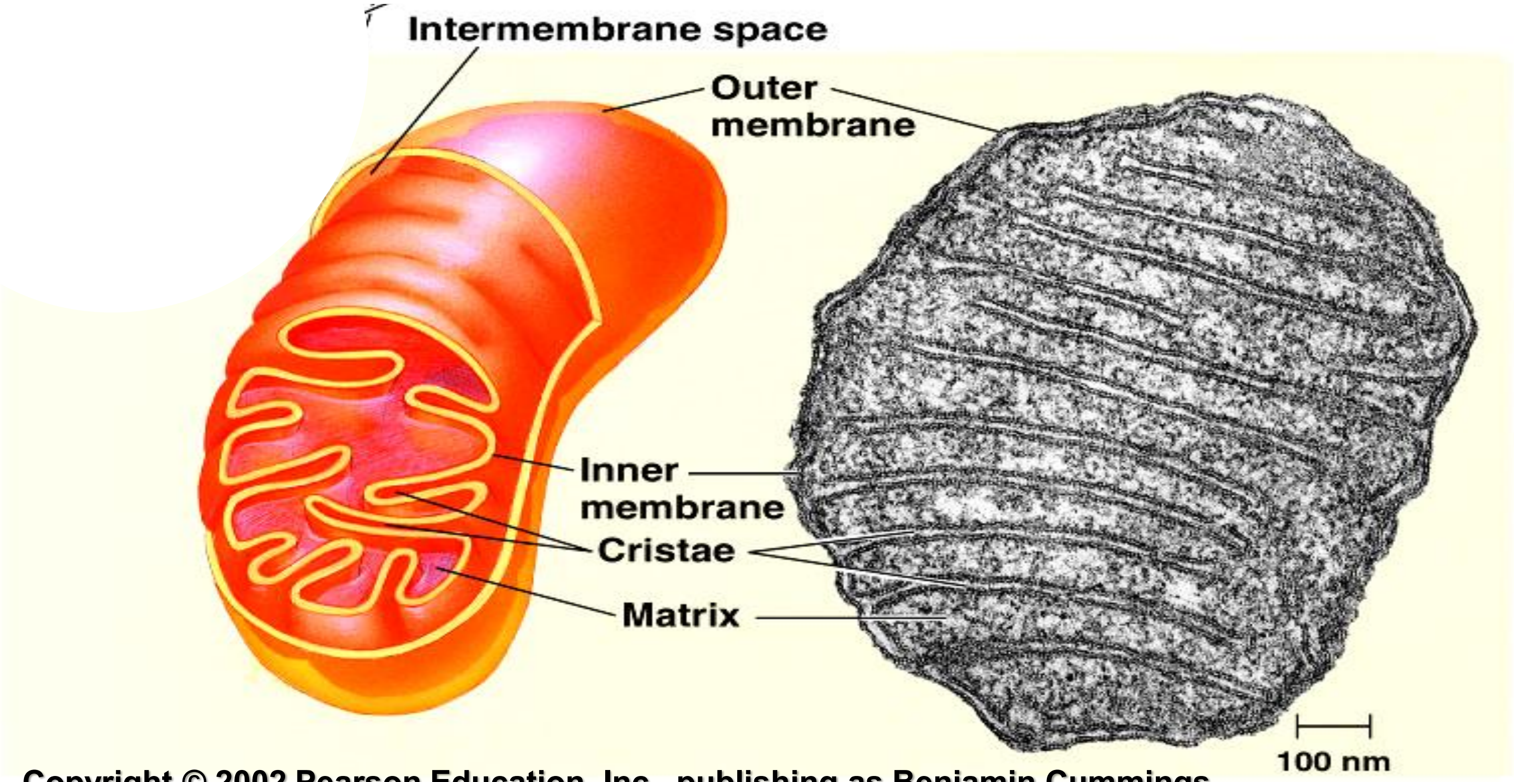
6 NADH

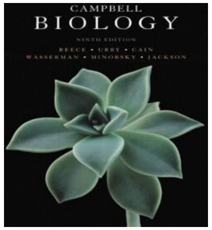
2 $FADH_2$

Flavin Adenine Dinucleotide

بسم الله الرحمن الرحيم

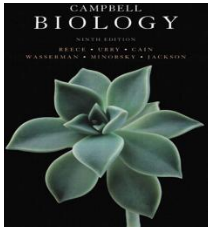
CELLULAR RESPIRATION: Electron Transport Chain and the Oxidative Phosphorylation





Objectives

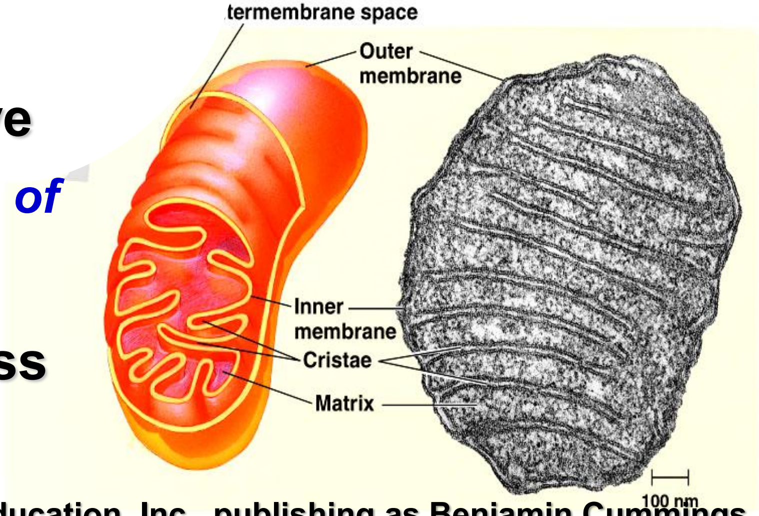
- **Electron Transport Chain and the Oxidative Phosphorylation**
  - Electron transport chain (The Pathway of Electron Transport).
  - Chemiosmosis (*the Oxidative Phosphorylation*)
- **Fermentation (*anaerobic respiration*): enables cells to produce ATP without the use of oxygen:**
  - Types of Fermentation.
  - Comparing Fermentation (Anaerobic Respiration) with Aerobic Respiration
- **The catabolism of various molecules from food**

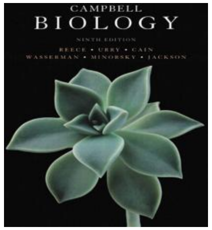


3- Electron transport chain:

(oxidative phosphorylation)

- Only 4 of 38 ATP ultimately produced by respiration of glucose are derived from substrate-level phosphorylation: **2 from glycolysis** (in the cytoplasm) **and 2 from Krebs Cycle** (in the mitochondrial matrix).
- The vast majority of the ATP (90%) comes from the energy in the electrons carried by NADH and $FADH_2$.
- The energy in these electrons is used in the electron transport chain to power لتدعم ATP synthesis.
- Thousands of copies of the electron transport chain are found in the extensive surface of the cristae (*the inner membrane of the mitochondrion*).
- Electrons drop in free energy as they pass down the electron transport chain.

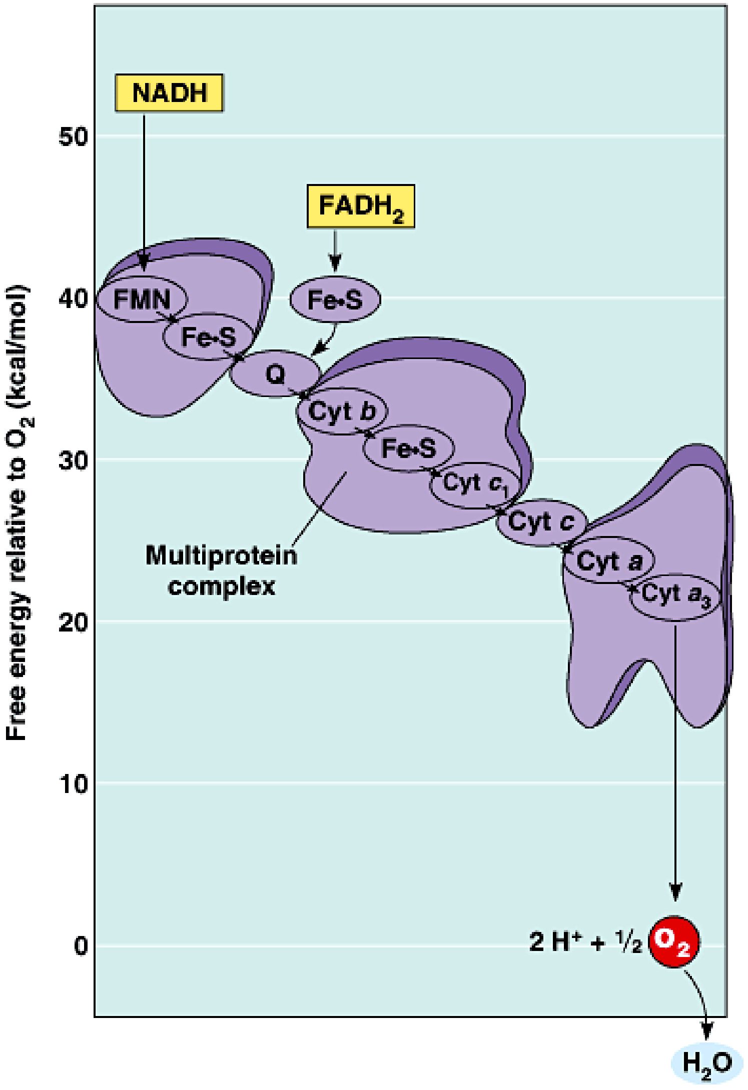




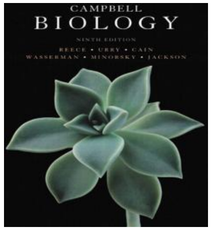
Electron transport chain

(Oxidative phosphorylation)

- Electrons carried by **NADH** are transferred to the first molecule in the electron transport chain (the flavoprotein; **FMN**).
- The electrons continue along the chain which includes several Cytochrome proteins and one lipid carrier.
- The electrons carried by **$FADH_2$** have lower free energy and are added to a later point in the chain.



- Electrons from **NADH** or **$FADH_2$** ultimately pass to **oxygen**.
- The electron transport chain generates no ATP directly. Rather, its function is to break the large free energy drop from food to oxygen into a series of smaller steps that release energy in manageable amounts كميات مناسبة.

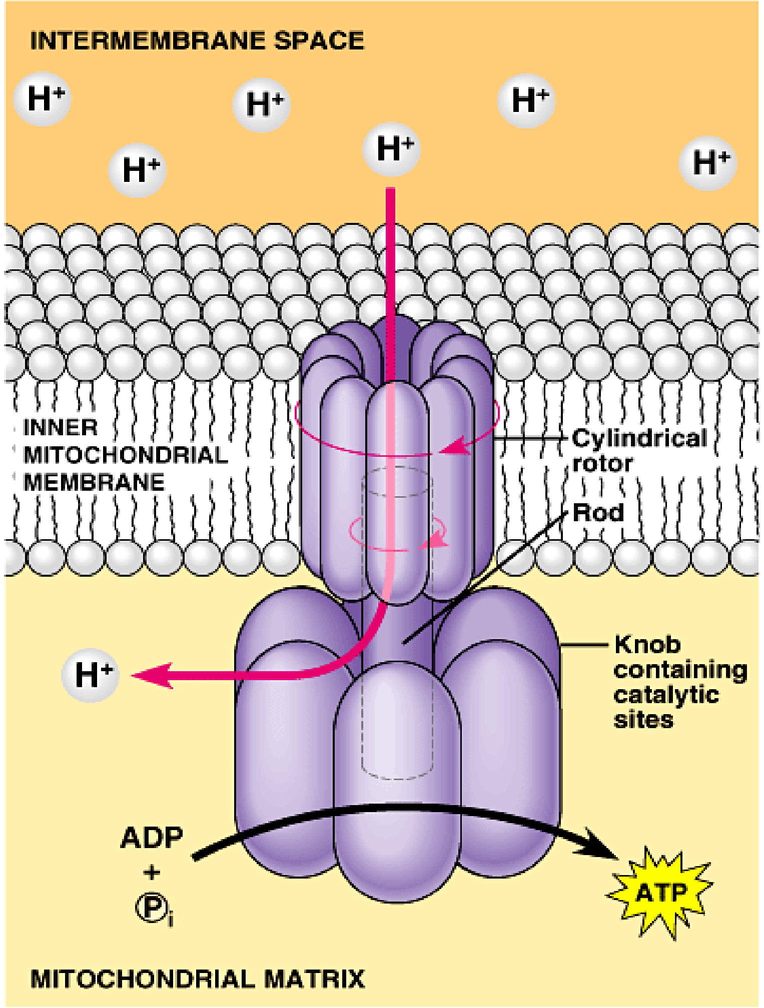


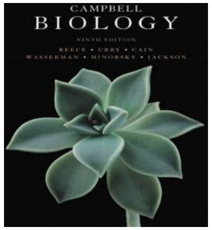
Electron transport chain

(Oxidative phosphorylation)

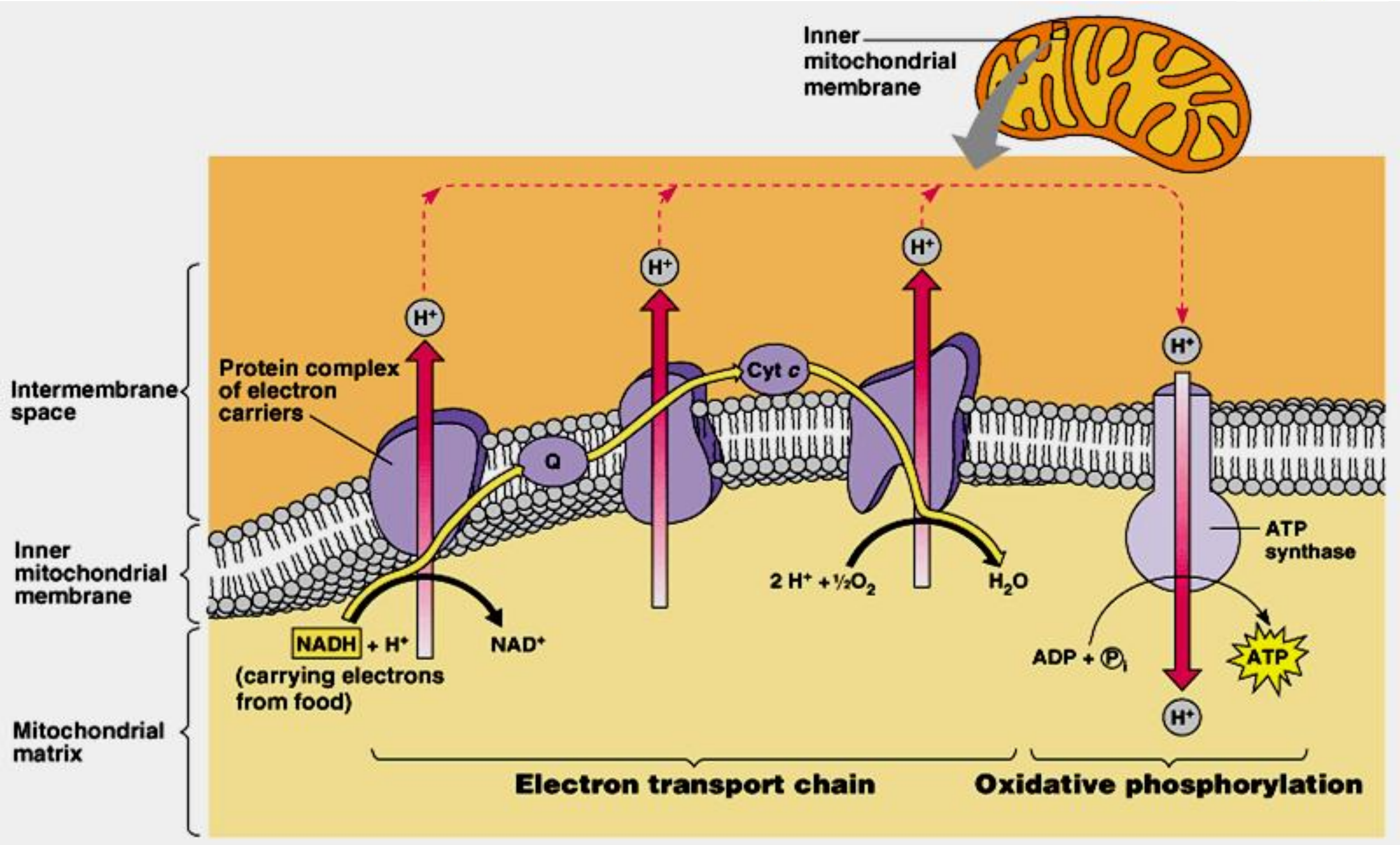
- **ATP-synthase**, in the cristae actually makes ATP from ADP and P_i.
- It uses the energy of an existing proton gradient to power ATP synthesis.
  - This proton gradient develops between the inter-membrane space and the matrix.
  - This concentration of H^+ is called: **proton-motive force.**
- The *ATP synthase* molecules are the only place that will allow H^+ to diffuse back to the matrix (exergonic flow of H^+).
- This flow of H^+ is used by the enzyme to generate ATP in a process called "**Chemiosmosis**".
- **Chemiosmosis:** (osmos = puch)

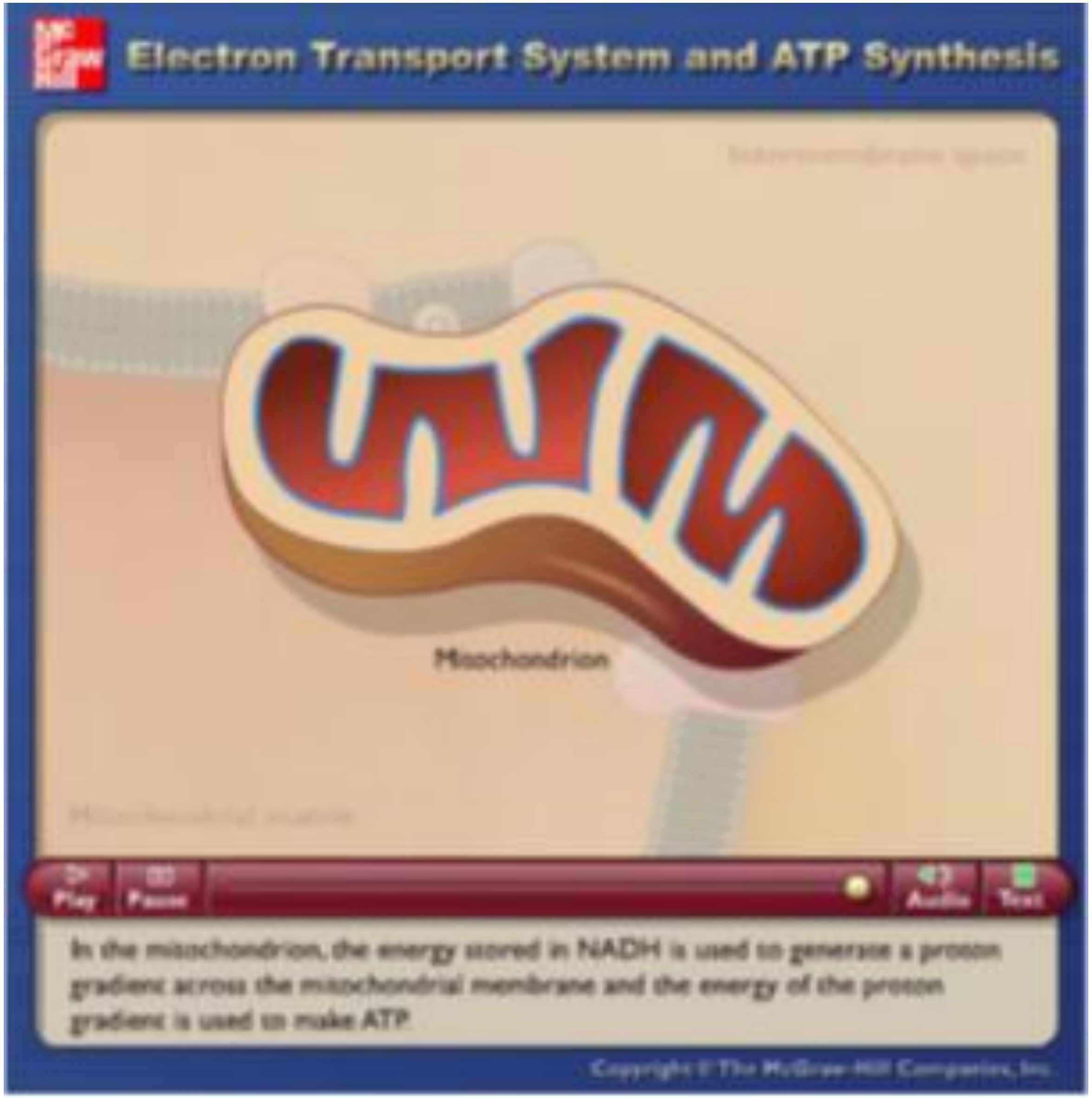
  It is the oxidative phosphorylation that results in ATP production in the inner membrane of mitochondria.





Energy carried by NADH and FADH$_2$ give a maximum yield of 34 ATP is produced by oxidative phosphorylation.

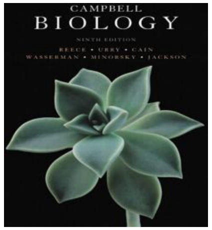




Electron Transport System and ATP Synthesis

In the mitochondrion, the energy stored in NADH is used to generate a proton gradient across the mitochondrial membrane and the energy of the proton gradient is used to make ATP.

Video: plays in LMS



Summary: Cellular respiration generates many ATP molecules for each sugar molecule it oxidizes

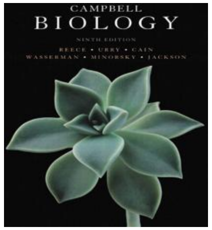
- During respiration, most energy flows from glucose → NADH → electron transport chain → proton-motive force → ATP.

- Some ATP is produced by substrate-level phosphorylation during glycolysis and the Krebs cycle, but most ATP comes from oxidative phosphorylation (through electron transport chain).

- Energy produced in Glycolysis and Krebs cycle gives a maximum yield of 4 ATP by substrate-level phosphorylation.

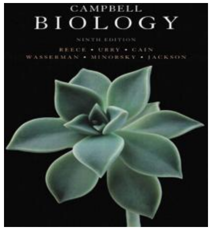
- Energy produced in electron transport chain gives a maximum yield of 34 ATP by oxidative phosphorylation *via* ATP-synthase.

- Substrate-level phosphorylation and oxidative phosphorylation of one glucose molecule give 38 ATP.

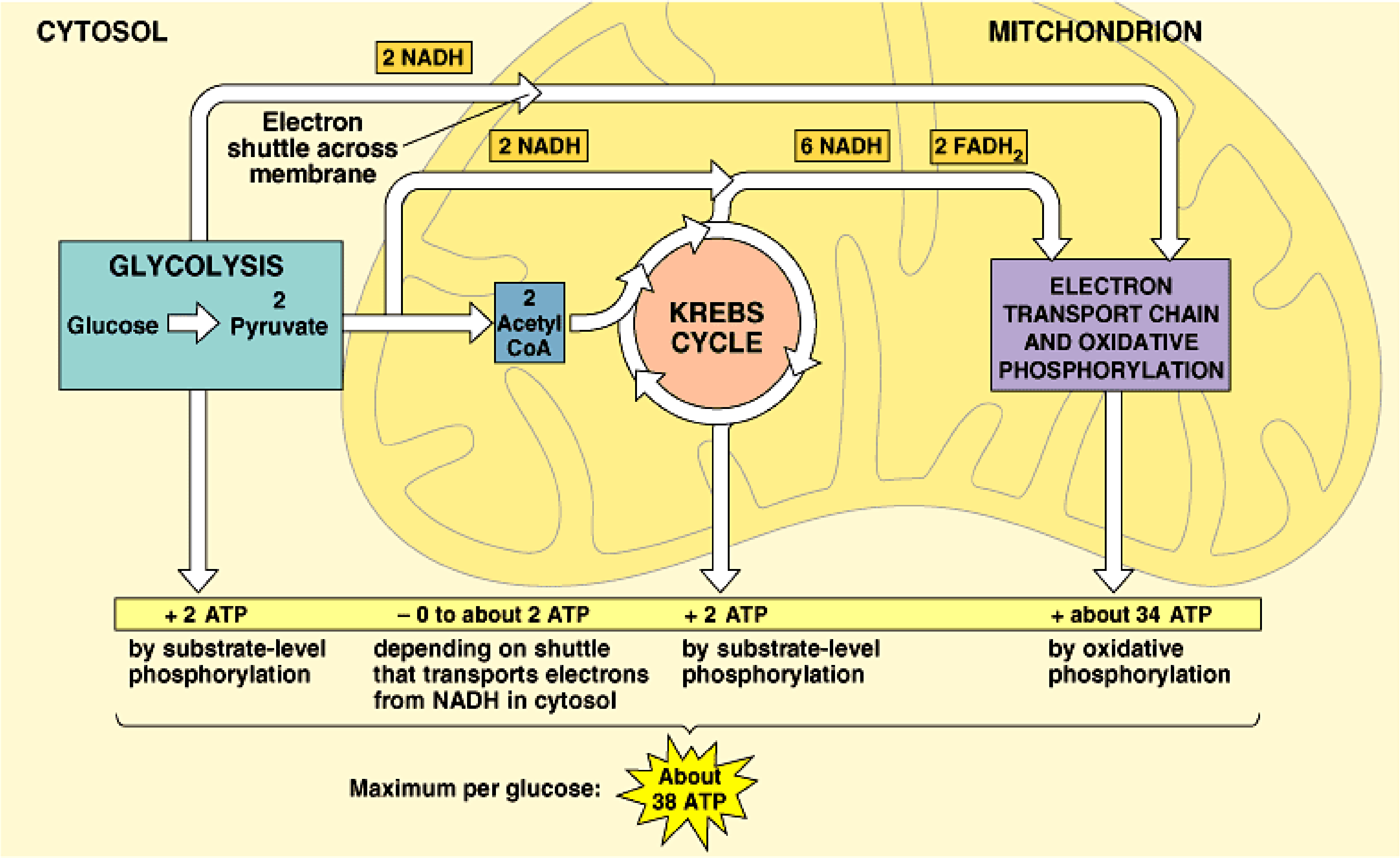


Summary of Cellular Respiration

- **Glycolysis** occurs in the cytosol and breaks glucose into two **pyruvates**
- **Krebs Cycle** takes place within the mitochondrial matrix, and breaks a pyruvate into CO_2 and produce some ATP and **NADH**.
- Some steps of Glycolysis and Krebs Cycle are Redox in which dehydrogenase enzyme reduces **NAD^+** into **NADH**.
- Some of ATP is produced at these two steps via (substrate-level-phosphorylation).
- **Electron Transport Chain** accepts e^- from **NADH** and passes these e^- from one protein molecule to another.
- At the end of the chain, e^- combine with both H^+ and O_2 to form H_2O and release energy.
- These energy are used by mitochondria to synthesis **90%** of the cellular ATP *via* **ATP-synthase**, a process called **Oxidative Phosphorylation**, in the inner membrane of mitochondria.

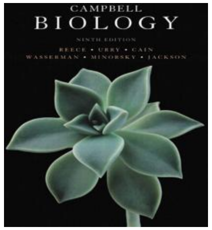


Summary of cell respiration



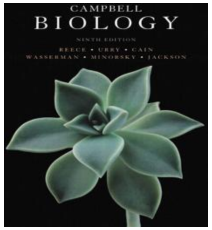
+ 2 ATP	– 0 to about 2 ATP	+ 2 ATP	+ about 34 ATP
by substrate-level phosphorylation	depending on shuttle that transports electrons from NADH in cytosol	by substrate-level phosphorylation	by oxidative phosphorylation

Maximum per glucose: About 38 ATP



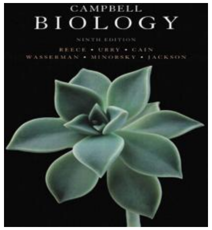
Summary of cell respiration

Video: plays in LMS



Definitions: تعريفات

- **Chemiosmosis:** a process *via* which **oxidative phosphorylation** takes place at the end of the Electron Transport Chain to produce 90% of ATP *via* ATP-synthase.
  - Or, is the process in which ATP synthesis powered by the flow of H+ back across ATP synthase.
- **ATP-synthase:** an enzyme presents in the inner mitochondrial membrane and used in making ATP by using H+ (protons).
- **NAD^+:** Nicotinamide adenine dinucleotide, which is a co-enzyme that helps electron transfer during redox reactions in cellular respiration.
- **FAD:** Flavin adenine dinucleotide, which is an electron acceptor that helps electron transfer during Krebs Cycle and Electron Transport Chain in cellular respiration.



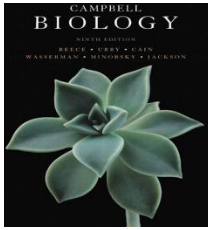
Fermentation: Enables يُمَكِن some cells to produce ATP without the help of oxygen

- Oxidation refers to the loss of electrons to any electron acceptor, not just to oxygen.
  - In glycolysis, glucose is oxidized to 2 pyruvate molecules with NAD^+ as the oxidizing agent (not O_2).
  - Some energy from this oxidation produce 2 ATP.
  - If oxygen is present, additional ATP can be generated when NADH delivers its electrons to the electron transport chain.

- Glycolysis generates 2 ATP when oxygen is absent (anaerobic لاهوائي).
- Anaerobic catabolism of sugars can occur by fermentation.

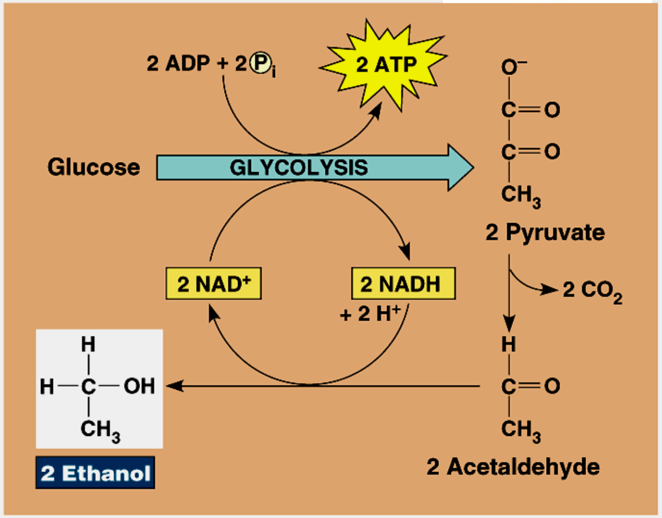
- Fermentation can generate ATP from glucose by substrate-level phosphorylation as long as there is a supply of NAD^+ (the oxidizing agent) to accept electrons.
  - If the NAD^+ pool is exhausted إستُنفِذ, glycolysis shuts down.
  - Under aerobic هوائى conditions, NADH transfers its electrons to the electron transfer chain, recycling NAD^+.

- Under anaerobic conditions, various fermentation pathways generate ATP by glycolysis and recycle NAD^+ by transferring electrons from NADH to pyruvate.



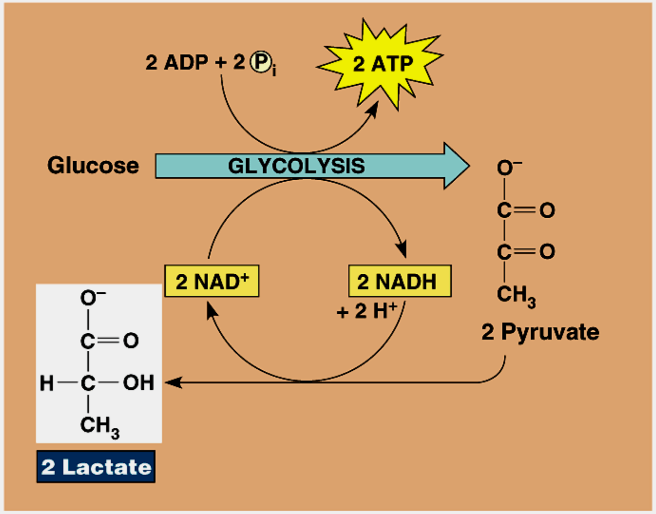
Fermentation

- **Alcohol fermentation:**
  the **pyruvate** is converted to **ethanol** in two steps.
  - First, pyruvate is converted to acetaldehyde by the removal of CO_2.
  - Second, acetaldehyde is reduced by **NADH** to ethanol.
  - Alcohol fermentation by **yeast** is used in wine-making.

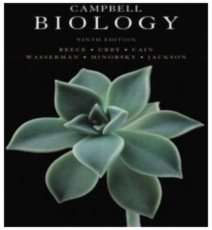


(a) Alcohol fermentation

- **Lactic acid fermentation:**
  The **pyruvate** is reduced directly by **NADH** to form **lactate** (ionized form of lactic acid).
  - Lactic acid fermentation by some **fungi** and **bacteria** is used to make **cheese** and **yogurt**.
  - Muscle cells switch from aerobic respiration to lactic acid fermentation to generate ATP when lack of O_2 (i.e. O_2 is scarce نادر)
    - The waste product is lactate, which may cause **muscle fatigue**, but ultimately it is converted back to pyruvate in the liver.



(b) Lactic acid fermentation



Examples of anaerobic respiration:

A)- During exercise our bodies require a lot of energy

- The body can only supply a limited amount of oxygen for cellular respiration.
- Energy is not produced at the rate required.
- Cells will use anaerobic respiration to release extra energy
- This produces lactic acid (a waste product).

B)- We use yeast to make bread

- CO_2 produced causes bread to rise by creating air pockets
- The ethanol (alcohol) produced is evaporating during baking

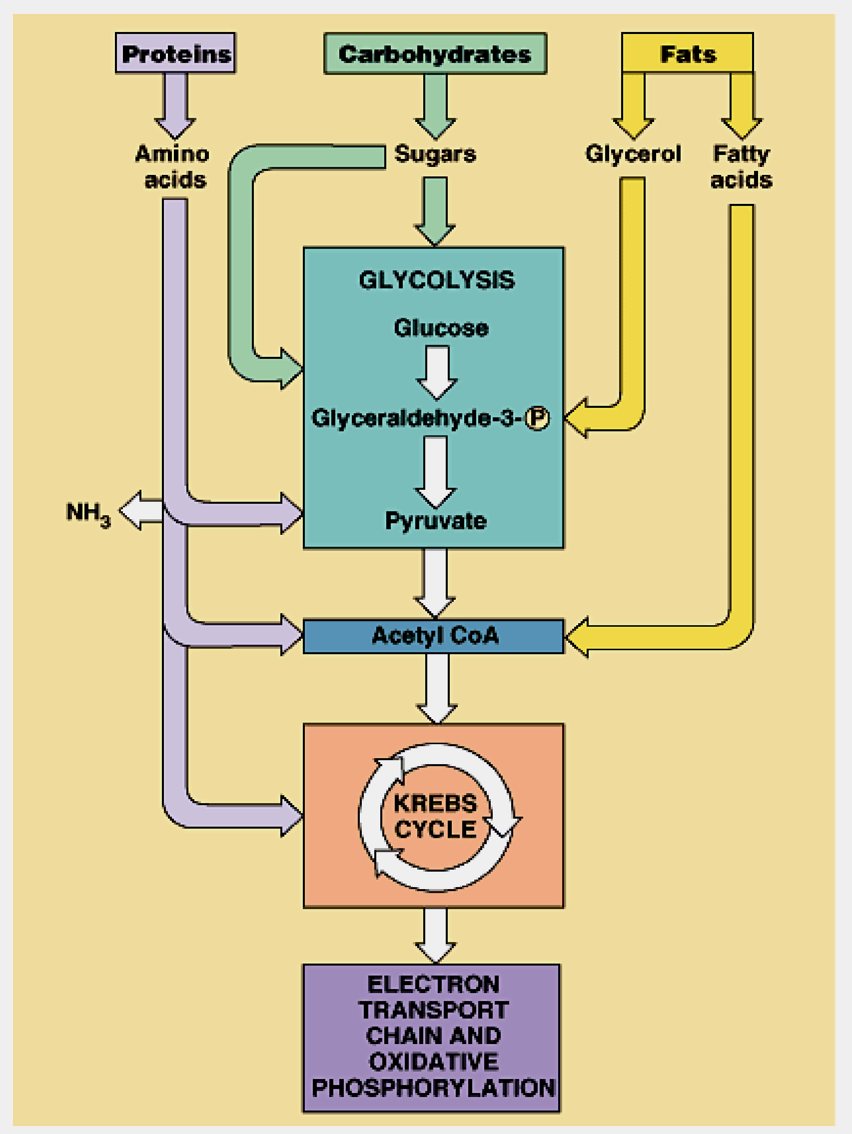
Fat and Protein Breakdown

A. Fats

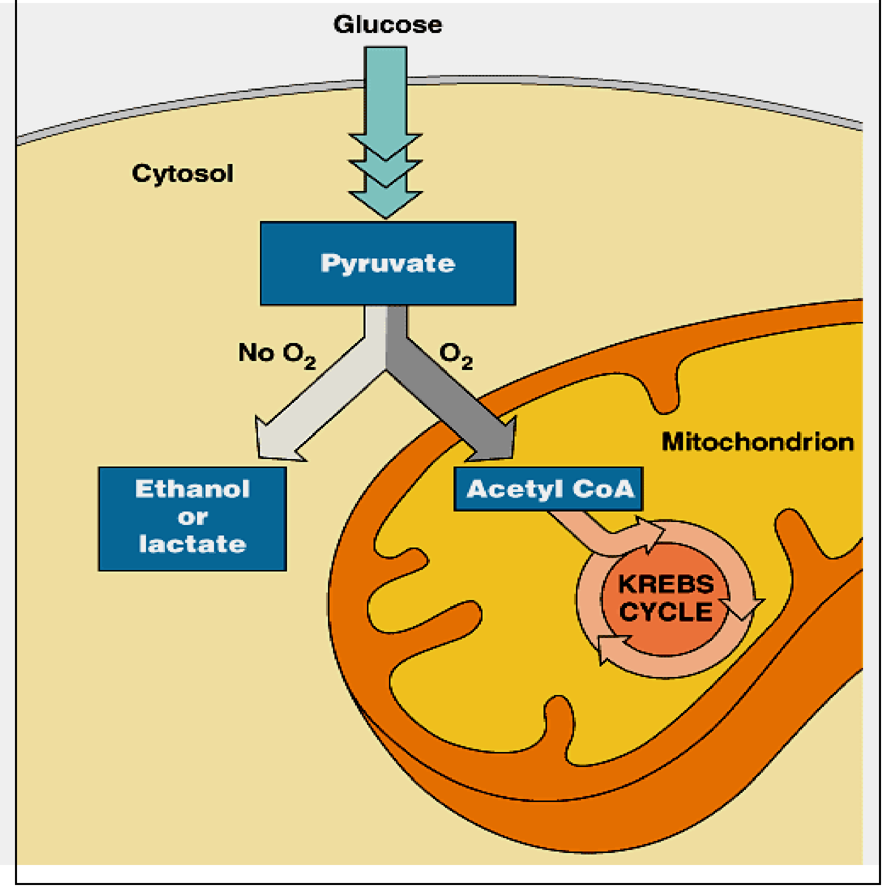
- have more energy per gram than carbohydrates or proteins.
- fatty acid chains are oxidized and broken into smaller 2 carbon chains.
- the 2 carbon chains are converted into acetyl CoA to enter the Kreb’s cycle.

B. Proteins

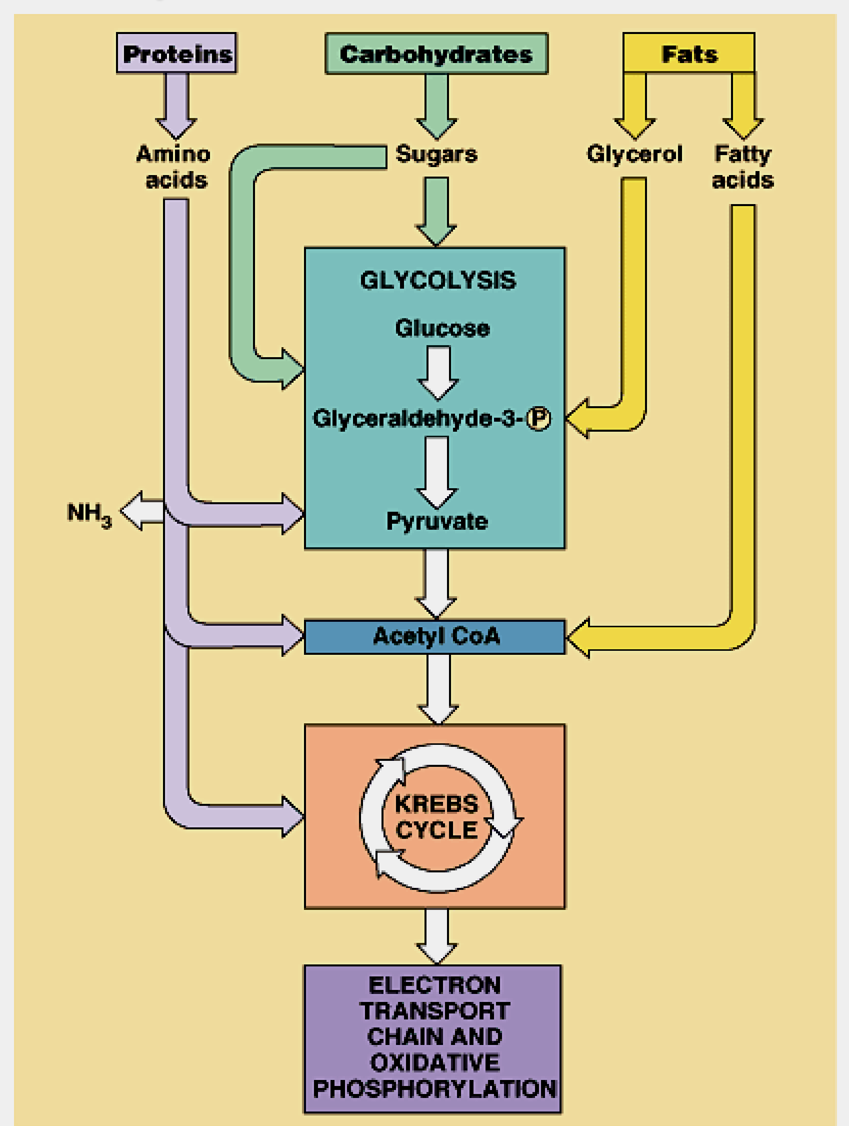
- must be converted into individual amino acids.
- excess amino acids are converted by enzymes into intermediated of glycolysis and Krebs cycle.
- amino acids go through deamination (amino groups are removed)
- nitrogenous wastes from the amino groups are released as wastes.
- new compounds enter glycolysis or Krebs.

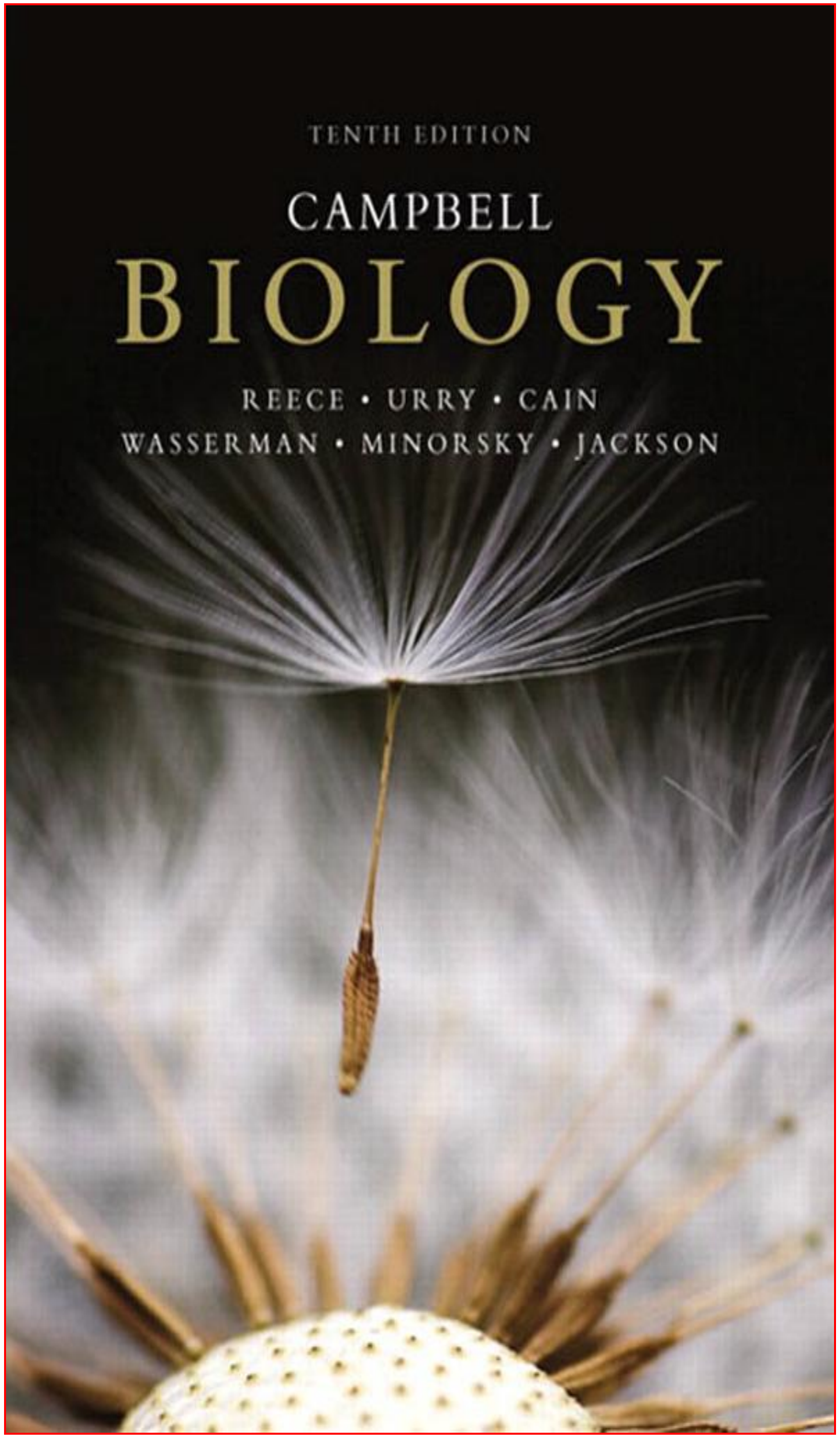


- Some organisms (**facultative anaerobes** اللاهوائية اختياريا), including yeast and many bacteria, can survive using either fermentation or respiration.
- At a cellular level, human muscle cells can behave as facultative anaerobes, but nerve cells cannot.



Proteins and fats, can also enter the respiratory pathways, including glycolysis and the Krebs cycle, like carbohydrates.

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Thank you very much

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