جامعة الملك سعود
King Saud University

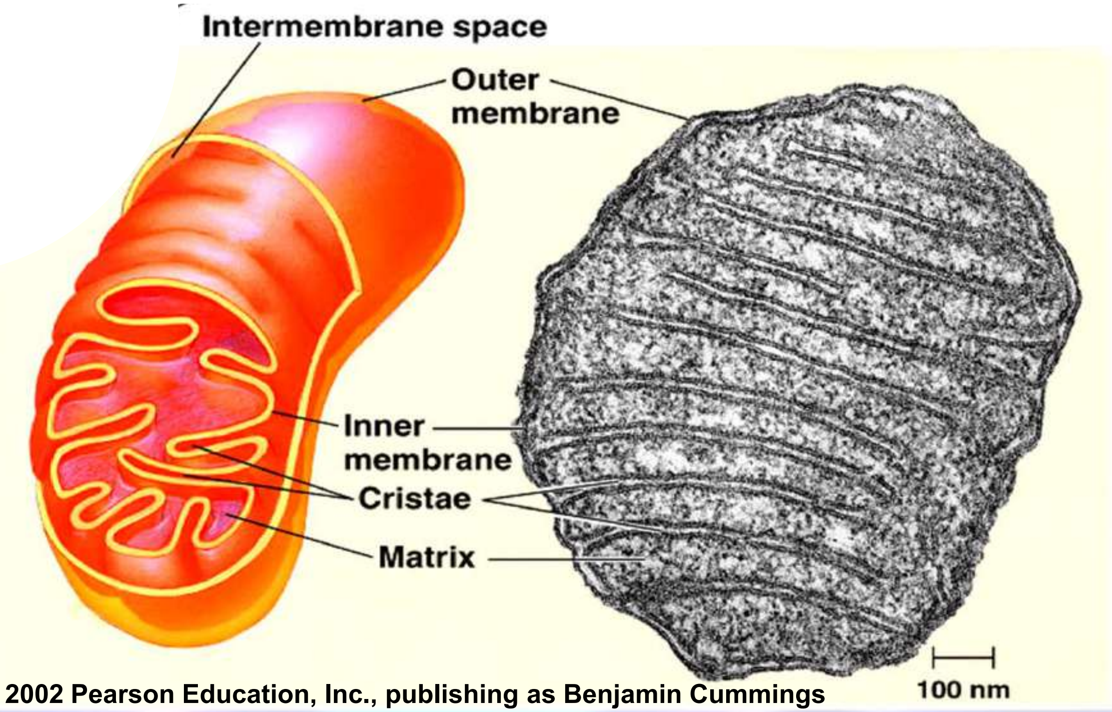
college of sciences
Zoology Department

Cell Biology and Physiology

ZOO (242)

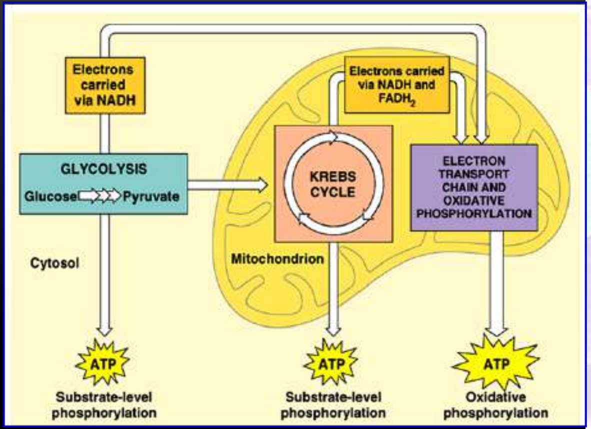
بسم الله الرحمن الرحيم

CELLULAR RESPIRATION: Harvesting chemical energy



Objectives

Cellular Respiration: involves three stages:



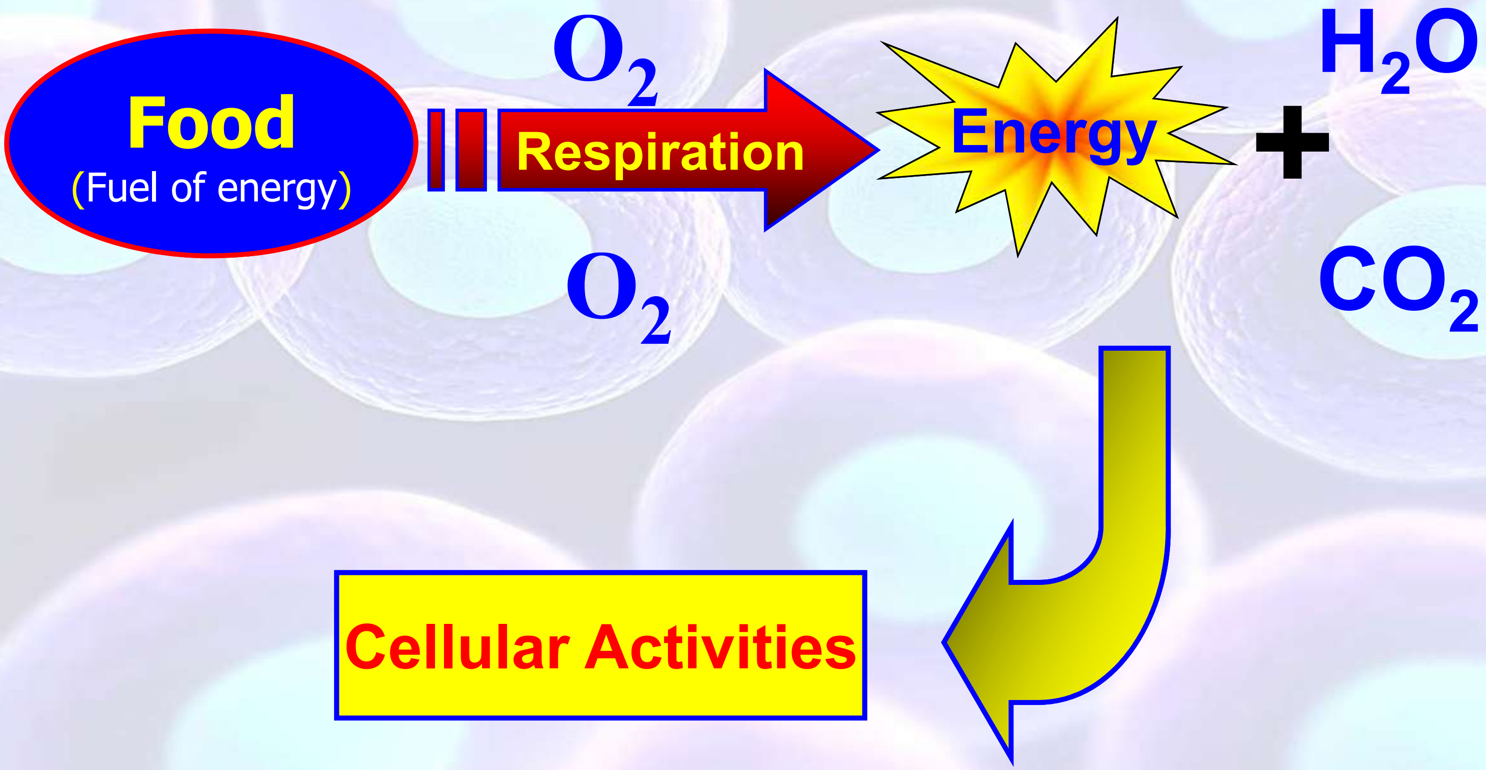
1. **Glycolysis** harvests chemical energy by oxidizing glucose into to two pyruvates and produces about 5% of ATP (in cytoplasm).
2. **Krebs cycle** completes the energy-yielding oxidation of organic molecules and produces about 5% of ATP (in mitochondrial matrix).
3. **Electron transport chain** to 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).

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



Organic compounds + O_2 → Energy + CO_2 + H_2O

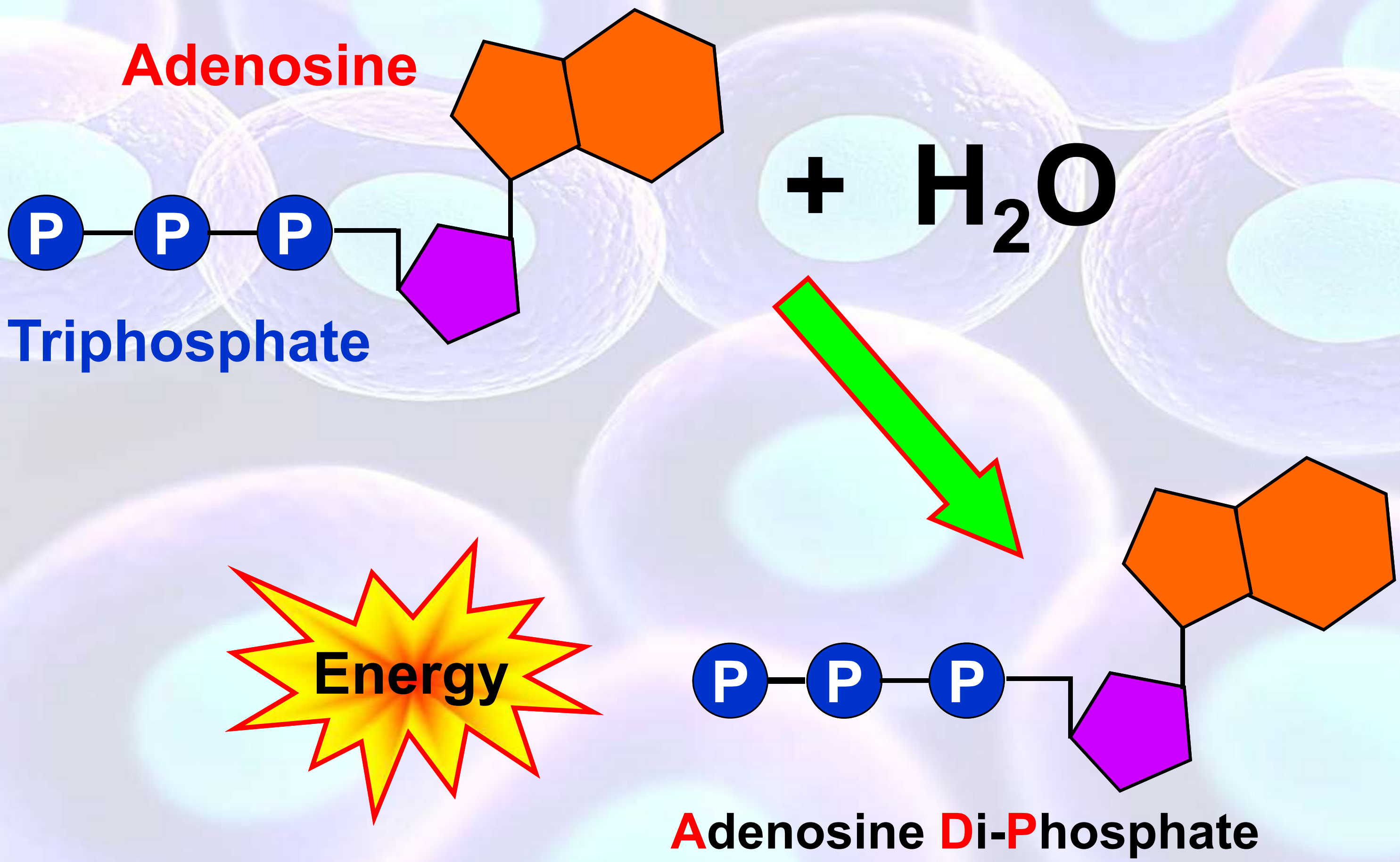
Cells recycle the ATP they use for work

- **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.**

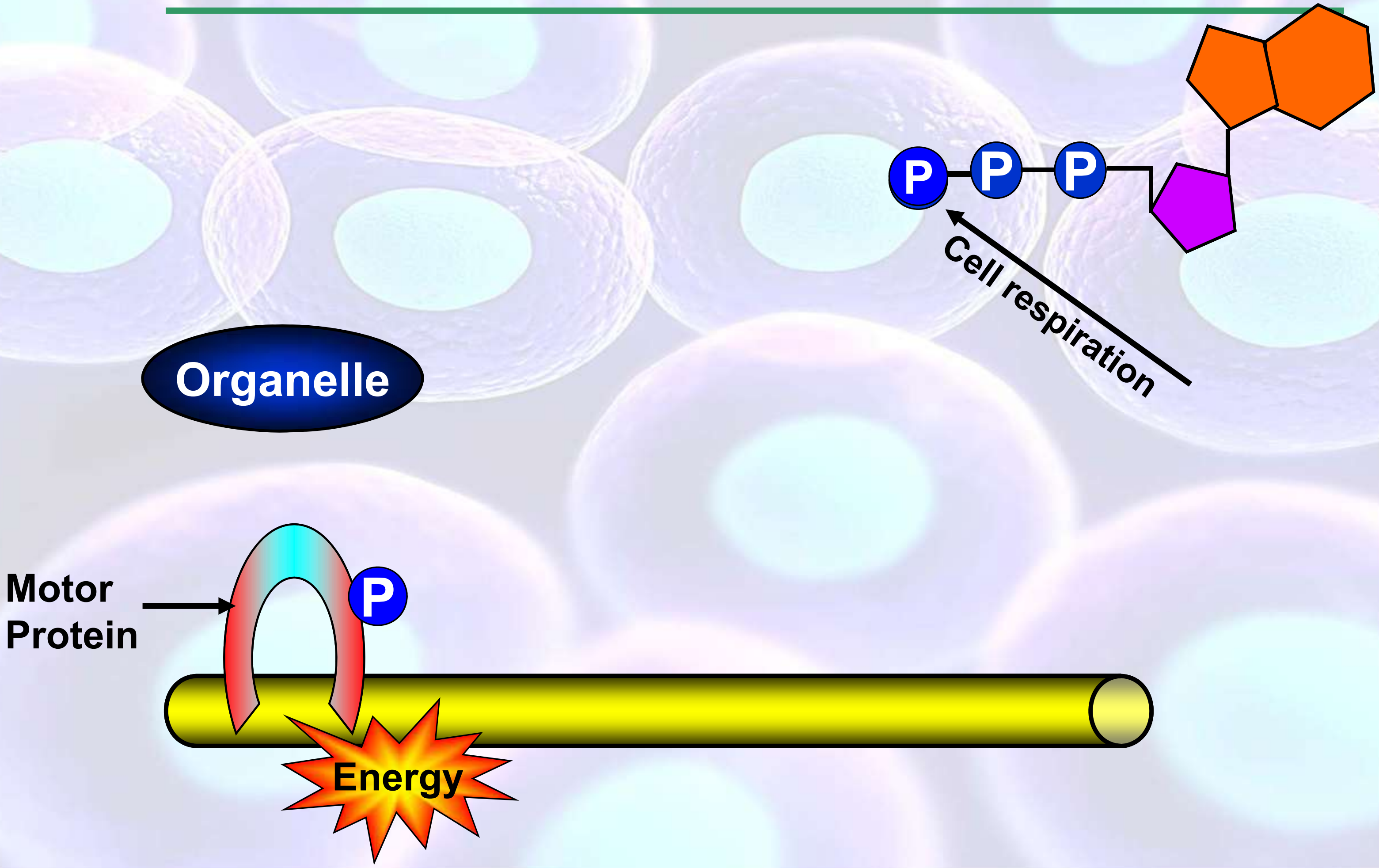
- **The price of most cellular work is the conversion of ATP to ADP and phosphate (P).**

- **An animal cell regenerates تعيد إنتاج ATP from ADP by adding P *via* the catabolism هدم of organic molecules.**

Adenosine Tri-Phosphate (ATP)



How dose ATP drive cellular work ?



Phosphorylation

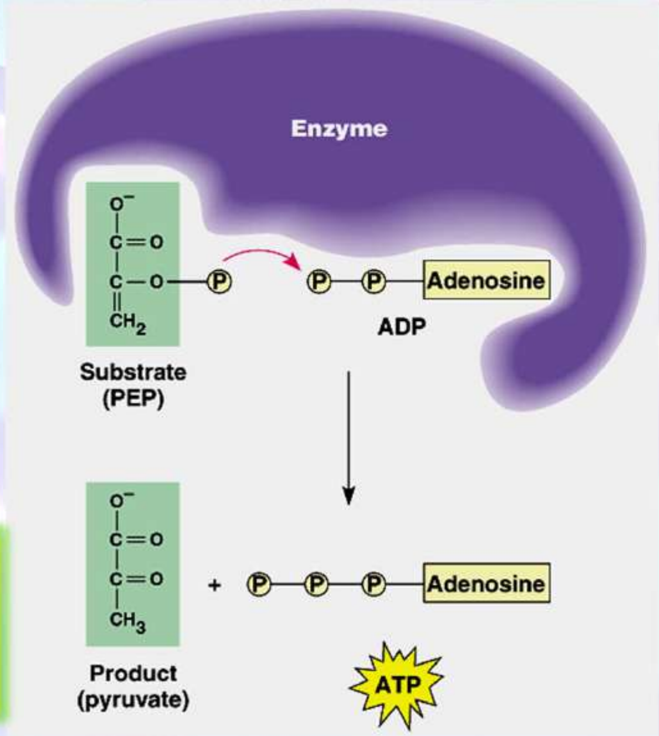
I- Substrate-level phosphorylation:

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

II- Oxidative phosphorylation:

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

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



1- Glycolysis (splitting glucose): harvests chemical energy by oxidizing glucose to 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:

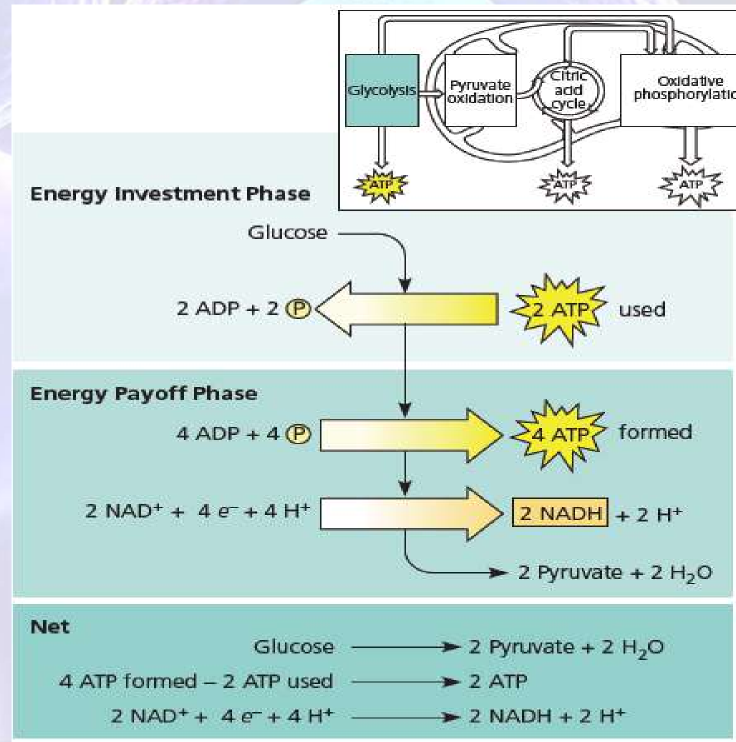
1)- Energy investment phase: إستهلاك طاقة

ATP is consumed to provides 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 glucose.
- Thus, the net yield from glycolysis is 2 ATP and 2 NADH per glucose.
- 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 and 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).

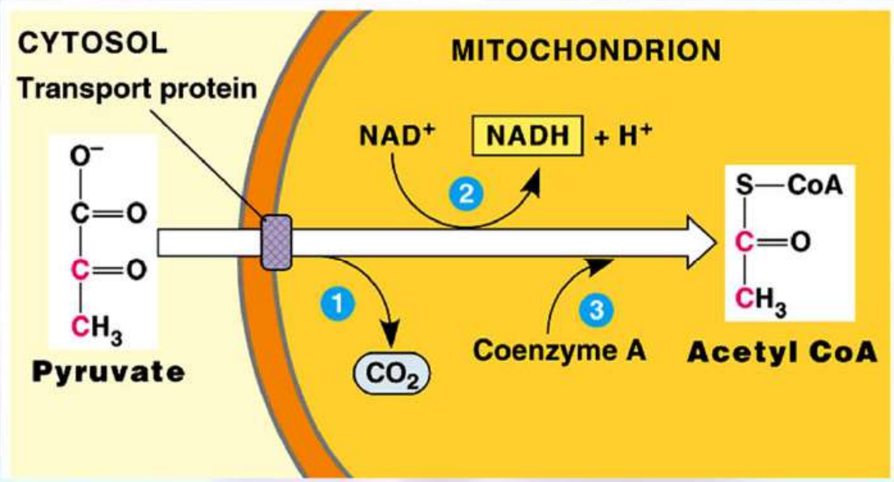
B)- Energy pay-off phase

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*)

- 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 pyruvate 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 coenzyme A to form acetyl-CoA.



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.

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

Krebs cycle

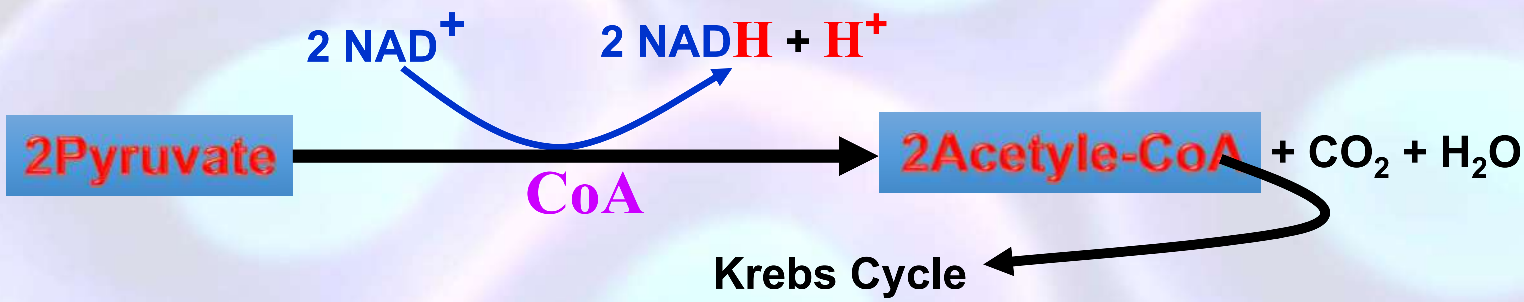
A)- Pre-Krebs cycle

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 acetyle-CoA, which will be ready for Krebs Cycle for further oxidation.



B)- Krebs cycle

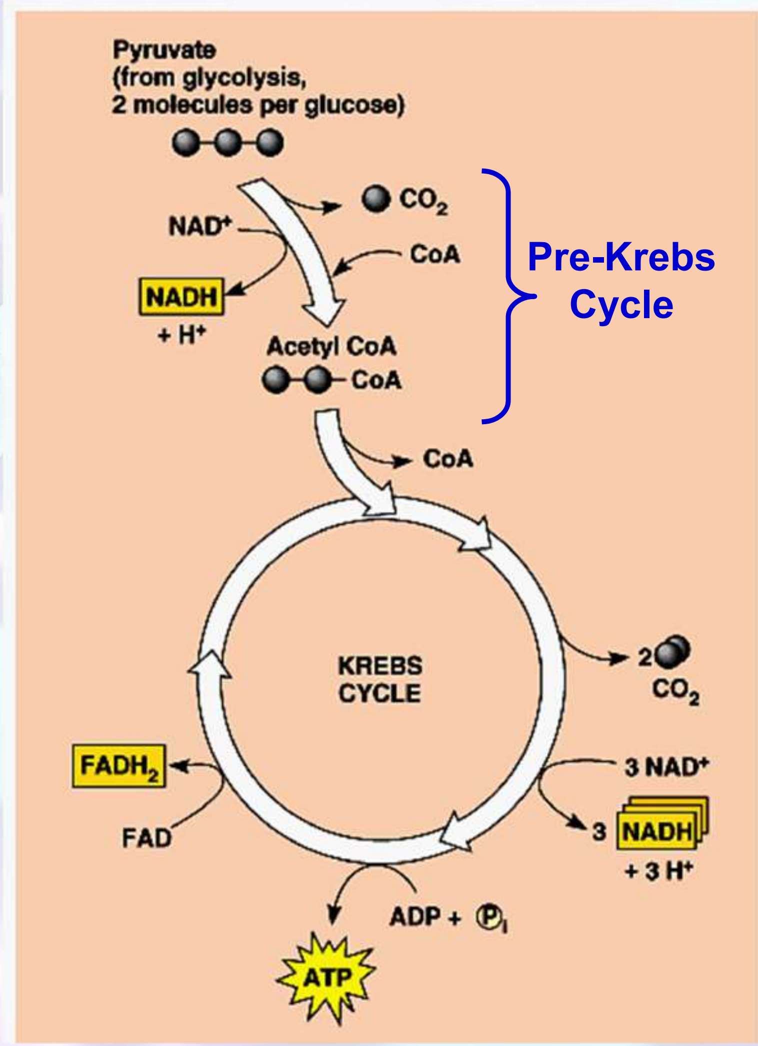
It has eight steps starting with 2 acetyle-CoA compunds. They are summarized as shown in the figure:

- 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, three NADH, and one $FADH_2$ (another electron carrier) per acetyl CoA.

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

Output
- 2 ATP
- 6 NADH
- 2 $FADH_2$

Flavin Adenine Dinucleotide



References

- **"Cellular respiration and Fermentation" chapter 09 Biology** by Jane B Reece; Neil A Campbell; et al Boston : Benjamin Cummings / Pearson, ©2011. English : 9th Ed.