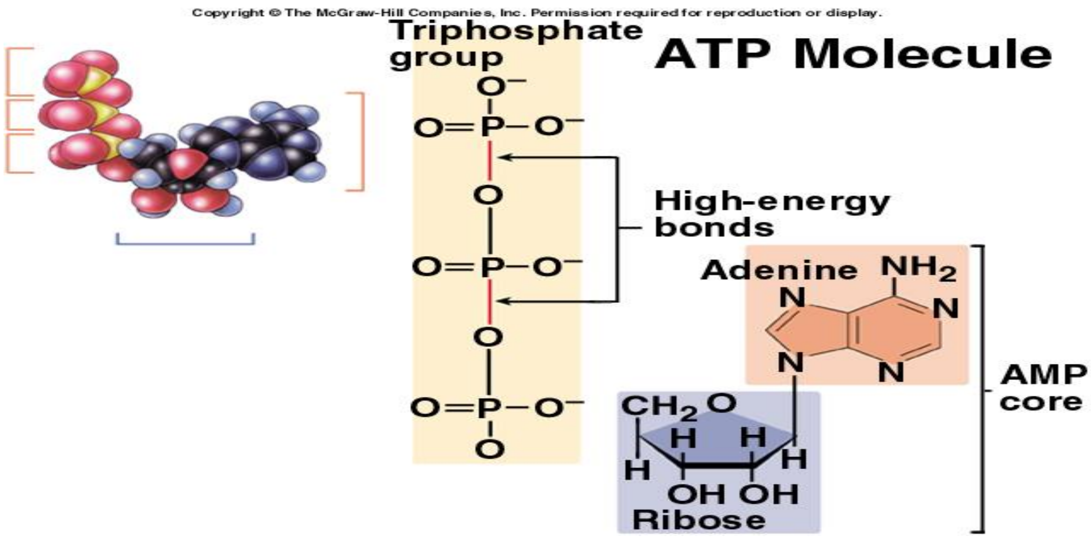
RESPIRATION

All living organisms need energy. Respiration: the life process by which organisms convert the chemical energy stored in food to a form of energy more easily utilized by the cell. Process of Cell Respiration: a biochemical process used by cells to release energy from organic molecules (food) such as glucose:

~This energy is stored in the molecule ATP

~ ATP = adenosine triphosphate or A~P~P~P

~ The process is controlled by enzymes



Life on Earth first evolved without free oxygen (O_2) in atmosphere and energy had to be captured from organic molecules in absence of O_2, so organisms that evolved glycolysis are ancestors of all modern life.

Cellular respiration is a chain of pathway, through which the carbohydrate molecule and other molecule is oxidized into CO_2 and H_2O and release of energy which is used in reactions that needs energy, as well as obtaining carbon skeletons needed for growth and development of the cell. Higher plants are aerobic organisms, that gets its energy and carbon by respiration

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

Oxidation of hexose sugar into CO_2 and H_2O takes place in three separate stages:

1. Glycolysis.
2. Citric acid cycle (or Krebs cycle).
3. Electron transport chain.

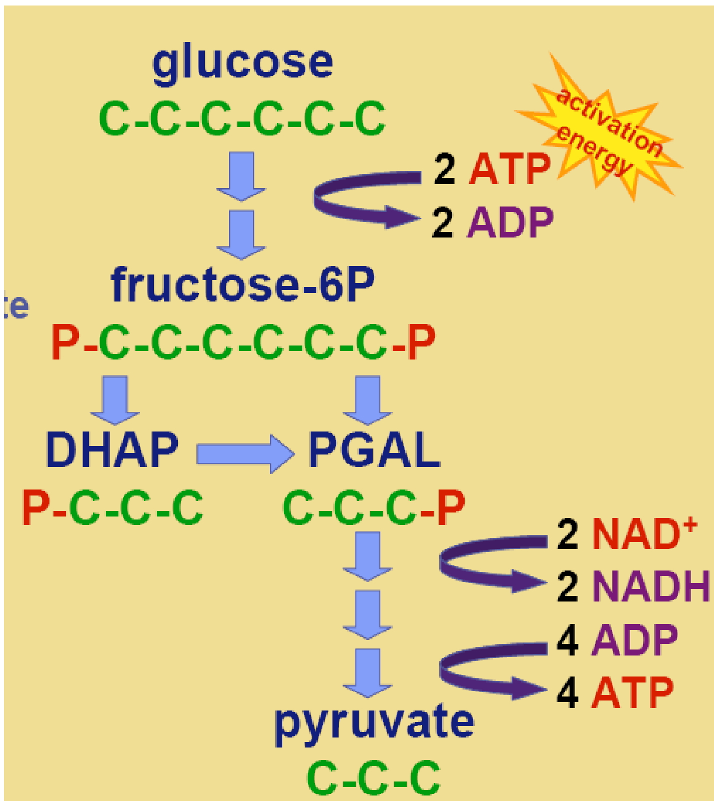
Glycolysis

Glycolysis is breaking down glucose□“glyco – lysis” (splitting sugar).

It is the most ancient form of energy capture and the starting point for all cellular respiration □inefficient □generate only 2 ATP for every 1 glucose □in cytosol.

It is also known as EMP (or Eembden - Myerhofparnas).

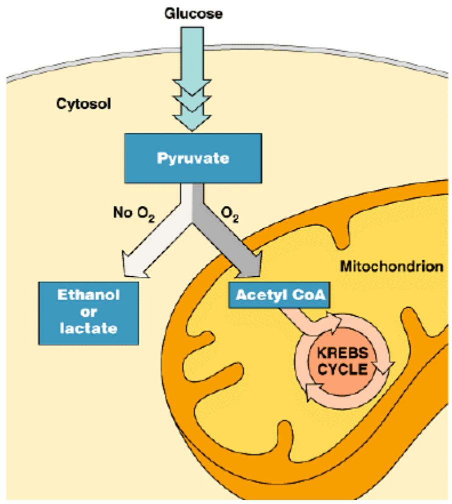
It represents the first stage of respiration. It consists of a chain of anaerobic reactions which takes place in the cytoplasm. The six-carbon sugar molecule is divided and partially oxidized into 3-carbon inorganic acid called pyruvic acid or pyruvate.



The overall balance (or balanced reaction) of glycolysis reaction:

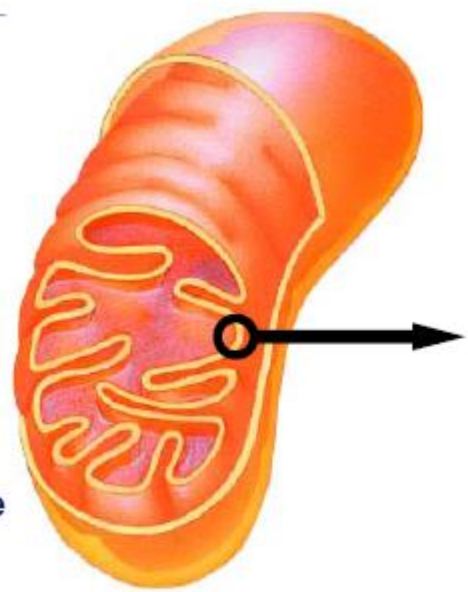
1 Clucose +2 ADP+2 ip+2 NAD $\longrightarrow$ 2 pyA+2 ATP+2 NADH

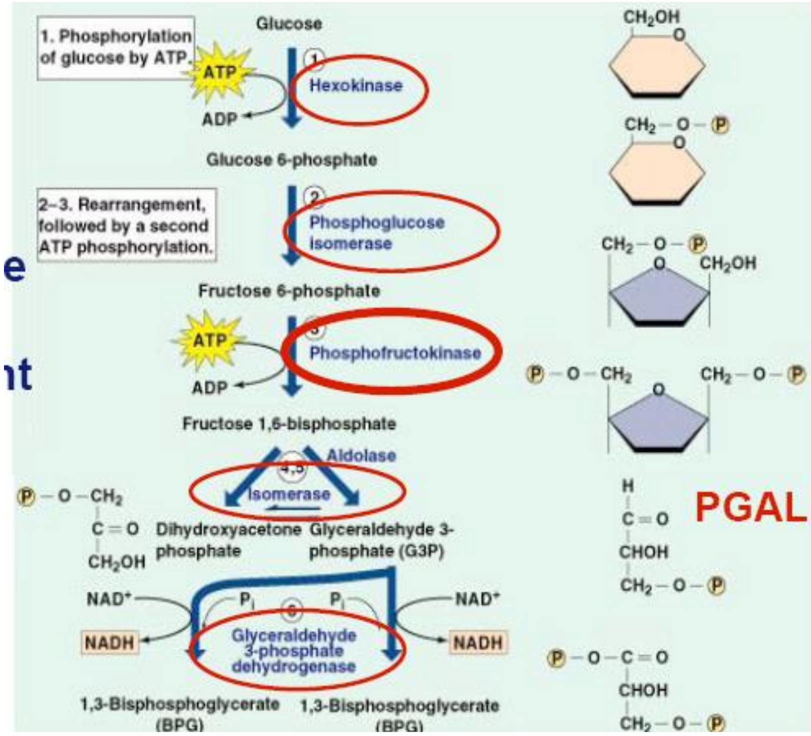
Further transformation of pyA depends on the presence or absence of oxygen. In aerobic conditions the pyA is transferred into mitochondria, where it is oxidized into CO_2 and H_2O. Under anaerobic conditions (e.g. in the roots when the soil is saturated with water).fermentation takes place, and here pyA will either be transformed into ethyl alcohol (which is the result of fermentation in most of the plants) or lactic acid or other organic acids depending on microorganism.



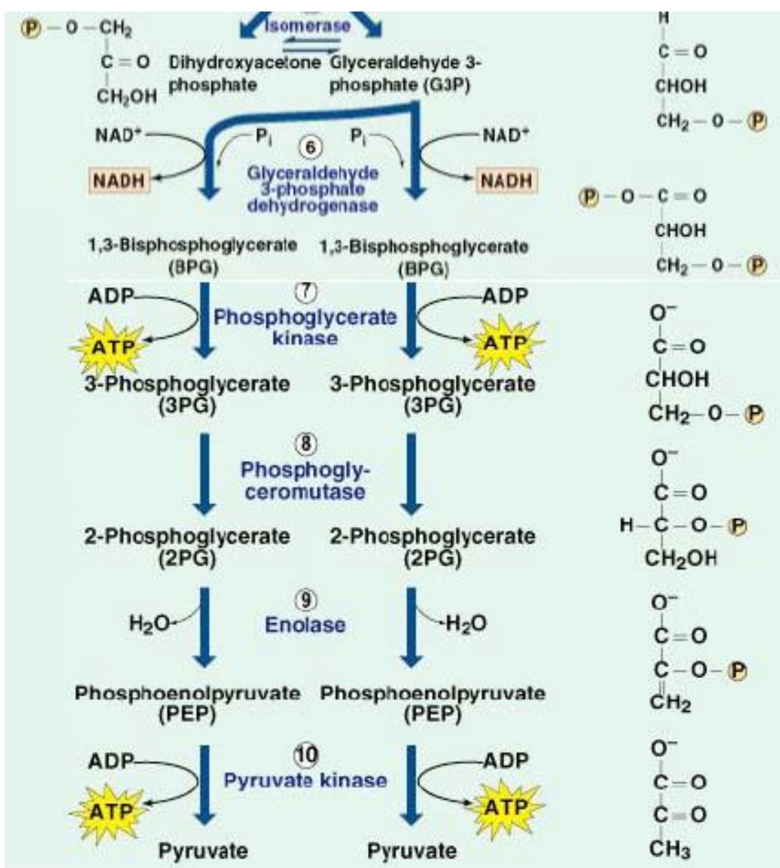
Mitochondria

- Double membrane
  - outer membrane
  - inner membrane
    - highly folded cristae*
    - fluid-filled space between membranes = intermembrane space
  - matrix
    - central fluid-filled space





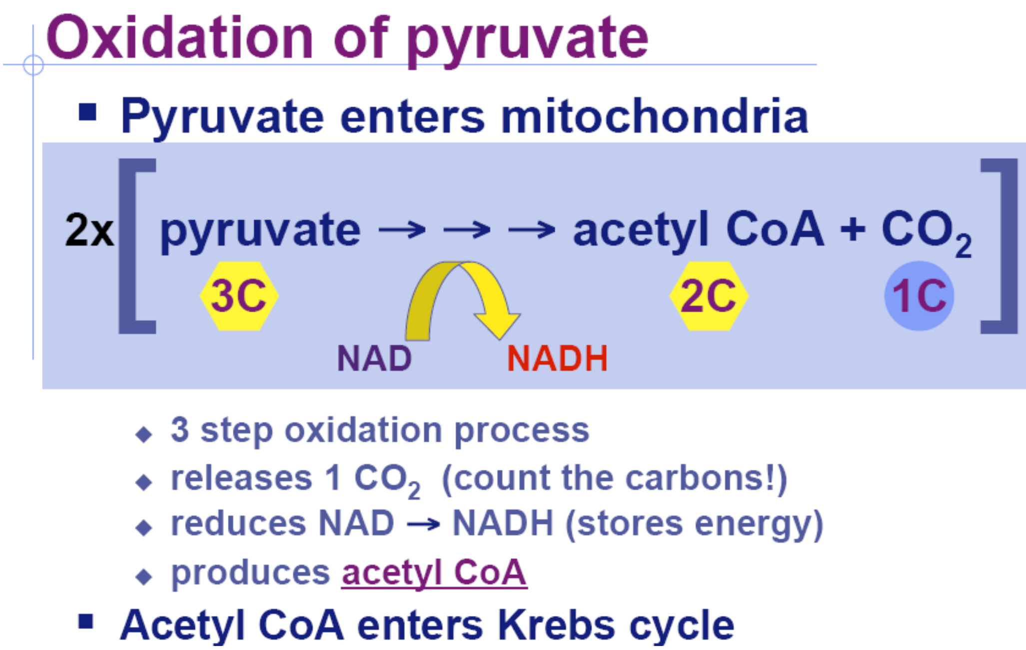
1. Phosphorylation of glucose by ATP.
Glucose
ATP
ADP
Hexokinase
Glucose 6-phosphate
2–3. Rearrangement, followed by a second ATP phosphorylation.
Phosphoglucose isomerase
Fructose 6-phosphate
Phosphofructokinase
Fructose 1,6-bisphosphate
Aldolase
Isomerase
Dihydroxyacetone phosphate
Glyceraldehyde 3-phosphate (G3P)
PGAL
NAD+
NADH
Glyceraldehyde 3-phosphate dehydrogenase
1,3-Bisphosphoglycerate (BPG)
1,3-Bisphosphoglycerate (BPG)



Isomerase
Dihydroxyacetone phosphate
Glyceraldehyde 3-phosphate (G3P)
NAD+
NADH
Glyceraldehyde 3-phosphate dehydrogenase
1,3-Bisphosphoglycerate (BPG)
1,3-Bisphosphoglycerate (BPG)
ADP
ATP
Phosphoglycerate kinase
3-Phosphoglycerate (3PG)
3-Phosphoglycerate (3PG)
Phosphoglycerомutase
2-Phosphoglycerate (2PG)
2-Phosphoglycerate (2PG)
Enolase
Phosphoenolpyruvate (PEP)
Phosphoenolpyruvate (PEP)
Pyruvate kinase
Pyruvate
Pyruvate

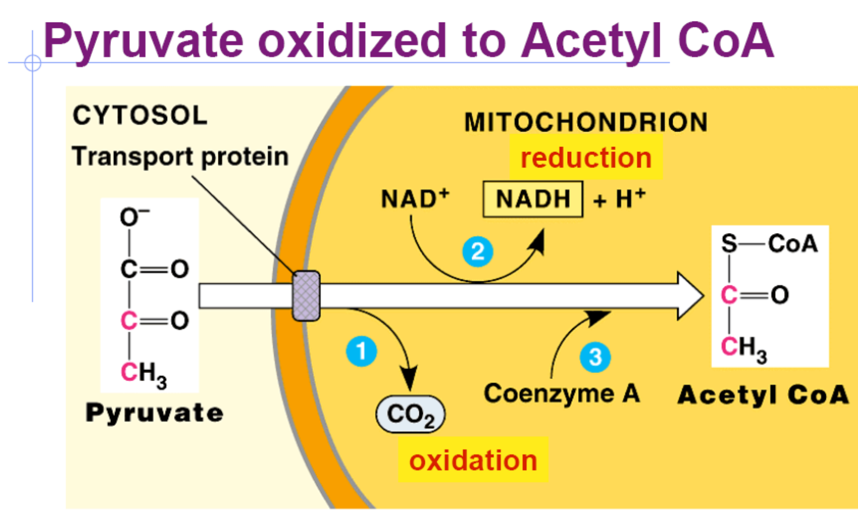
Citric acid cycle:

It is known as Krebs cycle or Tricabroxylic acid cycle (TCA).



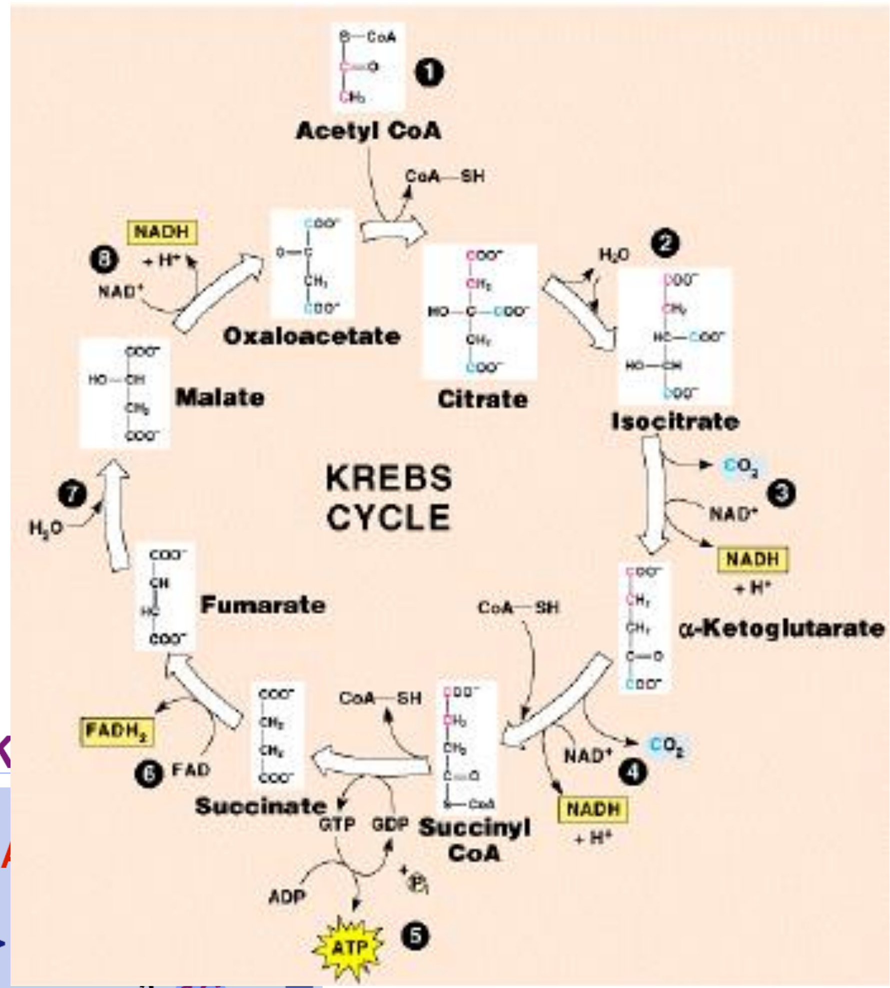
In the presence of oxygen, pyA is oxidized into CO_2 and H_2O in thecycle. It is the second stage in respiration and takes place in the mitochondria.

Pyruvic acid is transferred to the mitochondria and passes into a series of reactions (5 reactions), that ends up with the oxidation of pyA molecule and produces a 2-Carbon compound called Acetyl Co-A.



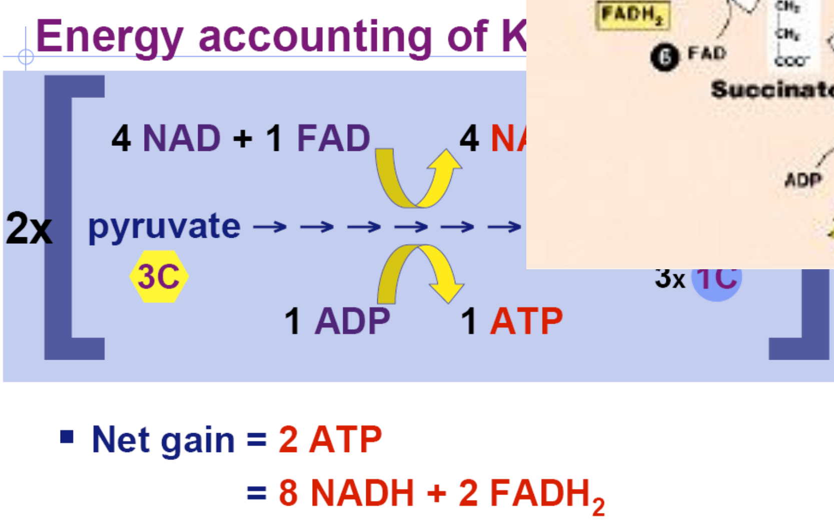
Pyruvate + NAD+ + Co-A $\longrightarrow$ Acetyl Co-A + NADH + H+ + CO2

The Acetyl-Co-A enters Krebs cycle where it first react with a 4-carbon organic acid called OAA (Oxaloacetic acid) forming Citric acid which enters a chain of reactions through which energy is released in the form of ATP, or used for reduction of the soluble (respiration carries) NAD into NADH2 and FAD+(flavin adenine dinucleotide) into FADH2 .

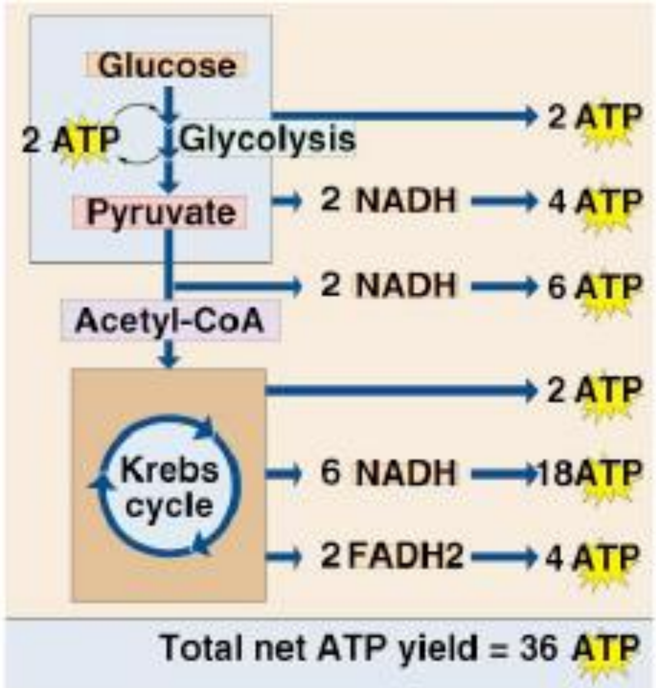


Every NADH that its electron is transferred into the ETC will produce 3 molecules of ATP, and each FADH2 produces 2 ATP.

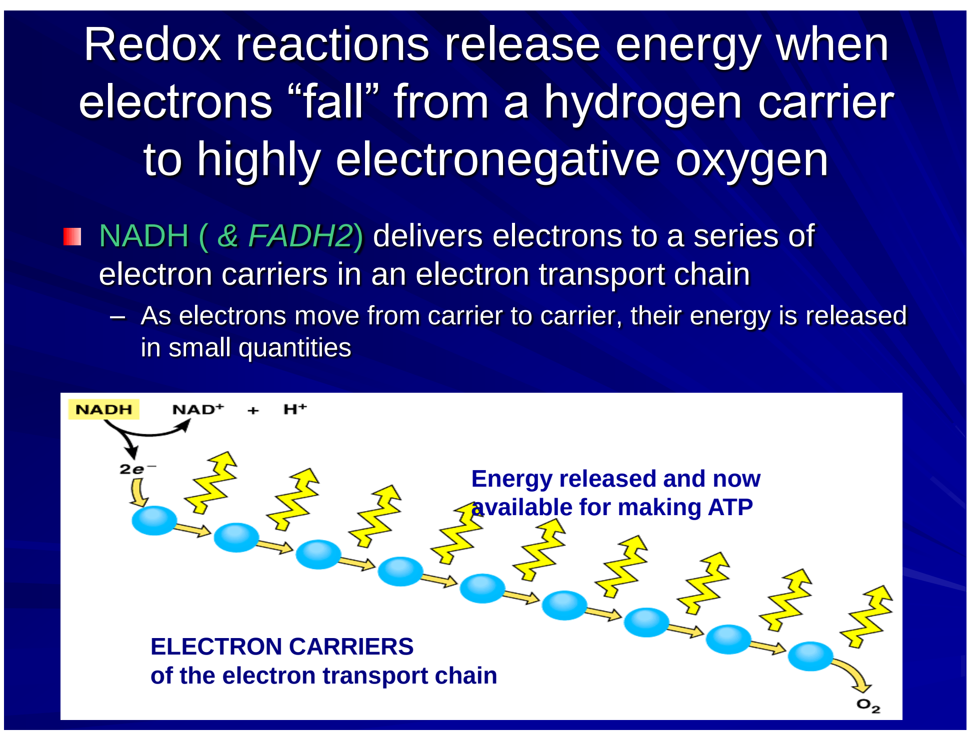
Overall energy (in the of ATP) that results from complete oxidation of one glucose molecule in respiration is as follow



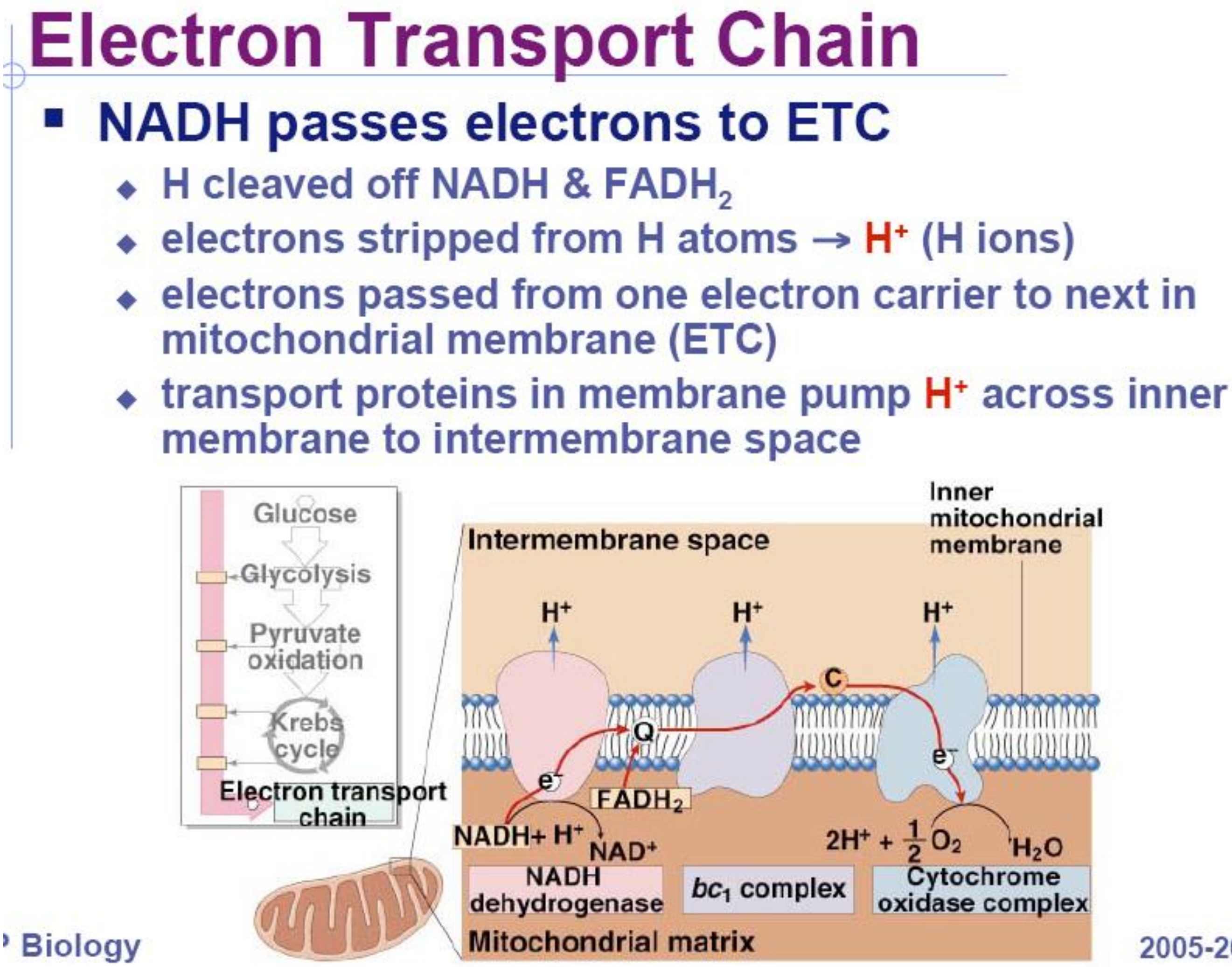
Pathway	NADH X3	$FADH_2$ X2	ATP	Total ATP
Glycolysis	2(6ATP)	0	2	8
PyA ⟶ acetyl Co-A	2(6ATP)	0	0	6
Krebs cycle	6(18ATP)	2(4ATP)	2	24
Total ATP	*10x3=30*	*2x2=4*	*4*	*38*



Electron Transfer Chain



The number of ATP molecules that results from glycolysis and Krebs cycle is low (i.e. four molecules only). Most of potential energy in the sugar (e.g. glucose molecule) is present in the form of electron pairs (12 pairs), 10 pairs in the form of NADH and 2 pairs in the form of FADH2. The stored energy in these reduced carriers is liberated in the form of ATP in the third stage of respiration. In this stage the electrons from NADH and FADH2 are transferred to the oxygen, coupled with transformation of energy in ATP in the electron transfer system which takes place in the inner membrane of the mitochondria.



The electron transfer chain consists of a chain of carriers of NAD, FMN, CoQ and cytochromes b, c, a and a3 with gradual reduction in energy (i.e. each carrier has an energy less than the previous one).The energy released in the different stages of the electron transfer chain is used for ATP building.

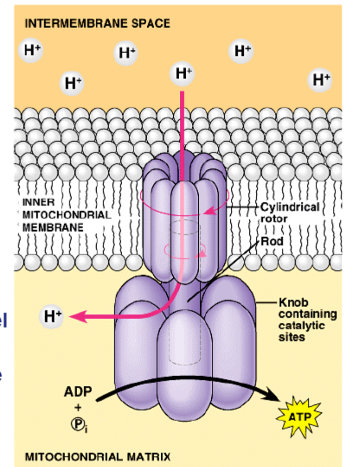
The carriers are enzyme & coenzymes located on the inner membrane of the mitochondria & it resembles the photosynthesis carriers that found in the thylakoids of the chloroplast.

Why the build up H^+?

- **ATP synthase**
  - enzyme in inner membrane of mitochondria

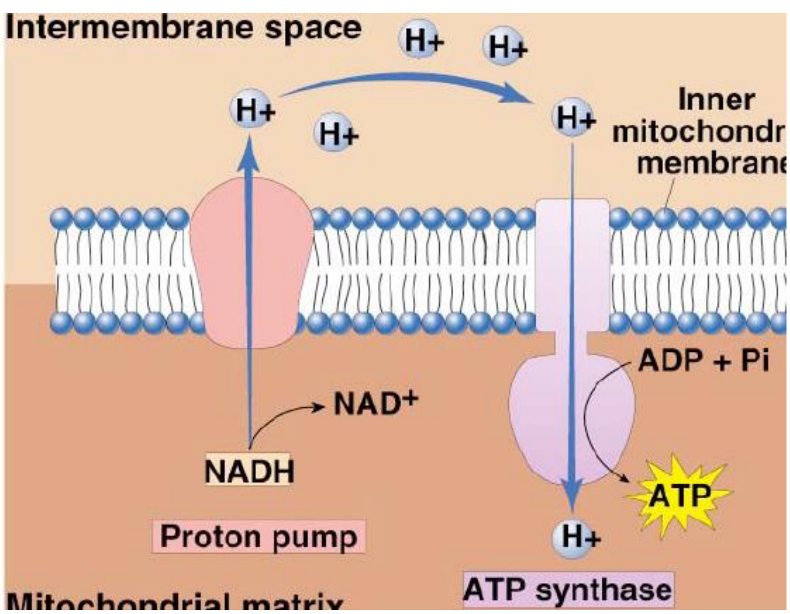
    ADP + P_i → ATP

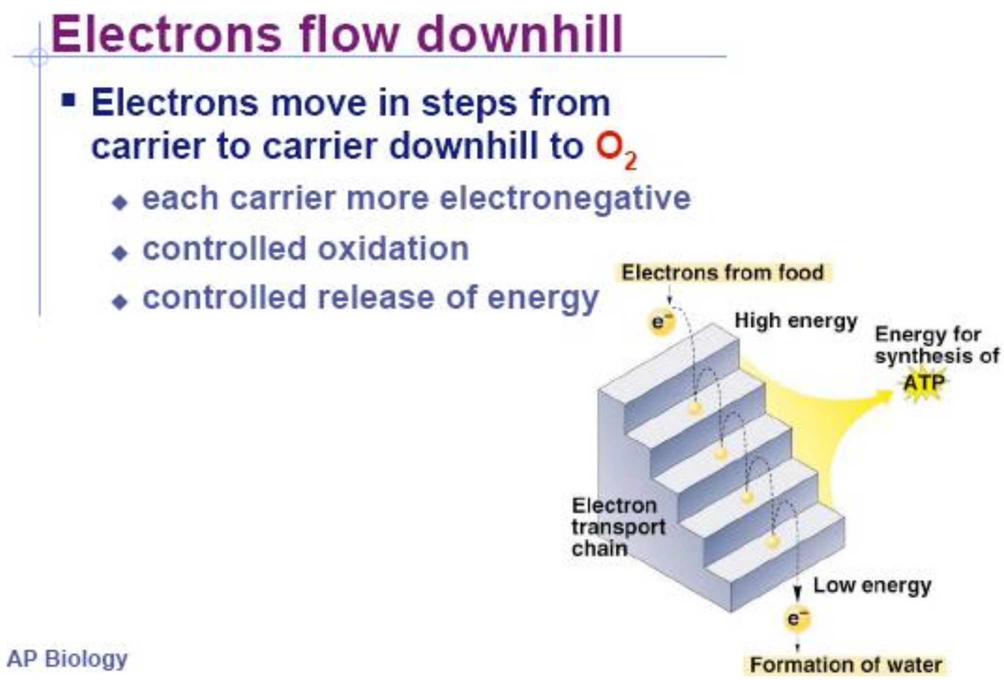
  - only channel permeable to H^+
  - H^+ flow down concentration gradient = provides energy for ATP synthesis
    - molecular power generator!
    - flow like water over water wheel
    - flowing H+ cause change in shape of ATP synthase enzyme
    - powers bonding of P_i to ADP
    - "proton-motive" force

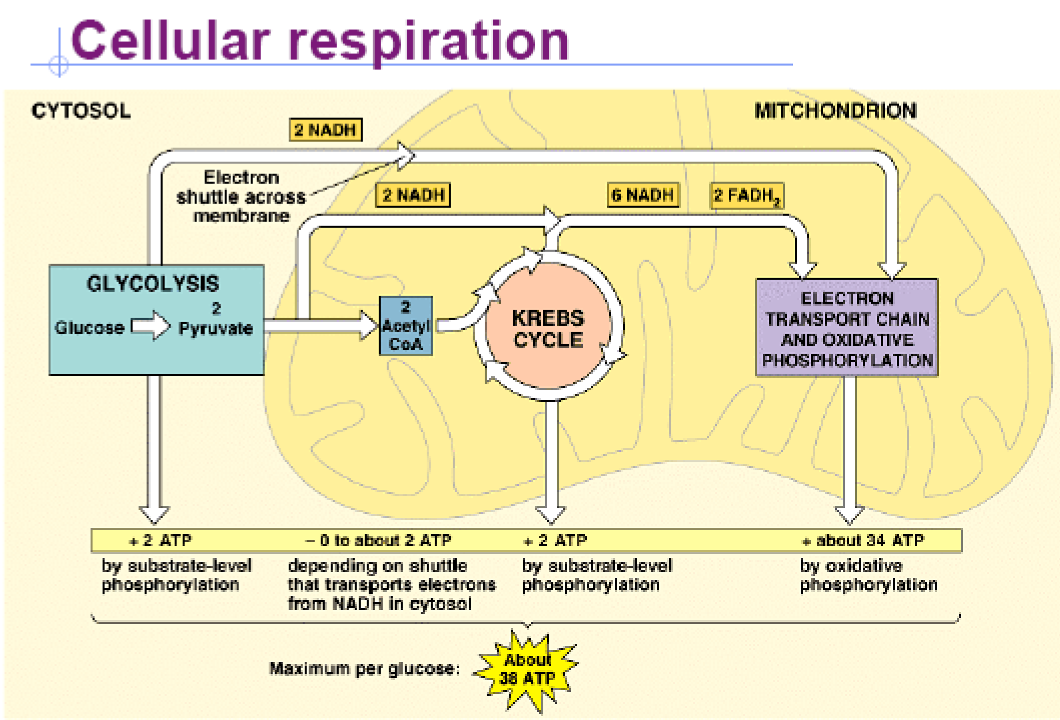


ATP synthesis

- **Chemiosmosis couples ETC to ATP synthesis**
  - build up of H+ gradient just so H+ could flow through ATP synthase enzyme to build ATP



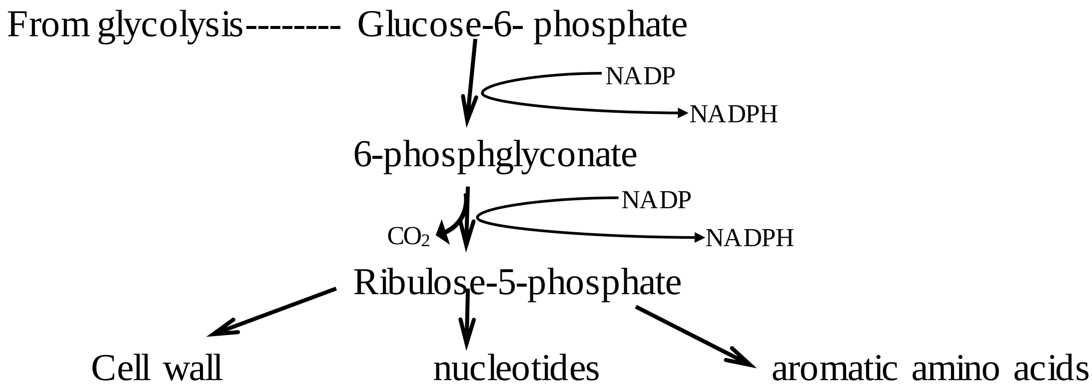




The Pentose Phosphate Pathway
(or Hexose Monophosphate Shunt).

In higher plant, as well as animals, this pathway for glucose metabolism is also found. It takes place in the cytoplasm and requires oxygen.The first step is oxidation of glucose -6-p to 6-phosphogluconate, which loses a CO2 to produce a phosphorylated 5-

carbon sugar called Ribulose-5-phosphate, which can be converted into other compound, or becomes a part of nucleotides of DNA and RNA or other compound.



Significance of this pathway:

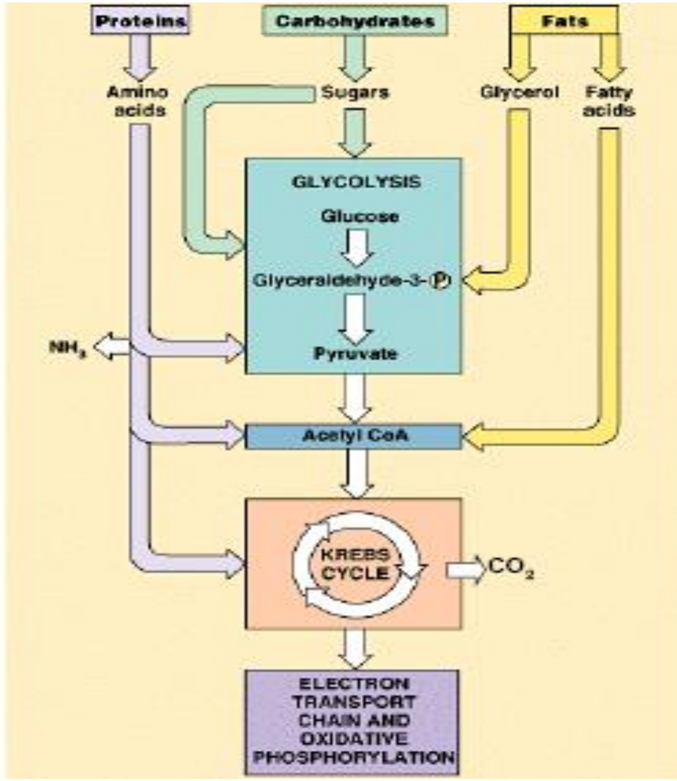
1. Production of reduction power NADPH (instead of NADH) which is used as a donor for electron in metabolic reactions.
2. Production of pentose sugar, which is the source for Ribose and deoxyribose needed for nucleic acid synthesis (DNA and RNA).
3. Production of erythrose-4-P, which is the source of aromatic amino acids, lignin and flavenoids.

Relationship between respiration and building blocks:-

The intermediate compound of respiration usually enters other metabolic pathways to build up building blocks for the cell before complete oxidation into CO2 and water.

This means that the main functions of Respiration are:-

1. Liberation of energy needed for metabolism.
2. Building of cell building blocks or units, regardless of their type.



Respiratory Quotient (RQ)

It is the ratio of liberated CO_2 to the absorbed O_2 when substrate (i.e. the matter of respiration) is oxidized.

In aerobic Respiration: This ratio is almost 1 always because:
$C_6H_{12}O_6 + 6O_2 \quad 6H_2O + 6CO_2 \qquad \longrightarrow$
Therefore for Carbohydrates:

$$RQ = \frac{6(CO_2)}{6(O_2)} = 1.0$$

For lipids:

RQ depends on the chemical structure of the molecule. It is usually between 0.7-0.8
Example: $C18H36O2+26O2 \longrightarrow 18CO2+18H2O$

$$RQ = \frac{18(CO_2)}{26(O_2)} = 0.7$$

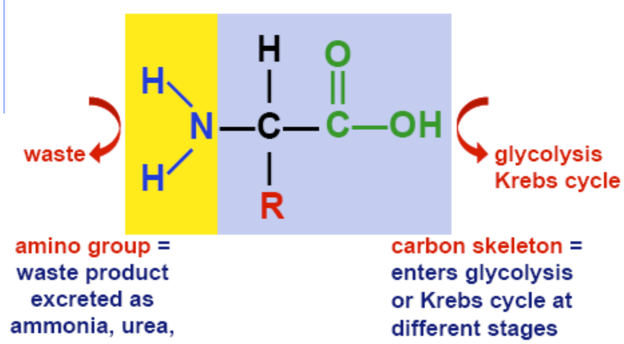
For Protein

RQ usually between 0.8 and 1.0, depending on the oxidation degree

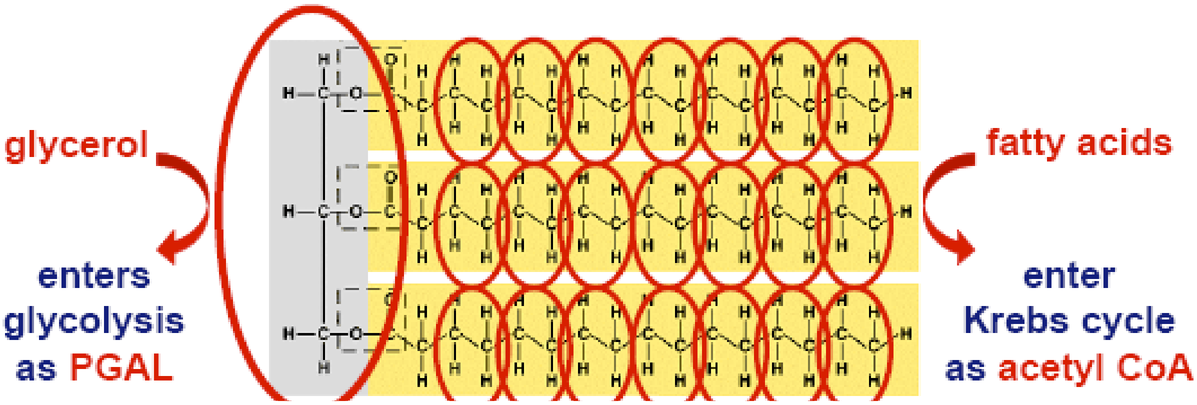
Measuring of RQ is necessary to determine the nature of the oxidized compound to produce the energy

- **Glycolysis accepts a wide range of carbohydrates fuels**
  - polysaccharides → → → glucose
    hydrolysis
    - ex. starch, glycogen
  - other 6C sugars → → → glucose
    modified
    - ex. galactose, fructose

- Proteins → → → → → amino acids
  hydrolysis



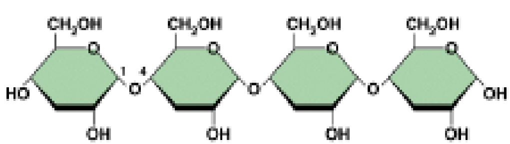
- **Fats → → → → → glycerol & fatty acids**
  hydrolysis
  - glycerol (3C) → → PGAL → → glycolysis
  - fatty acids → 2C acetyl groups → acetyl coA → Krebs cycle



Carbohydrates vs. Fats

- **Fat generates 2x ATP vs. carbohydrate**
  - more C in gram of fat
  - more O in gram of carbohydrate
    - so it's already partly oxidized

carbohydrate



fat