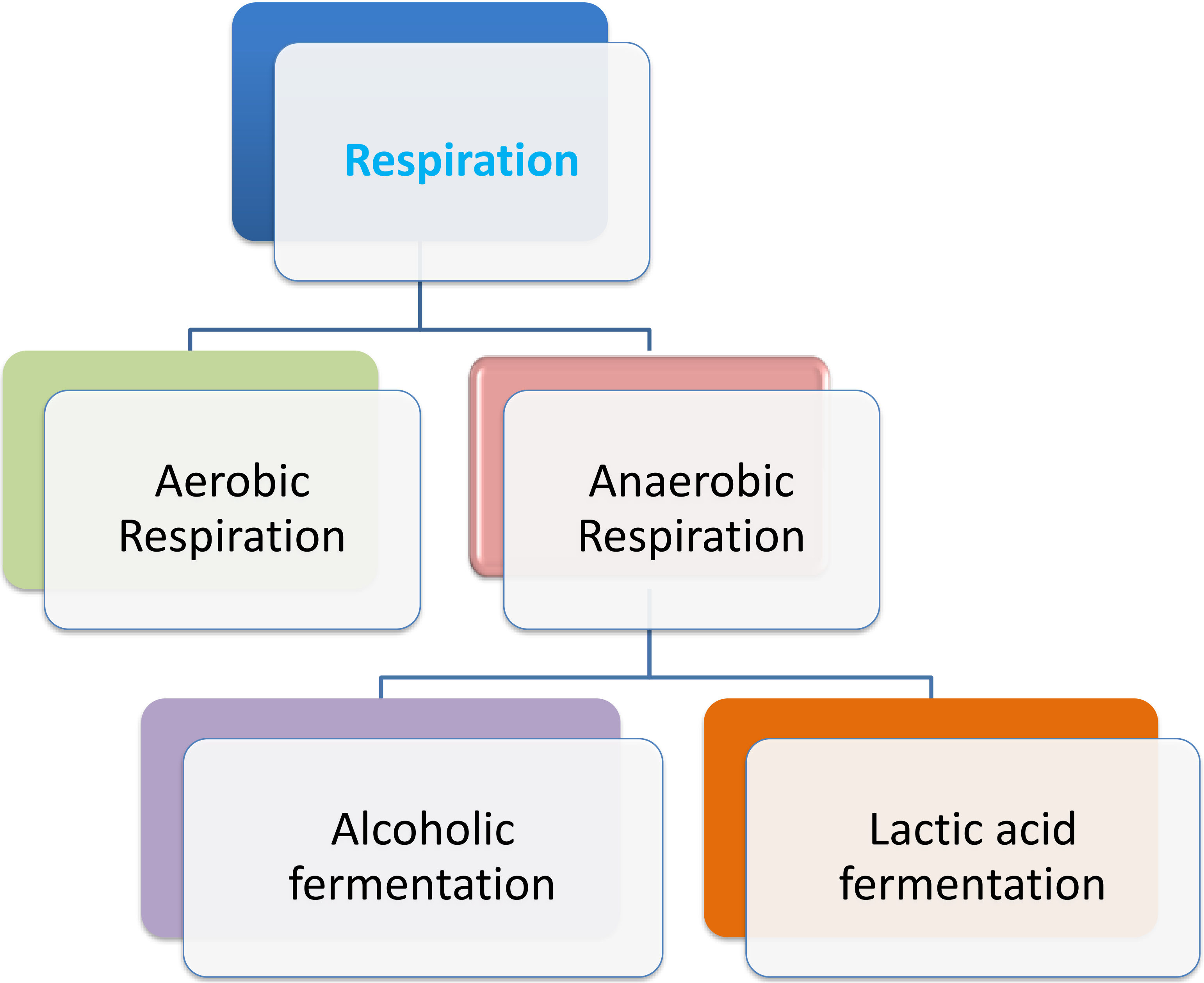
Cellular Respiration- Harvesting Chemical Energy

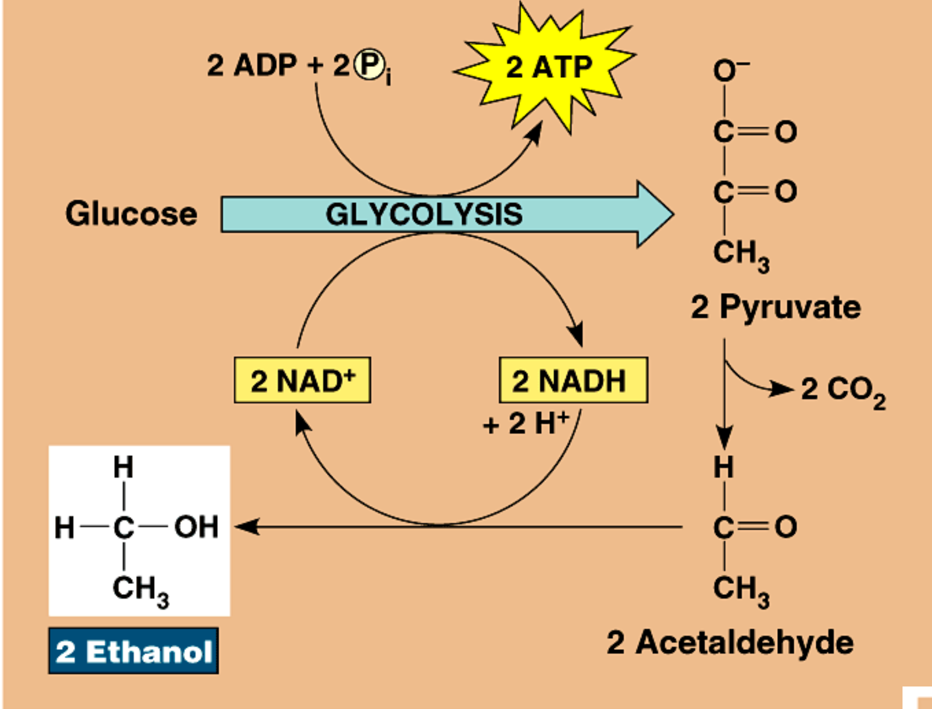
$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6H_2O + 6CO_2 + \text{Energy}$$

- Organic compounds store energy
- Fats, carbohydrates, protein all can be used as fuel. Traditionally, cellular respiration is studied using glucose as the source.

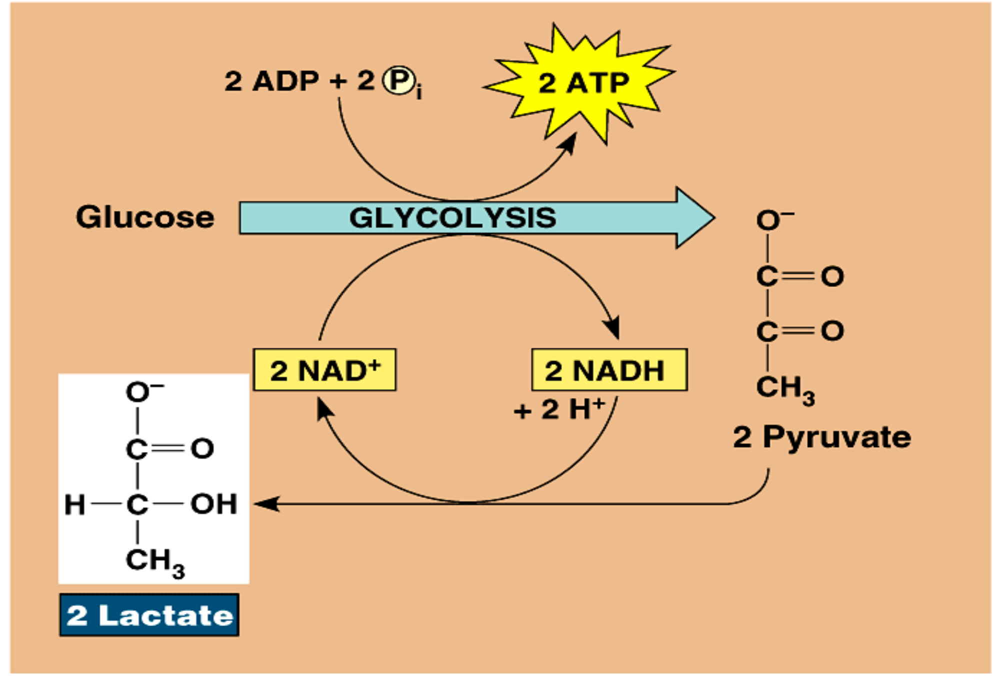
- There are 2 energy-providing (catabolic) pathways
  - **Cellular Respiration**
  - **Fermentation (partial degradation of sugar without oxygen)**



Respiration
Aerobic Respiration
Anaerobic Respiration
Alcoholic fermentation
Lactic acid fermentation



(a) Alcohol fermentation



(b) Lactic acid fermentation

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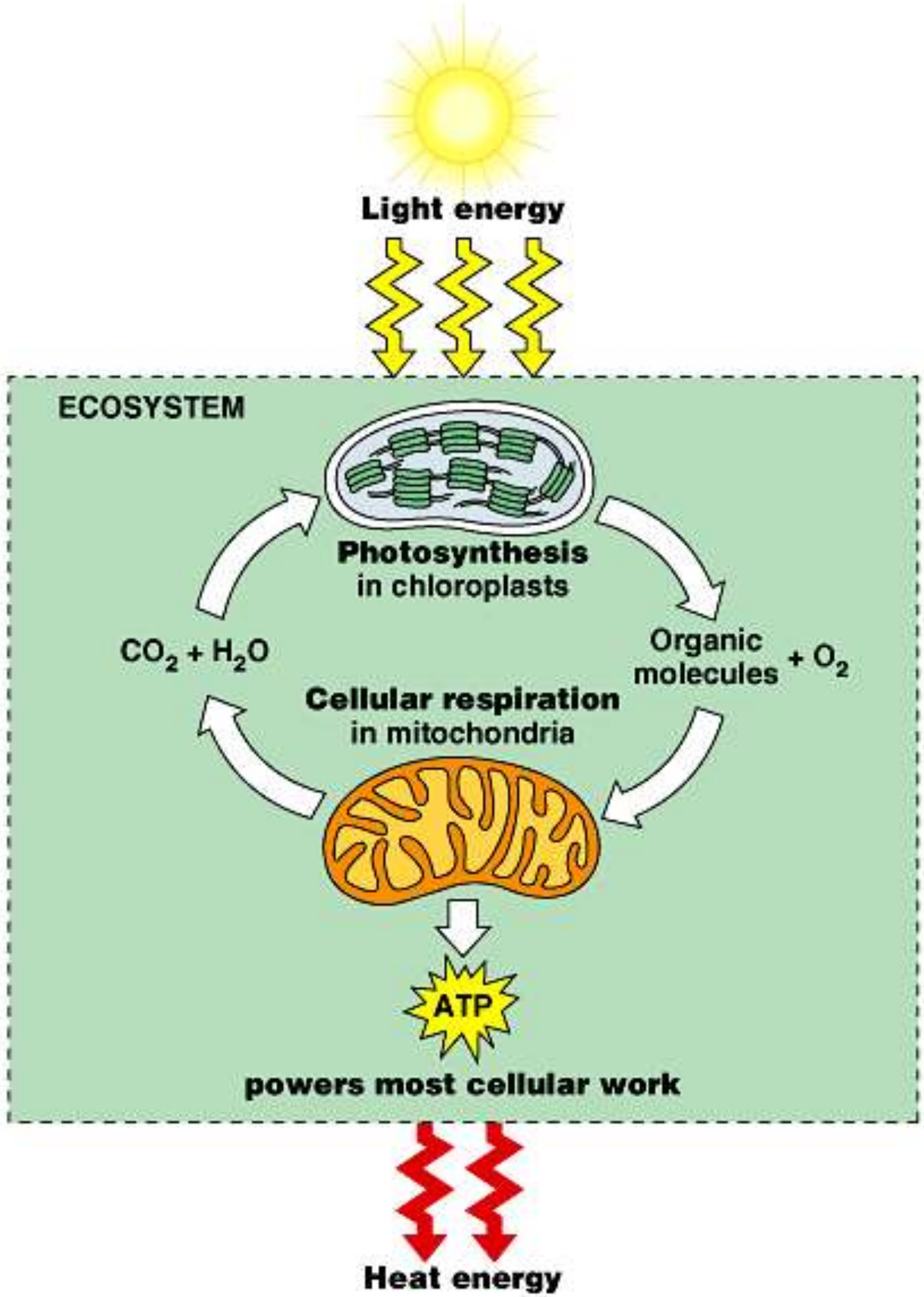
RESPIRATION IN PLANTS

- **Plants are aerobes**

- **Includes pathways that require oxygen**
- **Glucose is oxidized and O_2 is reduced**
- **Glucose breakdown is therefore an *oxidation-reduction* reaction**


Light energy
ECOSYSTEM
Photosynthesis
in chloroplasts
$CO_2 + H_2O$
Organic
molecules
$+ O_2$
Cellular respiration
in mitochondria
ATP
powers most cellular work
Heat energy

What Type of Process is Cellular Respiration?

- An Oxidation-Reduction Process or REDOX Reaction
- Oxidation of GLUCOSE --> CO_2 + H_2O (e^- removed from $C_6H_{12}O_6$)
- Reduction O_2 to H_2O (e^- passed to O_2)

oxidation

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

reduction

What are the Stages of Cellular Respiration?

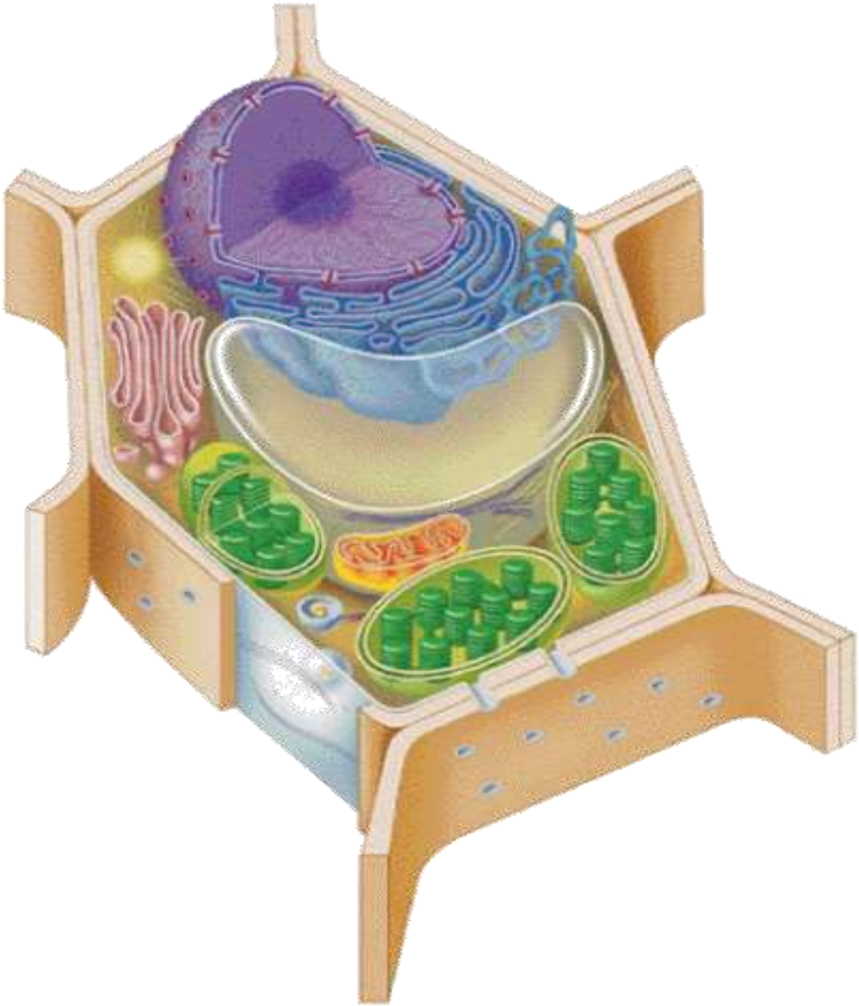
- Glycolysis
- The Krebs Cycle
- The Electron Transport Chain

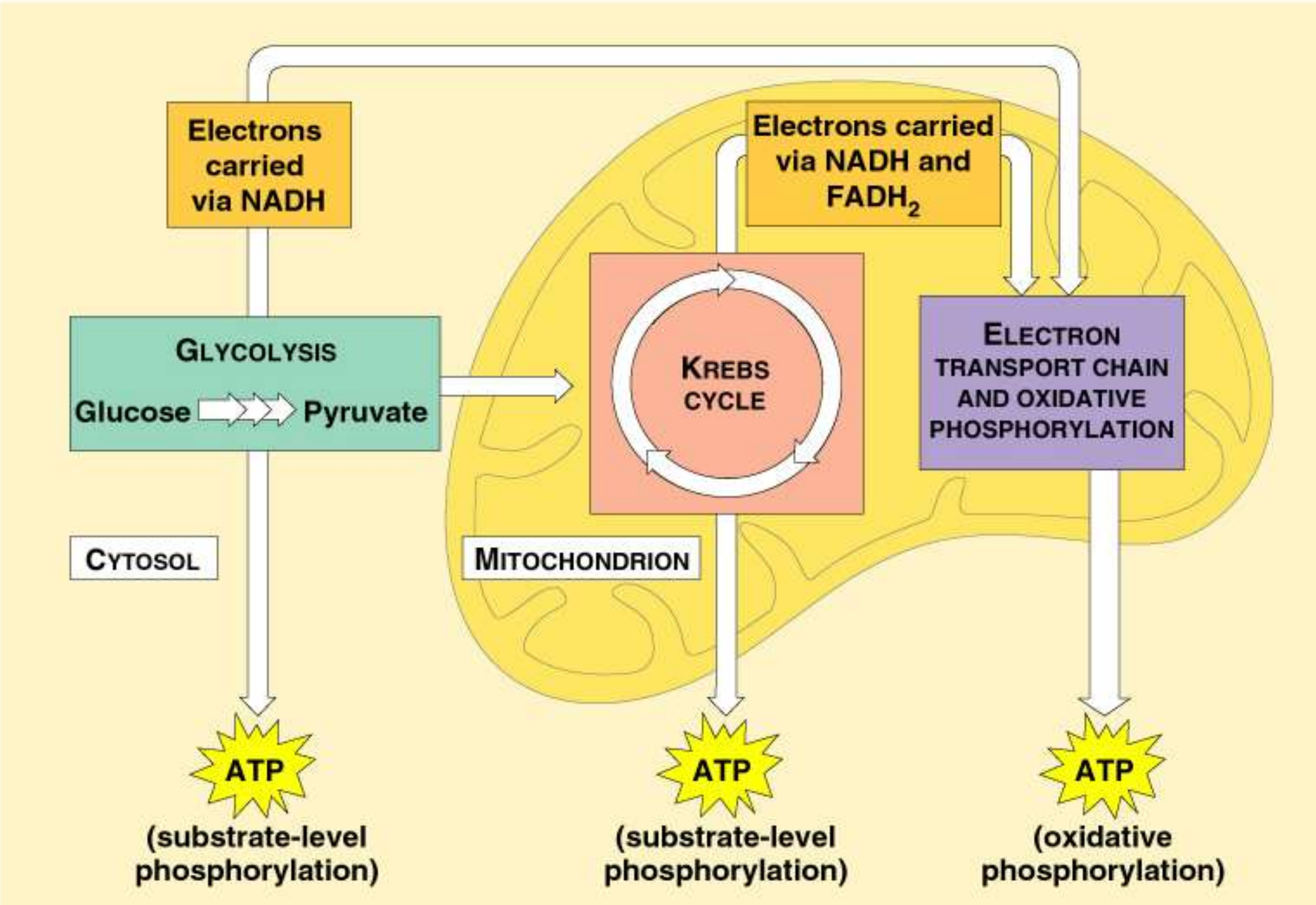
Where Does Cellular Respiration Take Place?

- It actually takes place in two parts of the cell:

Glycolysis occurs in the Cytoplasm

Krebs Cycle & ETC Take place in the Mitochondria




Electrons carried via NADH
Electrons carried via NADH and FADH2
GLYCOLYSIS
Glucose
Pyruvate
KREBS CYCLE
ELECTRON TRANSPORT CHAIN AND OXIDATIVE PHOSPHORYLATION
CYTOSOL
MITOCHONDRION
ATP
(substrate-level phosphorylation)
ATP
(substrate-level phosphorylation)
ATP
(oxidative phosphorylation)

Overall Equation for Cellular Respiration

$$C_6H_{12}O_6 \quad + 6O_2$$

↓

YIELDS

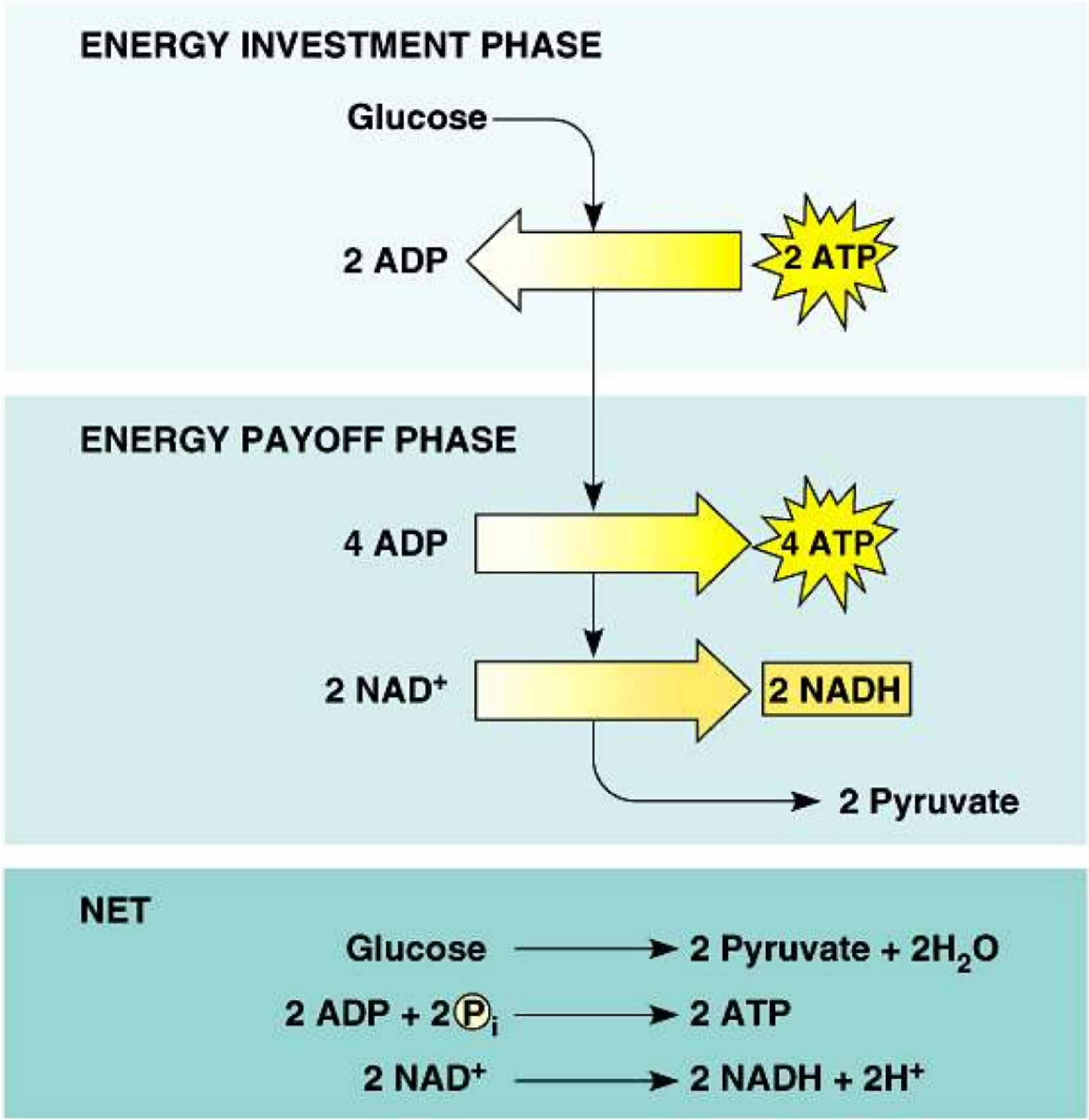
↓

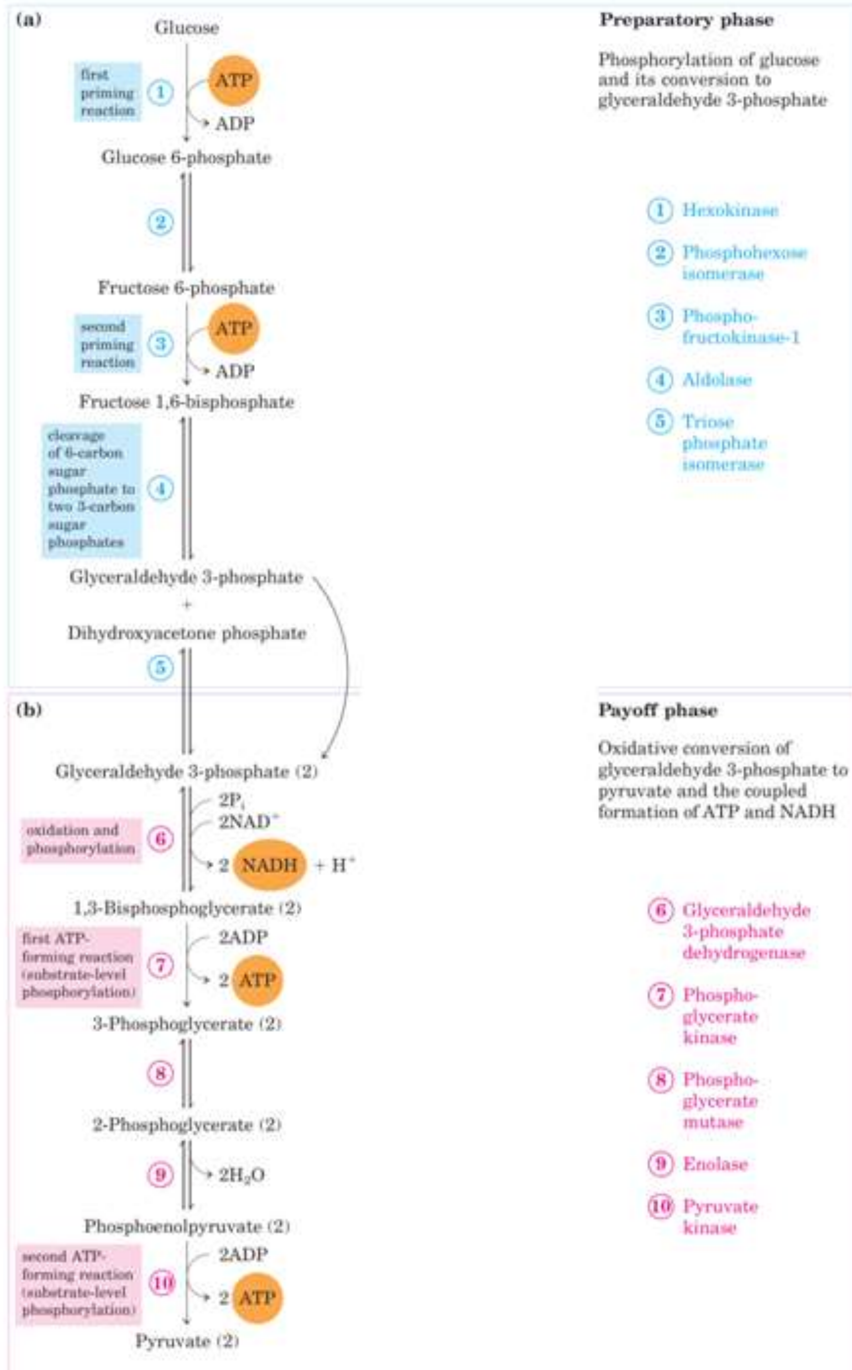
$$6CO_2 + 6H_20 + e^- + 36\text{-}38\text{ATP's}$$

Glycolysis

Splits a glucose molecule into two 3 Carbon molecules called PYRUVATE.

products: 2 ATP, NADH and pyruvate


ENERGY INVESTMENT PHASE
Glucose
2 ADP
2 ATP
ENERGY PAYOFF PHASE
4 ADP
4 ATP
2 NAD+
2 NADH
2 Pyruvate
NET
Glucose → 2 Pyruvate + 2H2O
2 ADP + 2 Pi → 2 ATP
2 NAD+ → 2 NADH + 2H+



(a)
Glucose
first priming reaction
1
ATP
ADP
Glucose 6-phosphate
2
Fructose 6-phosphate
second priming reaction
3
ATP
ADP
Fructose 1,6-bisphosphate
cleavage of 6-carbon sugar phosphate to two 3-carbon sugar phosphates
4
Glyceraldehyde 3-phosphate
+
Dihydroxyacetone phosphate
5
Preparatory phase
Phosphorylation of glucose and its conversion to glyceraldehyde 3-phosphate
1 Hexokinase
2 Phosphohexose isomerase
3 Phospho-fructokinase-1
4 Aldolase
5 Triose phosphate isomerase
(b)
Glyceraldehyde 3-phosphate (2)
2P$_i$
2NAD$^+$
oxidation and phosphorylation
6
2 NADH + H$^+$
1,3-Bisphosphoglycerate (2)
first ATP-forming reaction (substrate-level phosphorylation)
7
2ADP
2 ATP
3-Phosphoglycerate (2)
8
2-Phosphoglycerate (2)
9
2H$_2$O
Phosphoenolpyruvate (2)
second ATP-forming reaction (substrate-level phosphorylation)
10
2ADP
2 ATP
Pyruvate (2)
Payoff phase
Oxidative conversion of glyceraldehyde 3-phosphate to pyruvate and the coupled formation of ATP and NADH
6 Glyceraldehyde 3-phosphate dehydrogenase
7 Phospho-glycerate kinase
8 Phospho-glycerate mutase
9 Enolase
10 Pyruvate kinase

Glycolysis Summary

Takes place in the Cytoplasm

Anaerobic (Doesn't Use Oxygen)

Requires input of 2 ATP

Glucose split into two molecules of Pyruvate or Pyruvic Acid

Glycolysis Summary

- **Also produces 2 NADH and 4 ATP**
- **Pyruvate is oxidized to Acetyl CoA and CO_2 is removed**

Preparation for the Citric Acid Cycle

The pyruvate looses a carbon leaving the 2 carbon molecule
Acetyl CoA

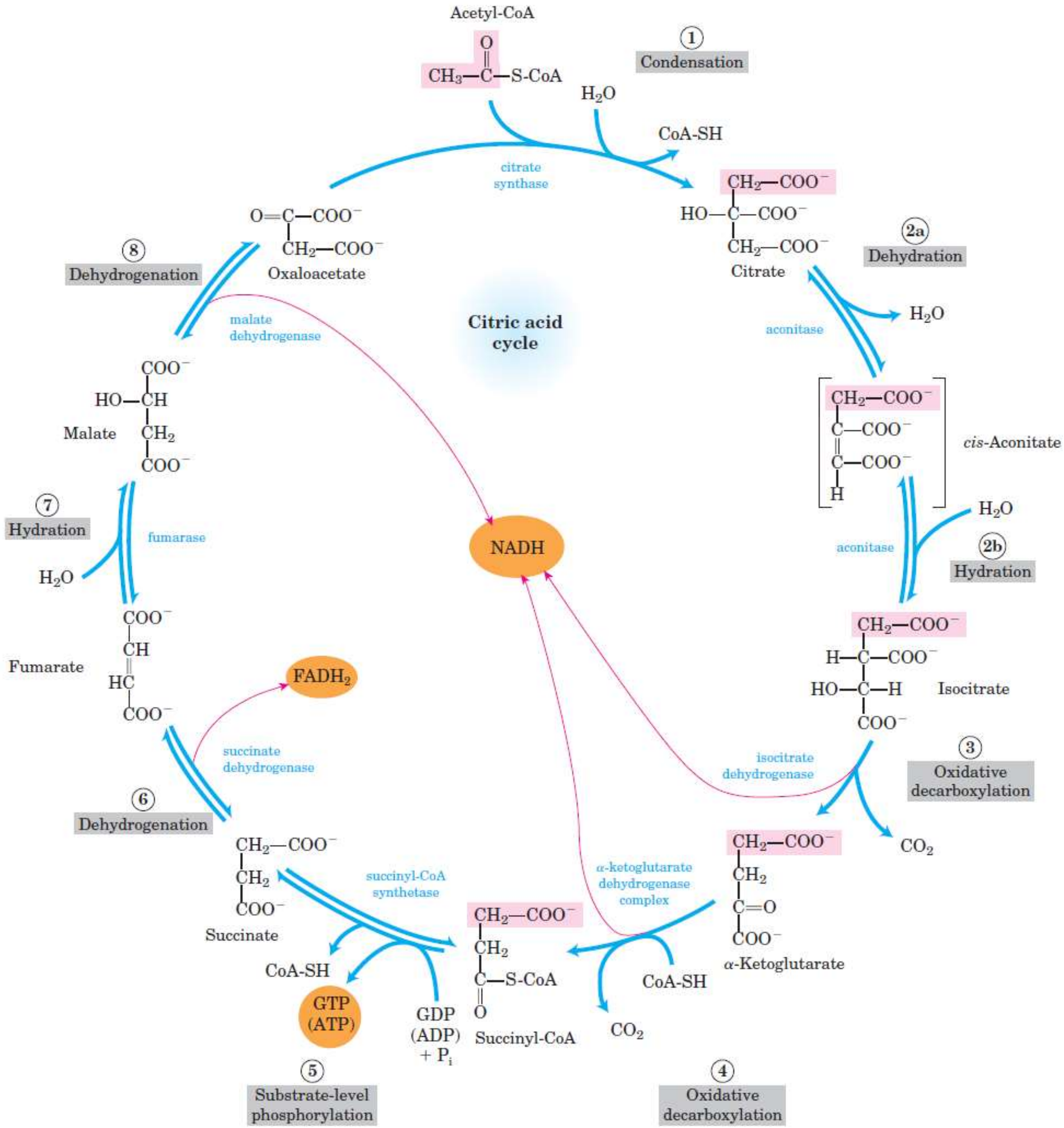
products: CO_2, **Acetyl CoA and NADH**

Next stage- Krebs Cycle

- **Requires Oxygen (Aerobic)**
- **Cyclical series of oxidation reactions that give off CO_2 and produce one ATP per cycle**
- **Turns twice per glucose molecule**
- **Produces two ATP**
- **Takes place in matrix of mitochondria**

A Little Krebs Cycle History

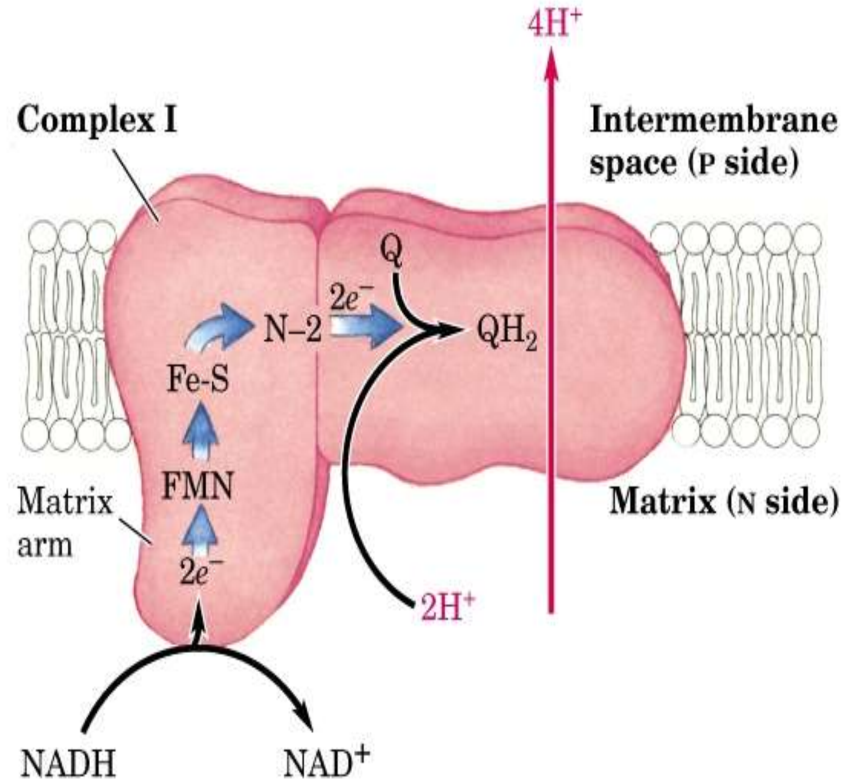
- **Discovered by Hans Krebs in 1937**
- **He received the Nobel Prize in physiology or medicine in 1953 for his discovery**


Acetyl-CoA
1 Condensation
H2O
CoA-SH
citrate synthase
Citrate
2a Dehydration
aconitase
H2O
cis-Aconitate
H2O
aconitase
2b Hydration
Isocitrate
isocitrate dehydrogenase
3 Oxidative decarboxylation
CO2
α-Ketoglutarate
α-ketoglutarate dehydrogenase complex
CoA-SH
CO2
4 Oxidative decarboxylation
Succinyl-CoA
GDP (ADP) + Pi
succinyl-CoA synthetase
CoA-SH
GTP (ATP)
5 Substrate-level phosphorylation
Succinate
6 Dehydrogenation
succinate dehydrogenase
FADH2
Fumarate
H2O
fumarase
7 Hydration
Malate
malate dehydrogenase
8 Dehydrogenation
Oxaloacetate
Citric acid cycle
NADH

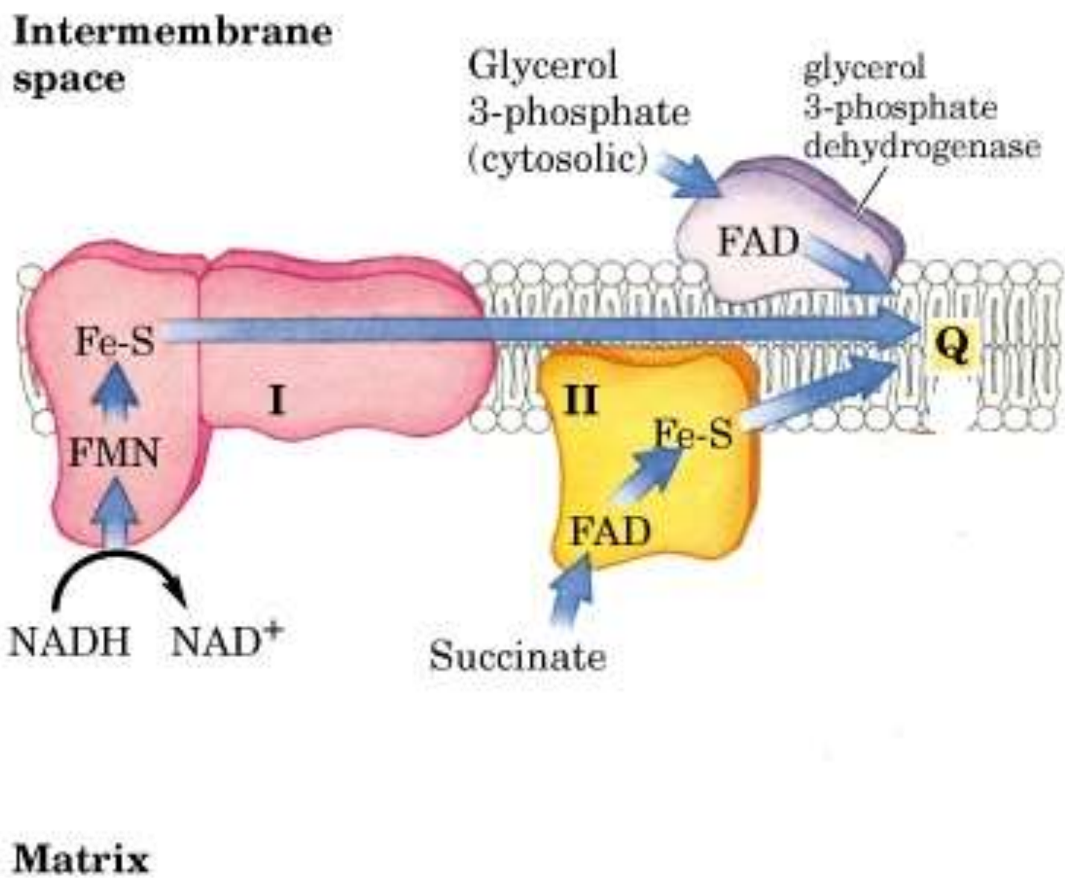
OXIDATIVE PHOSPHORYLATION

- The last stage of respiration
- ADP is phosphorylated to ATP
- **Electron transfer** in the electron transport chain causes proteins to **pump H^+** from the **mitochondrial matrix** to the **intermembrane space**
- H^+ then moves back across the membrane, through channels in **ATP synthase**
- ATP synthase uses the flow of H^+ to drive **phosph-orylation** of **ADP**

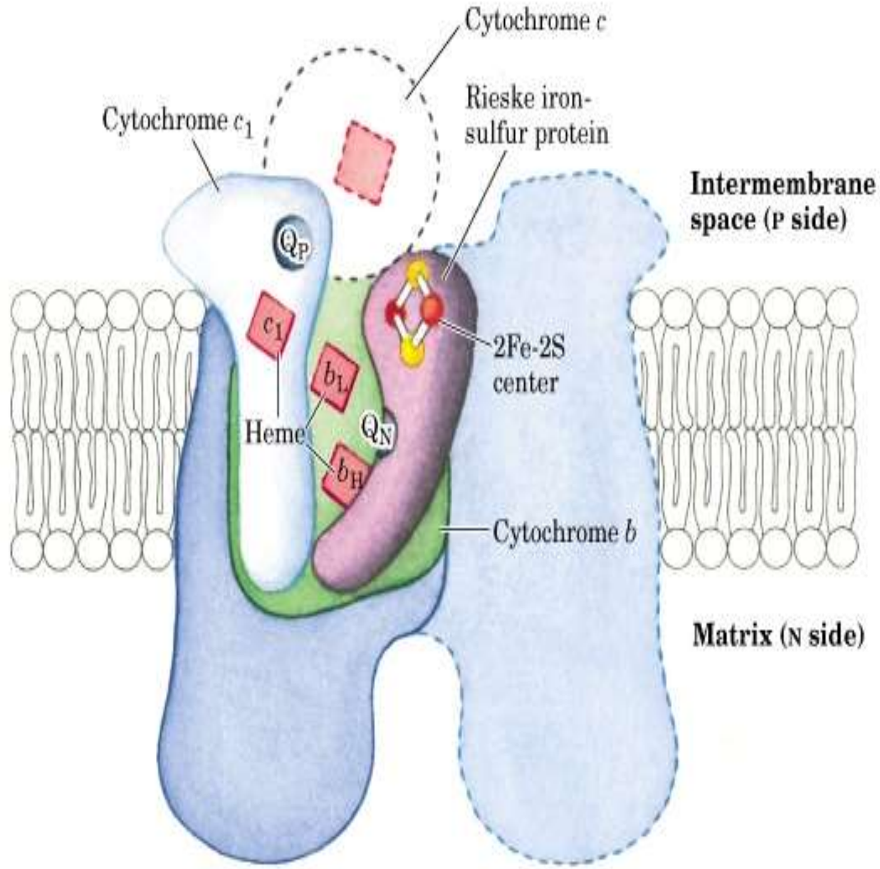
Complex I – NADH dehydrogenase



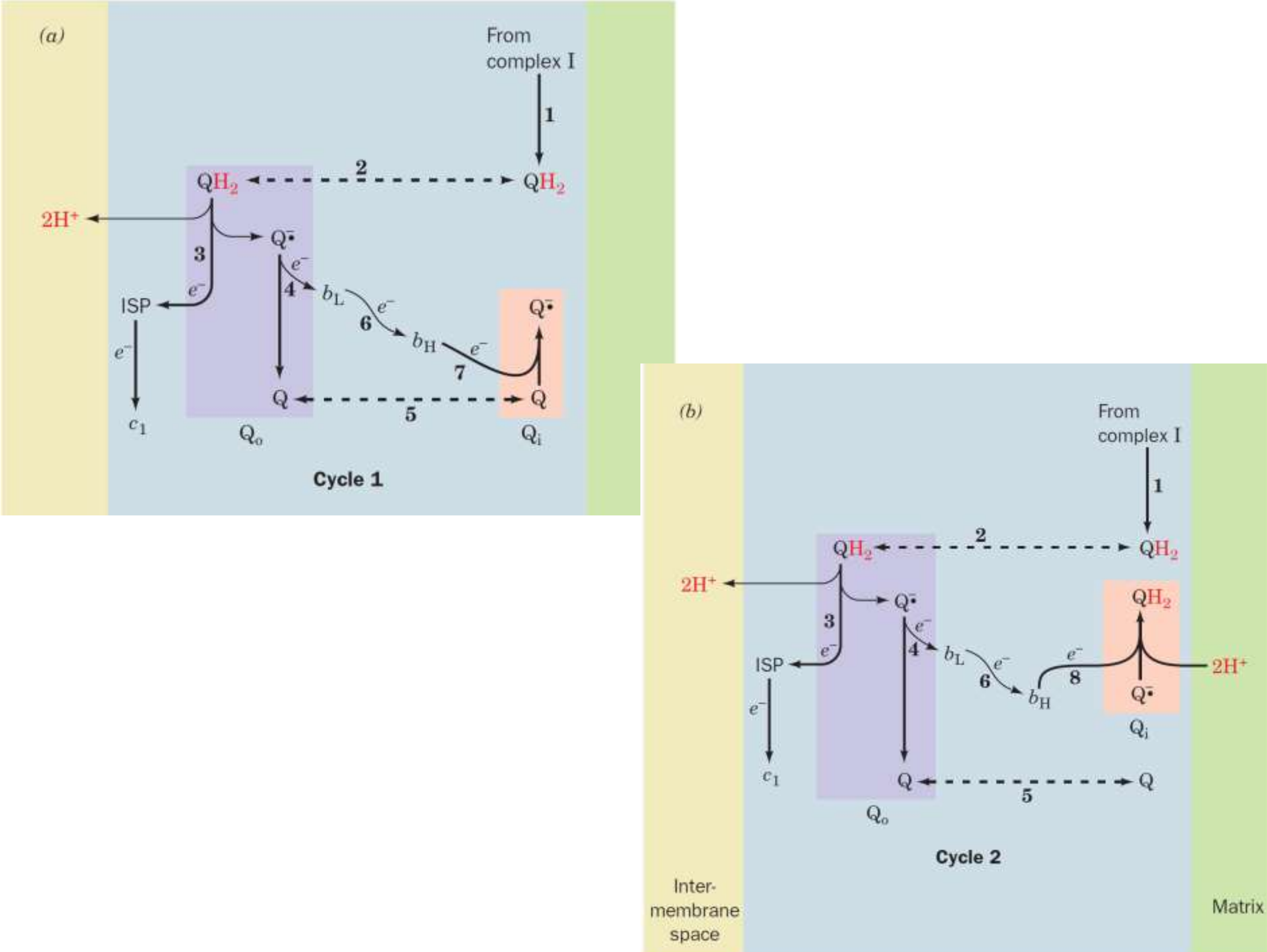
Complex II – Succinate dehydrogenase



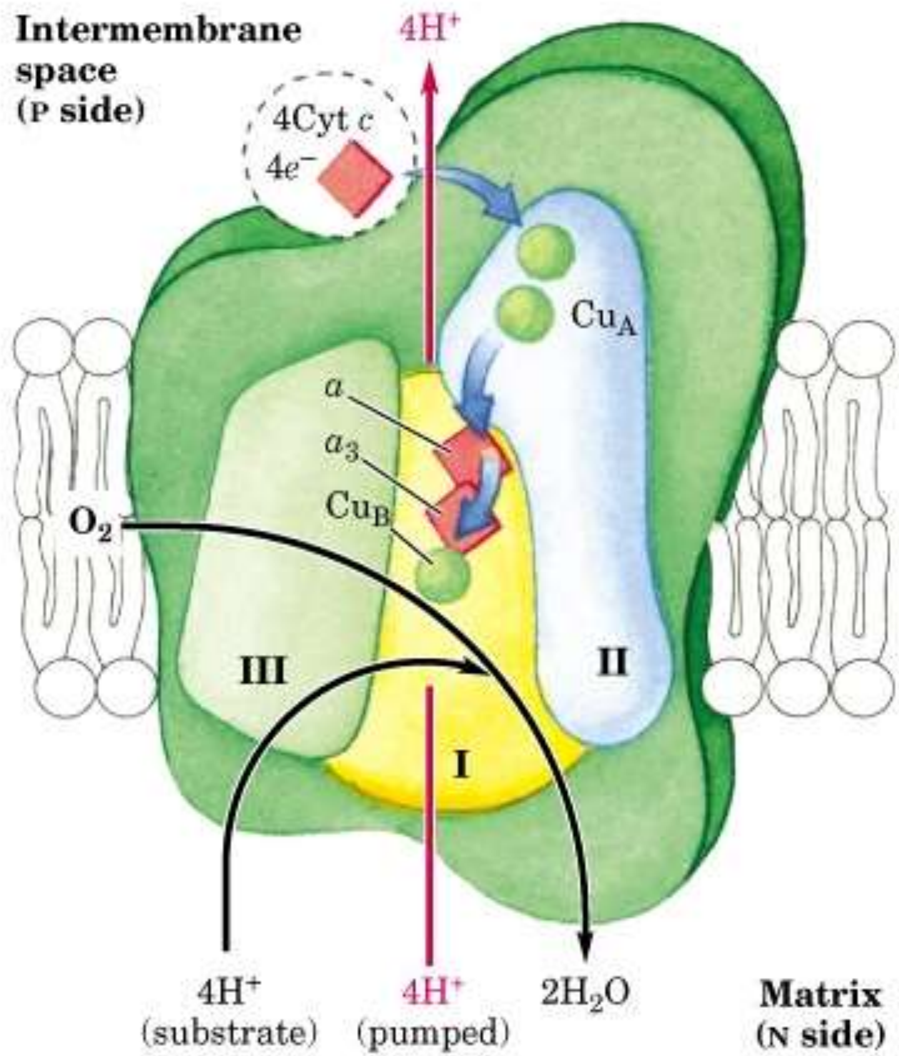
Complex III – Cytochrome bc1



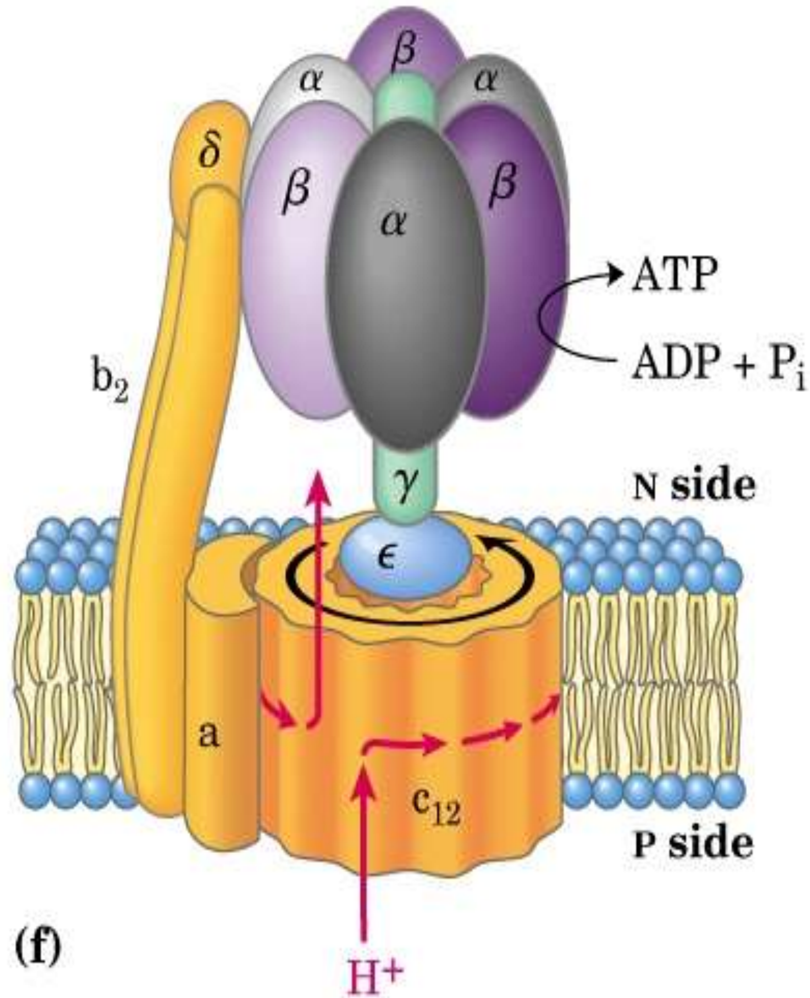
(b)

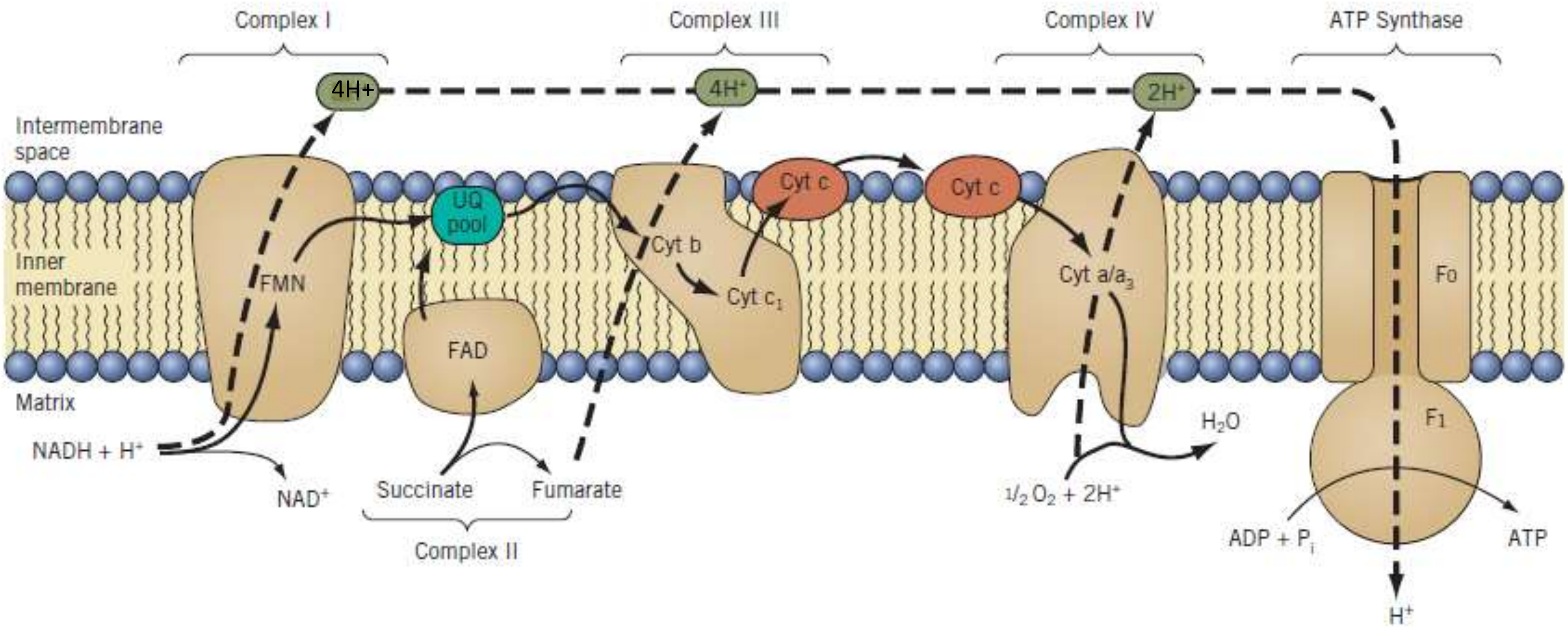

(a)
From
complex I
1
2
QH2
QH2
2H+
3
Q·
e−
4
e−
bL
e−
6
ISP
bH
e−
Q·
e−
7
Q
5
Q
c1
Qo
Qi
Cycle 1
(b)
From
complex I
1
2
QH2
QH2
2H+
Q·
3
QH2
e−
4
e−
bL
e−
e−
ISP
6
8
2H+
bH
Q·
e−
Qi
c1
Q
5
Q
Qo
Cycle 2
Inter-
membrane
space
Matrix

Complex IV – Cytochrome oxidase



ATP synthase





Complex I
Complex III
Complex IV
ATP Synthase
4H+
4H+
2H+
Intermembrane space
Inner membrane
Matrix
UQ pool
FMN
FAD
Cyt b
Cyt c
Cyt c
Cyt c_1
Cyt a/a_3
Fo
F1
NADH + H^+
NAD^+
Succinate
Fumarate
Complex II
H_2O
1/2 O_2 + $2H^+$
ADP + P_i
ATP
H^+

Stoichiometry of Coenzyme Reduction and ATP Formation in the Aerobic Oxidation of Glucose via Glycolysis, the Pyruvate Dehydrogenase Complex Reaction, the Citric Acid Cycle, and Oxidative Phosphorylation

Reaction	*Number of ATP or reduced coenzyme directly formed*	*Number of ATP ultimately formed**
Glucose ⟶ glucose 6-phosphate	−1 ATP	−1
Fructose 6-phosphate ⟶ fructose 1,6-bisphosphate	−1 ATP	−1
2 Glyceraldehyde 3-phosphate ⟶ 2 1,3-bisphosphoglycerate	2 NADH	5
2 1,3-Bisphosphoglycerate ⟶ 2 3-phosphoglycerate	2 ATP	2
2 Phosphoenolpyruvate ⟶ 2 pyruvate	2 ATP	2
2 Pyruvate ⟶ 2 acetyl-CoA	2 NADH	5
2 Isocitrate ⟶ 2 α-ketoglutarate	2 NADH	5
2 α-Ketoglutarate ⟶ 2 succinyl-CoA	2 NADH	5
2 Succinyl-CoA ⟶ 2 succinate	2 ATP (or 2 GTP)	2
2 Succinate ⟶ 2 fumarate	2 $FADH_2$	3
2 Malate ⟶ 2 oxaloacetate	2 NADH	5
Total		32

RESPIRATORY QUOTIENT(RQ)

- **Also called respiratory coefficient.**
- **It is estimated from carbon dioxide production.**
- **It is measured using Ganong's Respirometer**

- RQ is calculated from the ratio;

$$RQ = \frac{CO_{2\ ELIMINATED}}{O_{2\ CONSUMED}}$$

- The CO_2 and O_2 must be given in the same units
- Respiratory substrates include fatty acids, glycerol, carbohydrates, and ethanol.

- **The range of respiratory coefficients for organisms in metabolic balance usually ranges from 1.0 (the value expected for pure carbohydrate oxidation) to ~0.7**

RQ MAY DEVIATE FROM UNITY WHEN;

1. **Respiratory substrate is other than carbohydrates.**

2. **Carbohydrates and other respiratory substrates are partially oxidised.**

3. **Oxygen absorbed is used in a process other than respiration.**

4. **CO_2 formed is utilized metabolically instead of being given out.**

Carbohydrates

- **When they oxidised in respiration value of RQ is 1 or unity.**
- **Because,volume of CO_2 evolved equals to the volume of O_2 as is shown by the following equation;**
- $6C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O$

$$RQ = \frac{\text{Vol.of } CO_2}{\text{Vol.of } O_2} = \frac{6}{6} = 1 \text{ or unity}$$

Fats

- **When these are substrates,value of RQ becomes less than 1.**

- **Because fats are poorer in O_2 in comparison to carbon and they require more O_2 for their oxidation.**

$$2C_{51}H_{98}O_6 + 145\ O_2 \longrightarrow 102CO_2 + 98H_2O$$

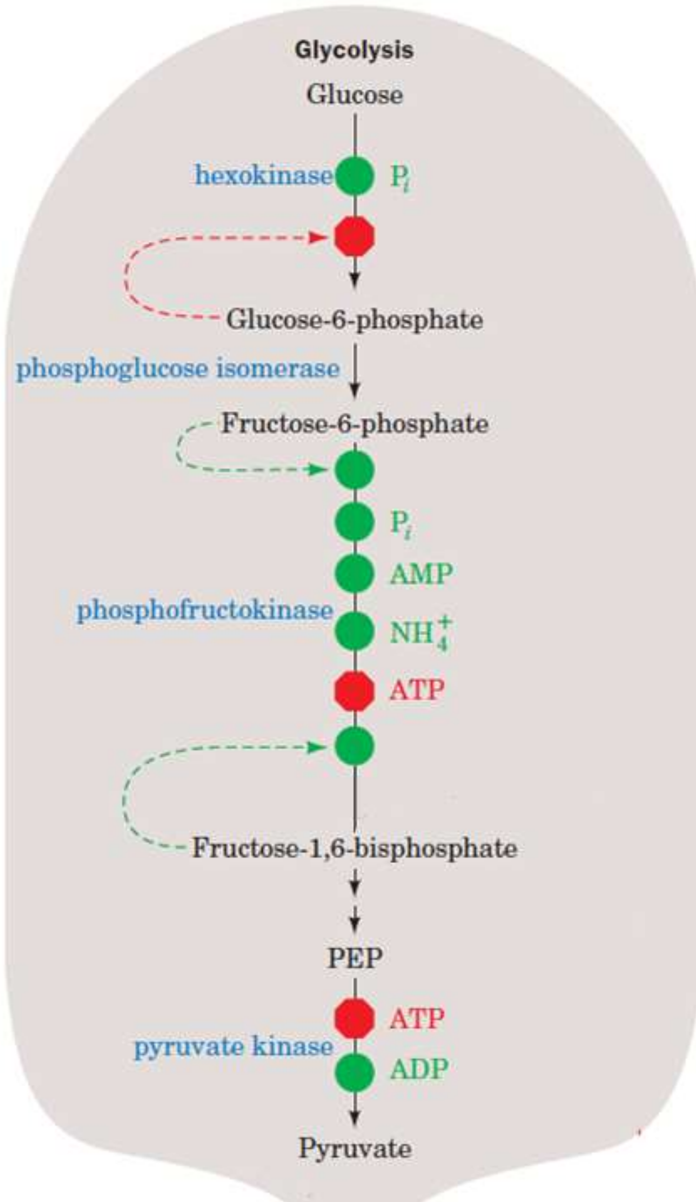
Tripalmitin

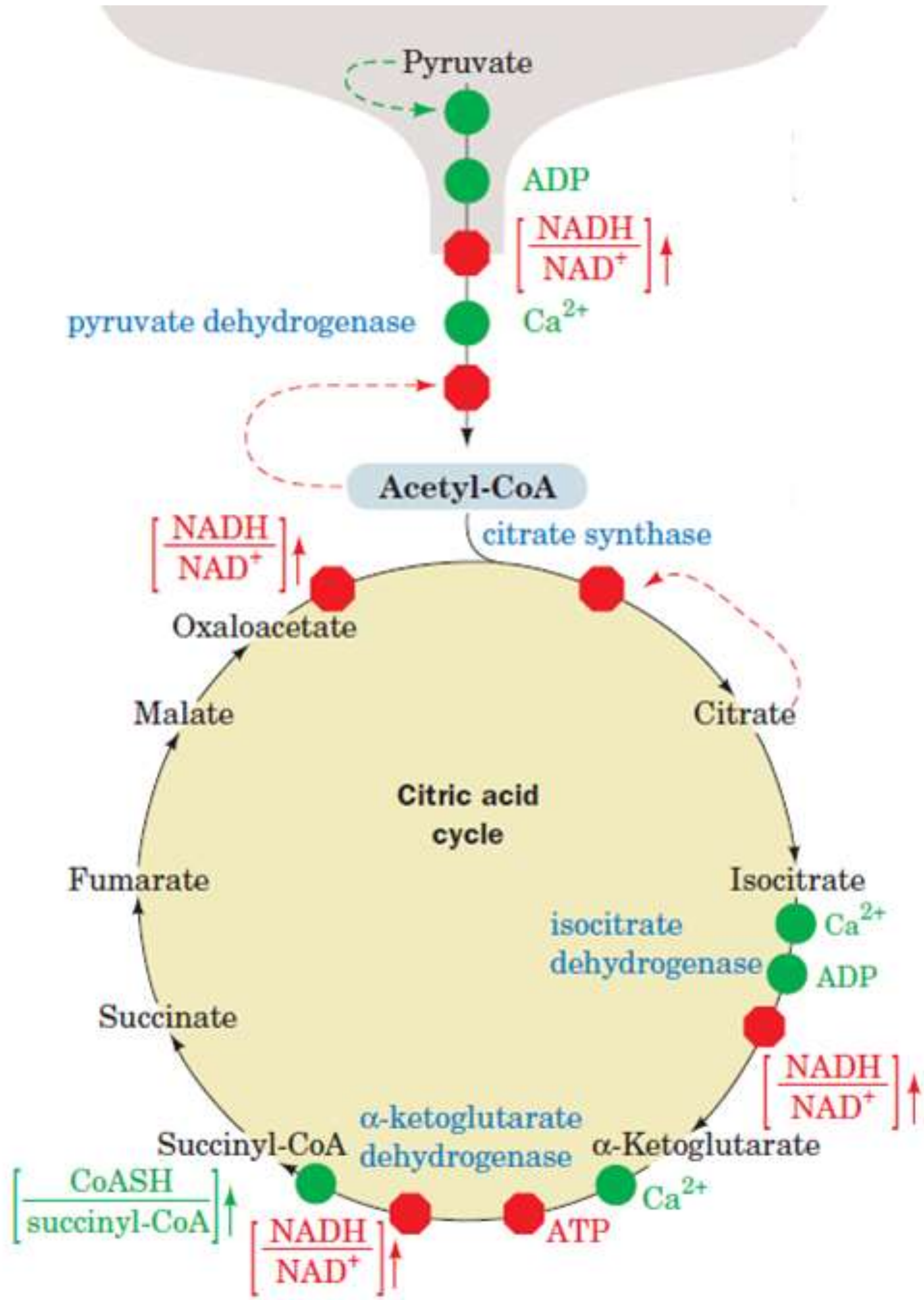
$$RQ = \frac{\text{Vol.of } CO_2}{\text{Vol.of } O_2} = \frac{102}{145} = 0.7 \text{ (less than 1)}$$

RQ OF SOME SUBSTANCES

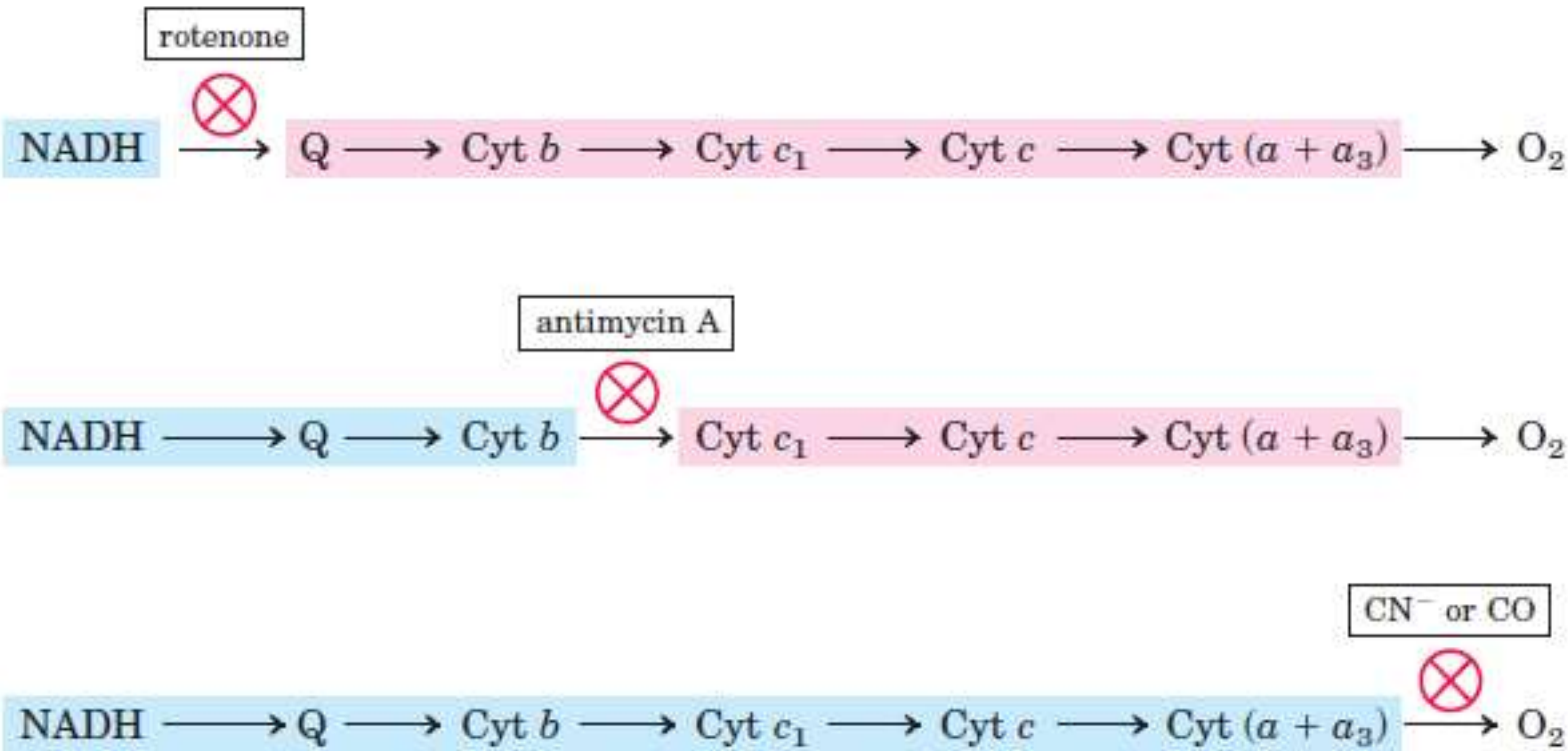
Name of the substance	Respiratory quotient
1. Carbohydrates	– 1
2. Proteins	– 0.8 - 0.9
3. Ketones	– 0.73
4. Triolein (Fat)	– 0.7
5. Oleic Acid (Fat)	– 0.71
6. Tripalmitin (Fat)	– 0.7
7. Malic acid	– 1.33
8. Tartaric acid	– 1.6
9. Oxalic acid	– 4.0

Inhibitors of respiration




Pyruvate
ADP
NADH / NAD+ ↑
pyruvate dehydrogenase
Ca2+
Acetyl-CoA
citrate synthase
NADH / NAD+ ↑
Oxaloacetate
Citrate
Malate
Citric acid cycle
Fumarate
Isocitrate
isocitrate dehydrogenase
Ca2+
ADP
NADH / NAD+ ↑
Succinate
Succinyl-CoA
α-ketoglutarate dehydrogenase
α-Ketoglutarate
CoASH / succinyl-CoA ↑
Ca2+
ATP
NADH / NAD+ ↑

Inhibitors of electron transport chain



Thank you………