BIOENERGITICS

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INTRODUCTION

- Bioenergetics means study of the **transformation of energy** in living organisms
- The goal of bioenergetics is to describe how living organisms acquire and transform energy in order to perform biological work
- The study of **metabolic pathways** is thus essential to bioenergetics **-** In a living organism, chemical bonds are broken and made as part of the exchange and transformation of energy
- Energy is available for work (**such as mechanical work**) or for other processes (**such as chemical synthesis and anabolic processes in growth)**, when weak bonds are broken and stronger bonds are made
- The production of stronger bonds allows release of usable energy

- Living organisms produce ATP from energy sources via **oxidative phosphorylation**
- The terminal phosphate bonds of ATP are relatively weak compared with the stronger bonds formed when ATP is hydrolyzed (broken down by water) to adenosine diphosphate and inorganic phosphate

TYPES OF BIOENERGETICS REACTIONS

1. **Exergonic Reaction -** Exergonic implies the release of energy from a spontaneous chemical reaction without any concomitant utilization of energy

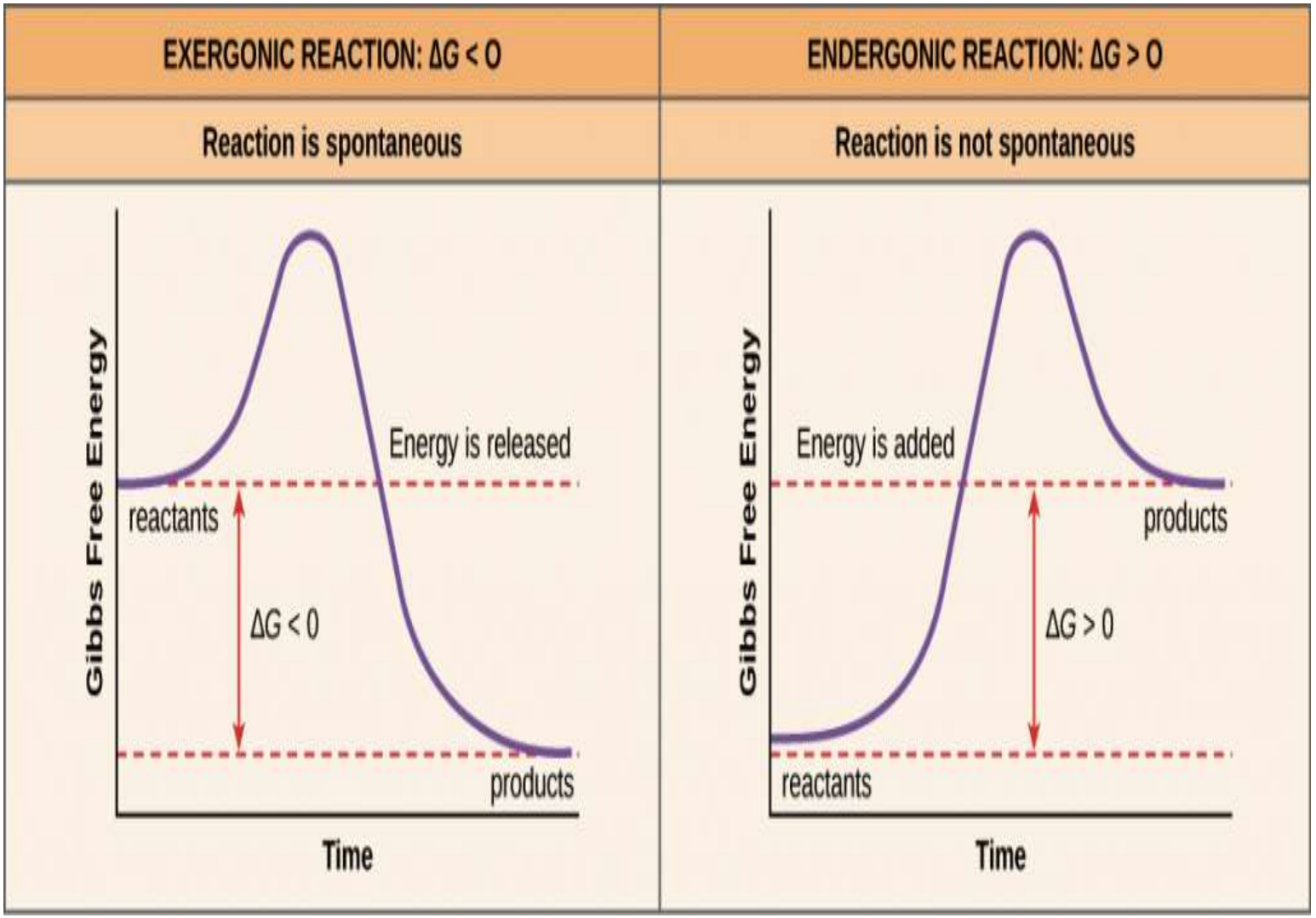
- Most of these reactions involve the breaking of bonds during the formation of reaction intermediates as is evidently observed during respiratory pathways
- The release of free energy, G, in an exergonic reaction (at constant pressure and temperature) is denoted as $\Delta G = G_{products} – G_{reactants}$

2. **Endergonic Reactions -** Endergonic in turn is the opposite of exergonic in being non-spontaneous and requires an input of free energy

- Most of the anabolic reactions like photosynthesis and DNA and protein synthesis are endergonic in nature
- The release of free energy, G, in an exergonic reaction (at constant pressure and temperature) is denoted as $\Delta G = G_{products} – G_{reactants}$

3. **Activation Energy -** Activation energy is the energy which must be available to a chemical system with potential reactants to result in a chemical reaction

- Activation energy may also be defined as **the minimum energy required starting a chemical reaction**


EXERGONIC REACTION: ΔG < 0
Reaction is spontaneous
Gibbs Free Energy
Energy is released
reactants
ΔG < 0
products
Time
ENDERGONIC REACTION: ΔG > 0
Reaction is not spontaneous
Gibbs Free Energy
Energy is added
products
ΔG > 0
reactants
Time

THERMODYNAMICS

- Thermodynamics is the study of energy changes, that is, the conversion of energy from one form into another
- Such changes obey the first two laws of thermo-dynamics

I LAW OF THERMODYNAMICS

- Energy cannot be created or destroyed but can be **converted from one form into another**: during such a conversion, the total amount of the energy of the system remains constant

Sight

light → chemical → electrical

Muscle Contraction

chemical → mechanical

Action Potentials

chemical → electrical

Vitamin D

light → chemical

Sweating

(change of state)

water → water vapor

II LAW OF THERMODYNAMICS

- Energy transfer will always proceed in the direction of increased entropy, and the release of “free energy”.

- The important state functions for the study of biological systems are
- **The Gibbs free energy** (G) which is equal to the total amount of energy capable of doing work during a process at constant temperature and pressure
- If ΔG is negative, then the process is spontaneous and termed exergonic
- If ΔG is positive, then the process is nonspontaneous and termed endergonic
- If ΔG is equal to zero, then the process has reached equilibrium

- **The Enthalpy** (H) which is the heat content of the system
- Enthalpy is the amount of heat energy transferred (heat absorbed or emitted) in a chemical process under constant pressure
- When ΔH is negative the process produces heat and is termed exothermic
- When ΔH is positive the process absorbs heat and is termed endothermic

- **The Entropy (S)** is a quantitative expression of the degree of randomness or disorder of the system
- Entropy measures the amount of heat dispersed or transferred during a chemical process
- When ΔS is positive then the disorder of the system has increased
- When ΔS is negative then the disorder of the system has decreased
- The conditions of biological systems are constant temperature and pressure

- Under such conditions the relationships between the change in free energy, enthalpy and entropy can be described by the expression where T is the temperature of the system in Kelvin
- $\Delta G = \Delta H - T\Delta S$

[ΔG = Gibbs Free Energy

ΔH = Change in Enthalpy

T = Temperature in K

ΔS = Change in Entropy]

DIFFERENCES BETWEEN ENTHALPY AND ENTROPY

BYJU'S The Learning App

ENTHALPY

Enthalpy is denoted by 'h' refers to the measure of total heat content in a thermodynamic system under constant pressure.

ENTROPY

Entropy is denoted by 's' refers to the measure of the level of disorder in a thermodynamic system.

REDOX POTENTIAL

- When a substance exists in the reduced state & oxidized state the pair is called as a redox couple

  NAD+ is oxidized form

  NADH is reduced form

- Redox potential is a measures of tendency of a redox couple to donate or accept electrons under standard condition

Redox Potential

- Redox = oxidation-reduction reactions
- Depends on the affinity for electrons of the molecules involved in each reaction
- Redox pairs – two molecules such as NADH and NAD^+ - NADH is a strong electron donor (reducing agent) while NAD^+ is a weak electron acceptor (oxidizing agent)
- Redox Potential – a measure of the tendency of a given system to donate or accept electrons

STEPWISE RELEASE OF ENERGY

- **Glycogenesis** – Biosynthesis of glycogen from glucose
- **Glycogenolysis-**Breakdown of glycogen into glucose
- **Glycolysis-** Breakdown of glucose into pyruvate
- **Citric acid cycle-**Oxidation of pyruvic acid into CO2 & water
- **Pentose phosphate pathway-**Oxidation of glucose with the production of CO2 and pentoses
- **Gluconeogenesis-** Synthesis of carbohydrates from non carbohydrates
- **Glucoronic acid path way-**Conversion of glucose to glucoronic acid

GLYCOLYSIS

- Glycolysis is a series of reactions for the **breakdown of Glucose** (a 6-carbon molecule) into **two molecules of pyruvate** (a 3-carbon molecule) under **aerobic conditions**; or lactate under **anaerobic conditions** along with the production of a small amount of energy.

TYPES OF GLYCOLYSIS

Aerobic Glycolysis

- Aerobic means in the presence of oxygen
- Aerobic glycolysis occurs when oxygen is sufficient
- First, glucose is converted into pyruvate, and then pyruvate will be oxidized to the final products CO2 and H2O

Anaerobic Glycolysis

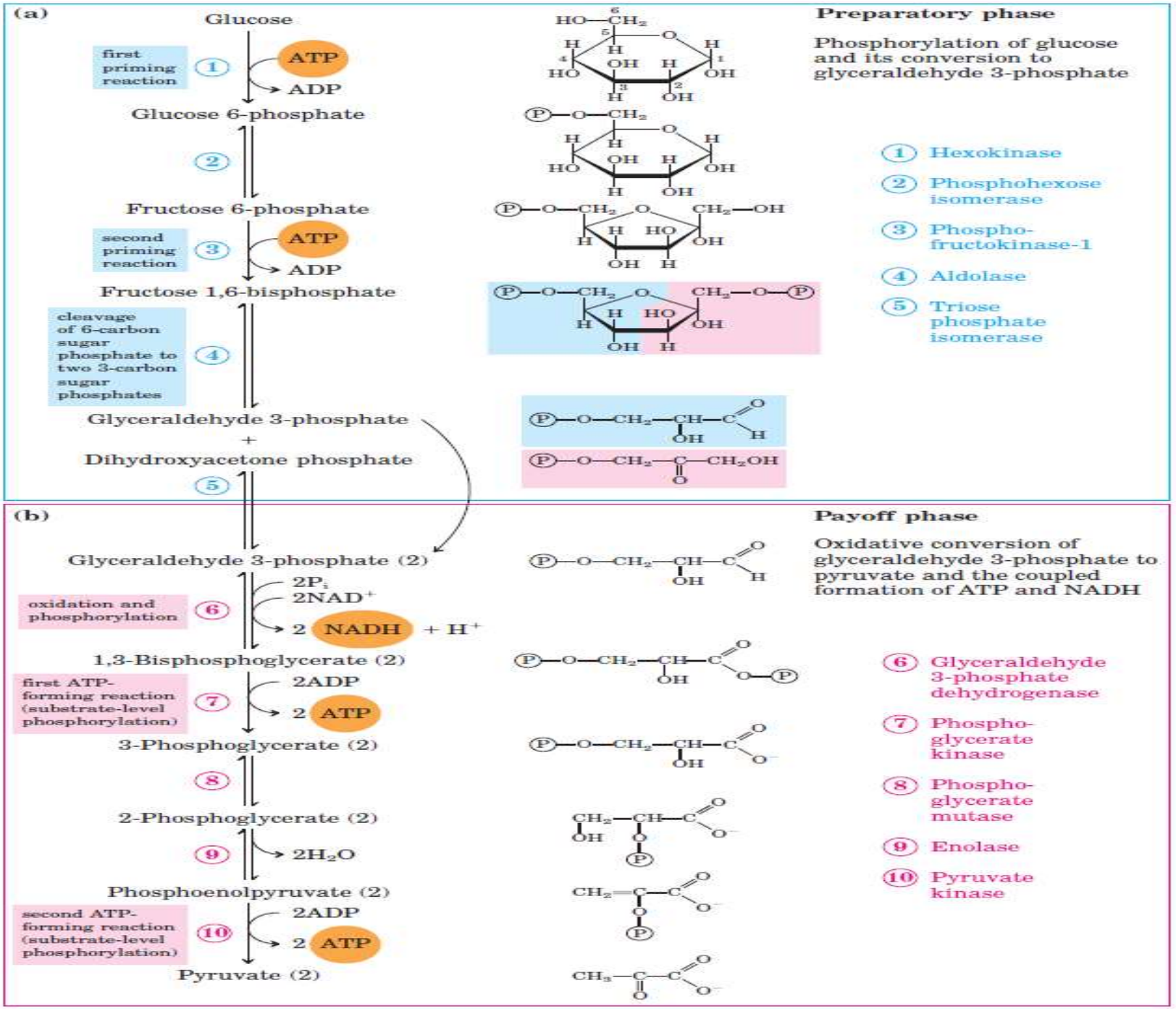
- Anaerobic means in the absence of oxygen
- First, glucose is converted into pyruvate and then pyruvate into lactate

PHASES OF GLYCOLYSIS

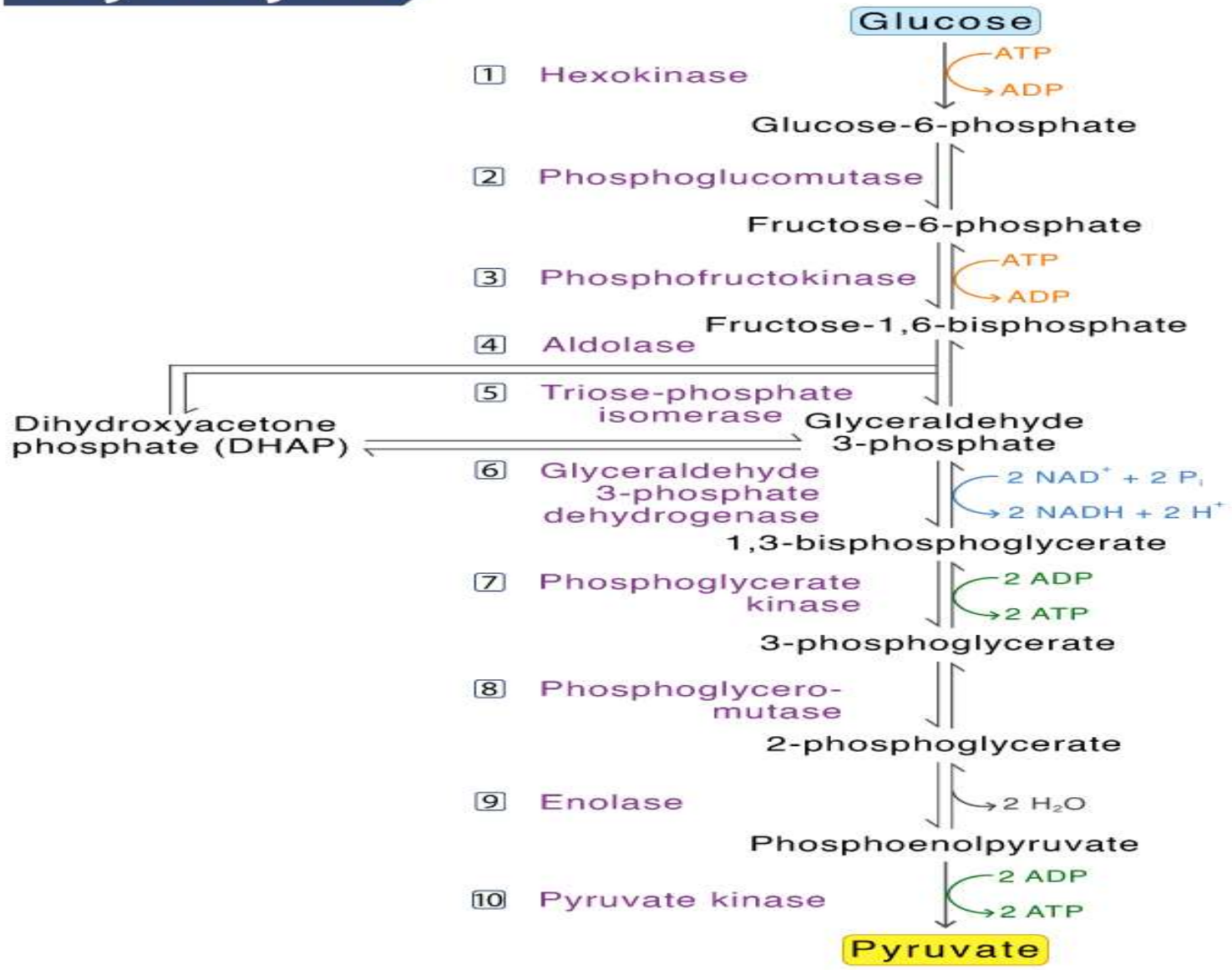
- The energy-requiring phase (Preparatory phase)
- The energy-releasing phase (Payoff phase)

- **Glucose-requiring phase (Preparatory Phase)**
- This phase is also called the glucose activation phase
- In this phase of glycolysis, two molecules of ATP are invested, and the hexose chain is cleaved into two triose phosphates
- During this phase, the phosphorylation of glucose and its conversion to glyceraldehyde-3-phosphate occurs

- **Energy-releasing phase (Payoff Phase)**
- This phase is also called the energy extraction phase
- During this phase, the conversion of glyceraldehyde-3-phosphate to pyruvate takes place
- In this process, one NADH and two ATP molecules are formed


(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)
oxidation and phosphorylation
6
2Pi
2NAD+
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
2H2O
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


ScienceFacts.net
Glucose
ATP
ADP
1 Hexokinase
Glucose-6-phosphate
2 Phosphoglucomutase
Fructose-6-phosphate
ATP
ADP
3 Phosphofructokinase
Fructose-1,6-bisphosphate
4 Aldolase
5 Triose-phosphate isomerase
Dihydroxyacetone phosphate (DHAP)
Glyceraldehyde 3-phosphate
2 NAD+ + 2 Pi
2 NADH + 2 H+
6 Glyceraldehyde 3-phosphate dehydrogenase
1,3-bisphosphoglycerate
2 ADP
2 ATP
7 Phosphoglycerate kinase
3-phosphoglycerate
8 Phosphoglycero-mutase
2-phosphoglycerate
2 H2O
9 Enolase
Phosphoenolpyruvate
2 ADP
2 ATP
10 Pyruvate kinase
Pyruvate

THE PROCESS OF GLYCOLYSIS THUS REVEALS THAT

- Glycolysis occurs in the **cytoplasm** and during the process oxygen is not used up
- It is common pathway between **anaerobic and aerobic phases of cellular respiration**
- In glycolysis one molecule of glucose is used up to form two molecules of pyruvic acid
- In the process **two molecules of ATP** are used in activation of glucose and **four molecules of ATP are formed** hence there is net gain of ATP molecules

- One ATP molecule produces nearly **8000** calories and **2x8000=16000** cal means the amount of energy produced in glycolysis is **16000 cal or 16 k.cal** .This is about 2.3% of total energy contents of a glucose molecule
- In glycolysis 4 hydrogen atoms are also liberetaed which are accepted by NAD and is then reduced into NADH

Energy Yield in Aerobic Glycolysis

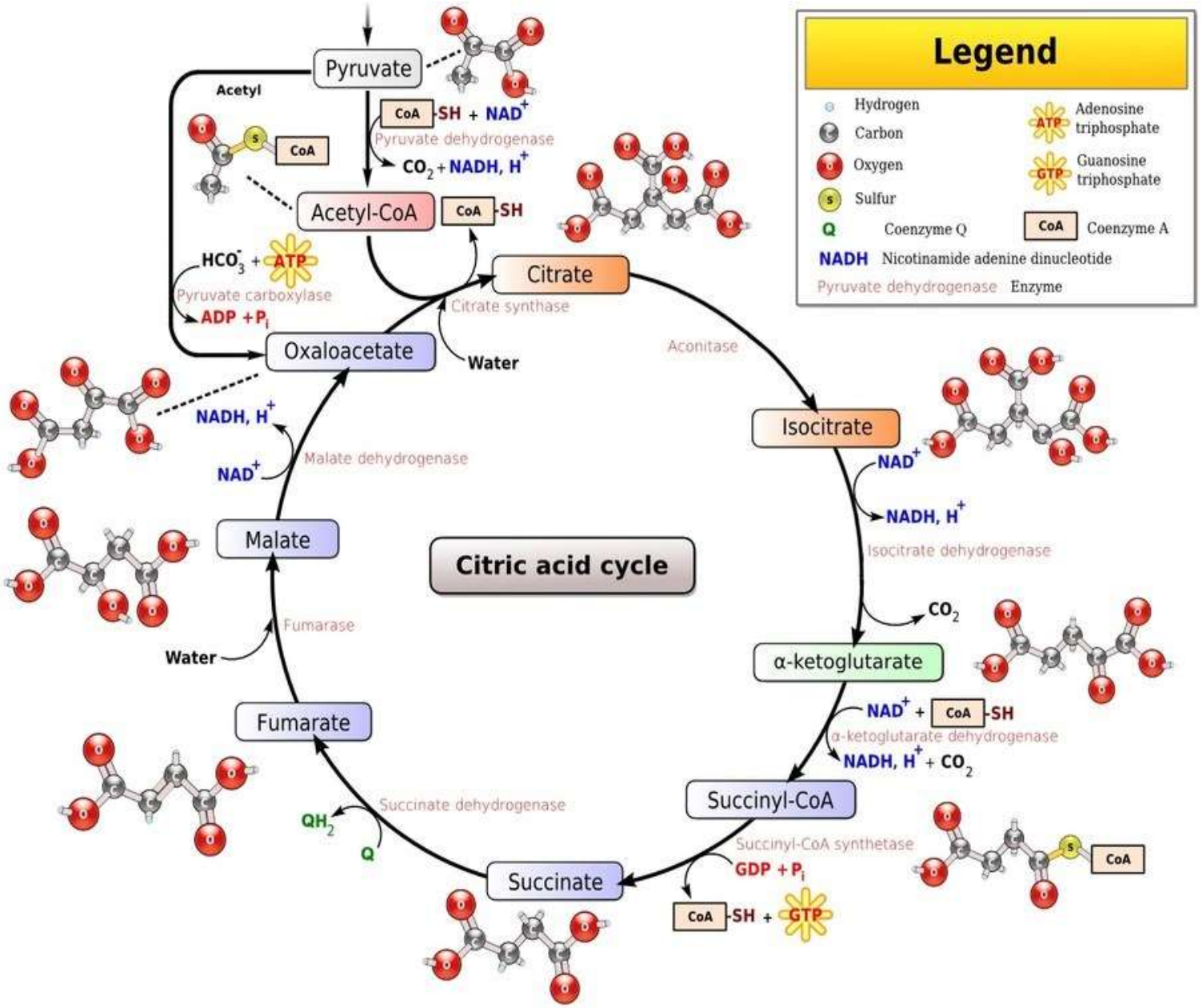
Step	Enzyme	Source	No. of ATP
1	Hexokinase	–	-1
3	Phosphofructokinase	–	-1
6	Glyceraldehyde-3-phosphate dehydrogenase	NADH	(+3) x 2 = +6
7	Phosphoglycerate kinase	ATP	(+1) x 2 = +2
10	Pyruvate kinase	ATP	(+1) x 2 = +2
Net Yield			**8 ATPs**

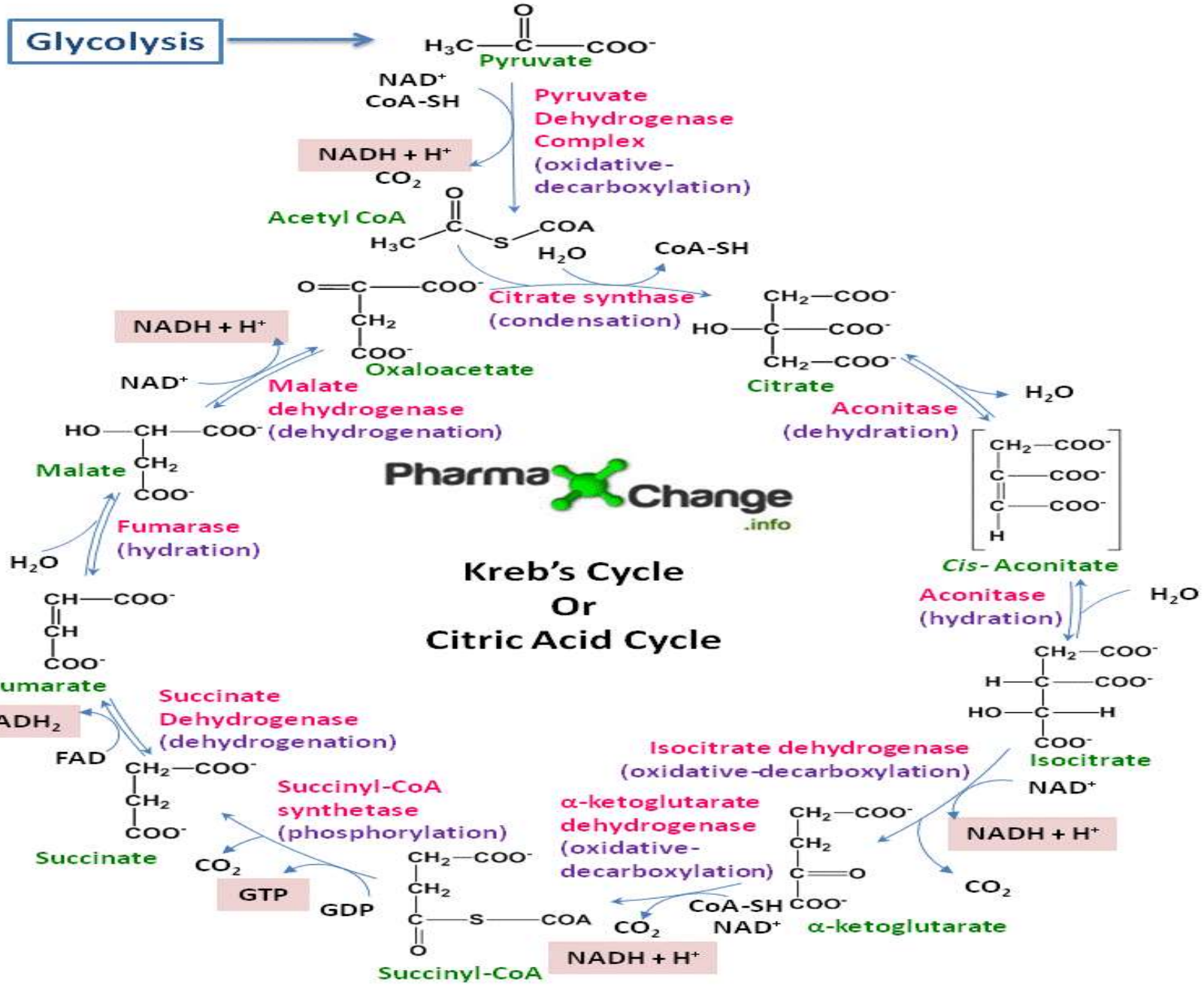
ENERGY YIELD IN ANAEROBIC GLYCOLYSIS

Step	Enzyme	Source	No. of ATP Formed/consumed
1	Hexokinase	–	-1
3	Phosphofructokinase	–	-1
7	Phosphoglycerate kinase	ATP	(+1) x 2 = +2
10	Pyruvate kinase	ATP	(+1) x 2 = +2
Net Yield			**2 ATPs**

CITRIC ACID CYCLE

- The oxidation of pyruvic acid into carbondioxide and water is called **Krebs cycle or citric acid cycle**
- Because the cycle begins with the formation of citric acid
- It is a carboxylic acid contains three COOH group- tricarboxylic acid cycle
- Cycle was first described by **Krebs in 1936**
- This cycle occurs only in the presence of oxygen – aerobic process
- Mainly in mitochondria

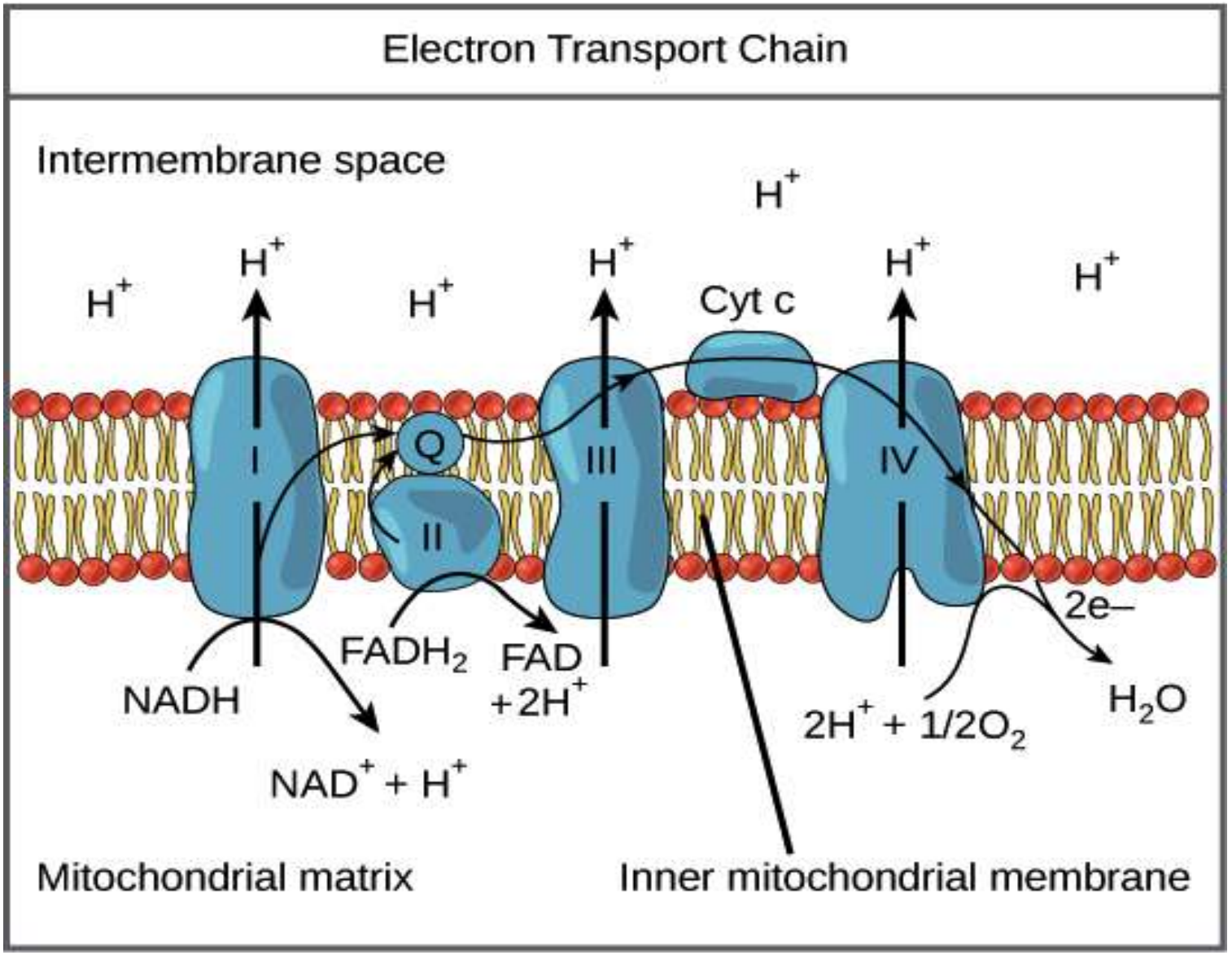

Legend
Hydrogen
Carbon
Oxygen
Sulfur
Coenzyme Q
Nicotinamide adenine dinucleotide
Pyruvate dehydrogenase Enzyme
Adenosine triphosphate
Guanosine triphosphate
Coenzyme A
Citric acid cycle
Pyruvate
Acetyl
CoA
SH + NAD+
Pyruvate dehydrogenase
CO2 + NADH, H+
Acetyl-CoA
HCO3- + ATP
Pyruvate carboxylase
ADP + Pi
Oxaloacetate
Citrate synthase
Water
Citrate
Aconitase
Isocitrate
NAD+
NADH, H+
Isocitrate dehydrogenase
CO2
α-ketoglutarate
NAD+ + CoA SH
α-ketoglutarate dehydrogenase
NADH, H+ + CO2
Succinyl-CoA
Succinyl-CoA synthetase
GDP + Pi
CoA SH + GTP
Succinate
Succinate dehydrogenase
QH2
Q
Fumarate
Fumarase
Water
Malate
Malate dehydrogenase
NADH, H+
NAD+

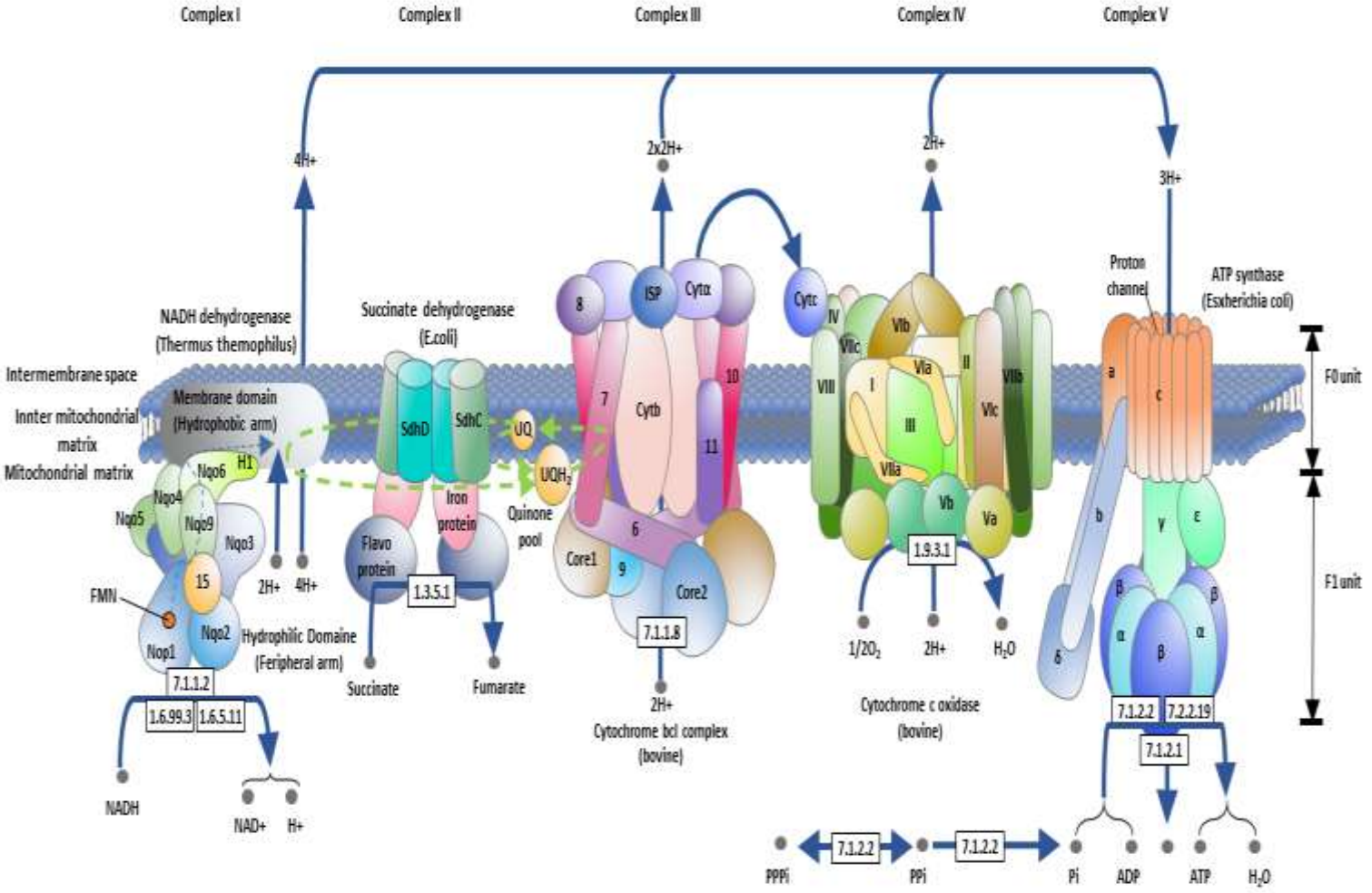

Glycolysis
Pyruvate
NAD+
CoA-SH
Pyruvate Dehydrogenase Complex (oxidative-decarboxylation)
NADH + H+
CO2
Acetyl CoA
CoA-SH
H2O
Citrate synthase (condensation)
Oxaloacetate
NADH + H+
NAD+
Malate dehydrogenase (dehydrogenation)
Malate
Citrate
Aconitase (dehydration)
H2O
Fumarase (hydration)
H2O
Cis-Aconitate
Aconitase (hydration)
H2O
Fumarate
Succinate Dehydrogenase (dehydrogenation)
FADH2
FAD
Isocitrate dehydrogenase (oxidative-decarboxylation)
Isocitrate
NAD+
NADH + H+
CO2
α-ketoglutarate dehydrogenase (oxidative-decarboxylation)
Succinyl-CoA synthetase (phosphorylation)
Succinate
CO2
GTP
GDP
CoA-SH
NAD+
α-ketoglutarate
CO2
NADH + H+
Succinyl-CoA
Kreb's Cycle
Or
Citric Acid Cycle
PharmaXChange.info

- https://www.youtube.com/watch?v=rSPUYA3gWK8
- https://www.youtube.com/watch?v=BO0zL03CtDs
- https://www.youtube.com/watch?v=_SkPwVO9BFI
- https://www.youtube.com/watch?v=LQmTKxI4Wn4

OXIDATIVE PHOSPHORYLATION

- Oxidative phosphorylation, also known as electron transport-linked phosphorylation
- Refers to the metabolic pathway in which the energy released by nutrients during oxidation is utilized to generate ATP through electrical transport chain
- And it is an important cellular energy conversion process and the final process of cell respiration in eukaryotes
- Oxidative phosphorylation occurs in the mitochondrial inner membrane of eukaryotic cells or the cytoplasm of prokaryotes


Electron Transport Chain
Intermembrane space
H+
H+
H+
H+
H+
H+
H+
Cyt c
I
Q
II
III
IV
2e–
FADH2
FAD
+2H+
NADH
NAD+ + H+
2H+ + 1/2O2
H2O
Mitochondrial matrix
Inner mitochondrial membrane


Complex I
Complex II
Complex III
Complex IV
Complex V
4H+
2x2H+
2H+
3H+
NADH dehydrogenase
(Thermus themophilus)
Succinate dehydrogenase
(E.coli)
Proton
channel
ATP synthase
(Esxherichia coli)
Intermembrane space
Innter mitochondrial
matrix
Mitochondrial matrix
Membrane domain
(Hydrophobic arm)
Nqo6
H1
Nqo4
Nqo5
Nqo9
Nqo3
15
FMN
Nqo2
Nqo1
Hydrophilic Domaine
(Feripheral arm)
7.1.1.2
1.6.99.3
1.6.5.11
NADH
NAD+
H+
2H+
4H+
SdhD
SdhC
UQ
UQH2
Iron
protein
Flavo
protein
1.3.5.1
Succinate
Fumarate
Quinone
pool
8
ISP
Cytα
Cytc1
7
Cytb
10
11
6
Core1
9
Core2
7.1.1.8
2H+
Cytochrome bcl complex
(bovine)
Cytc
IV
VIb
VIIc
VIa
II
VIIb
VIII
I
VIc
III
VIIa
Vb
Va
1.9.3.1
1/2O2
2H+
H2O
Cytochrome c oxidase
(bovine)
a
c
b
γ
ε
β
α
β
α
β
δ
7.1.2.2
7.2.2.19
7.1.2.1
F0 unit
F1 unit
PPPi
7.1.2.2
PPi
7.1.2.2
Pi
ADP
ATP
H2O

INHIBITORS

- Under normal conditions, electron transfer and phosphorylation are tightly coupled
- Some compounds can affect electron transport or interfere with phosphorylation reactions, all of which cause oxidative phosphorylation abnormalities
- Here introduce four factors affecting oxidative phosphorylation

RESPIRATORY CHAIN INHIBITOR

- A substance that blocks electron transport at a certain part of the respiratory chain and inhibits the oxidation process
- Some substances inhibit the electron transfer between Cytb and Cytc1, such as antimycin A and dimercaptopropanol
- Cyanide, azide, H2S, and C0 inhibit cytochrome oxidase, making electrons unable to pass to oxygen

OXIDATIVE PHOSPHORYLATION INHIBITORS

- These reagents directly interfere with the formation of ATP and also prevent electron transfer
- The combination of oligomycin and di cyclo hexyl carbonyl di imide with the F0 unit of ATP synthase prevents the hydrogen ions from flowing back from the proton channel, rendering the phosphorylation process incomplete, thus blocking the oxidative phosphorylation of intact mitochondria

HMP SHUNT

- This pathway of oxidation of glucose occurs in certain tissues ,liver, mammary gland, adrenal cortex and adipose tissue
- It is an alternative respiratory path which involves neither glycolysis nor the kerbs cycle
- This pathway occurs in the cytosol
- This path way divided into 2 phase
- Oxidative phase
- Non oxidative phase

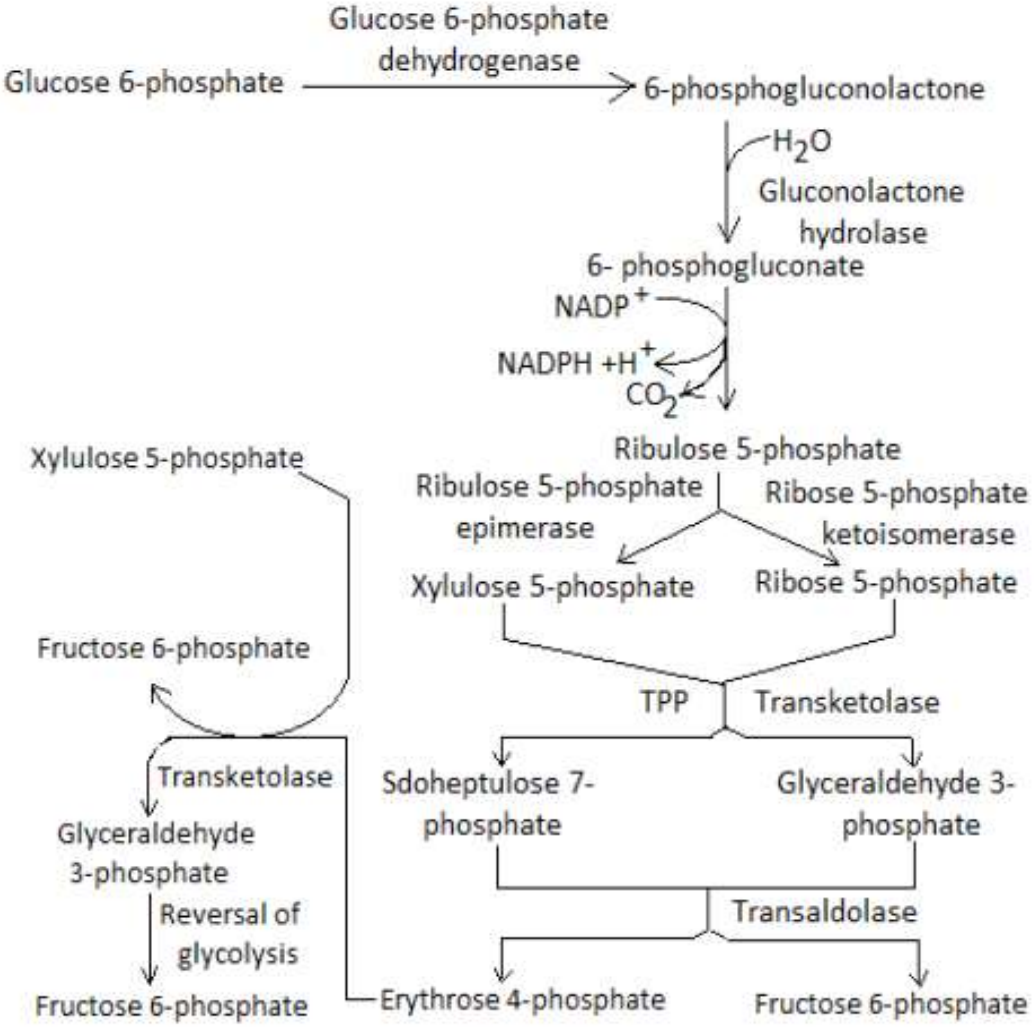
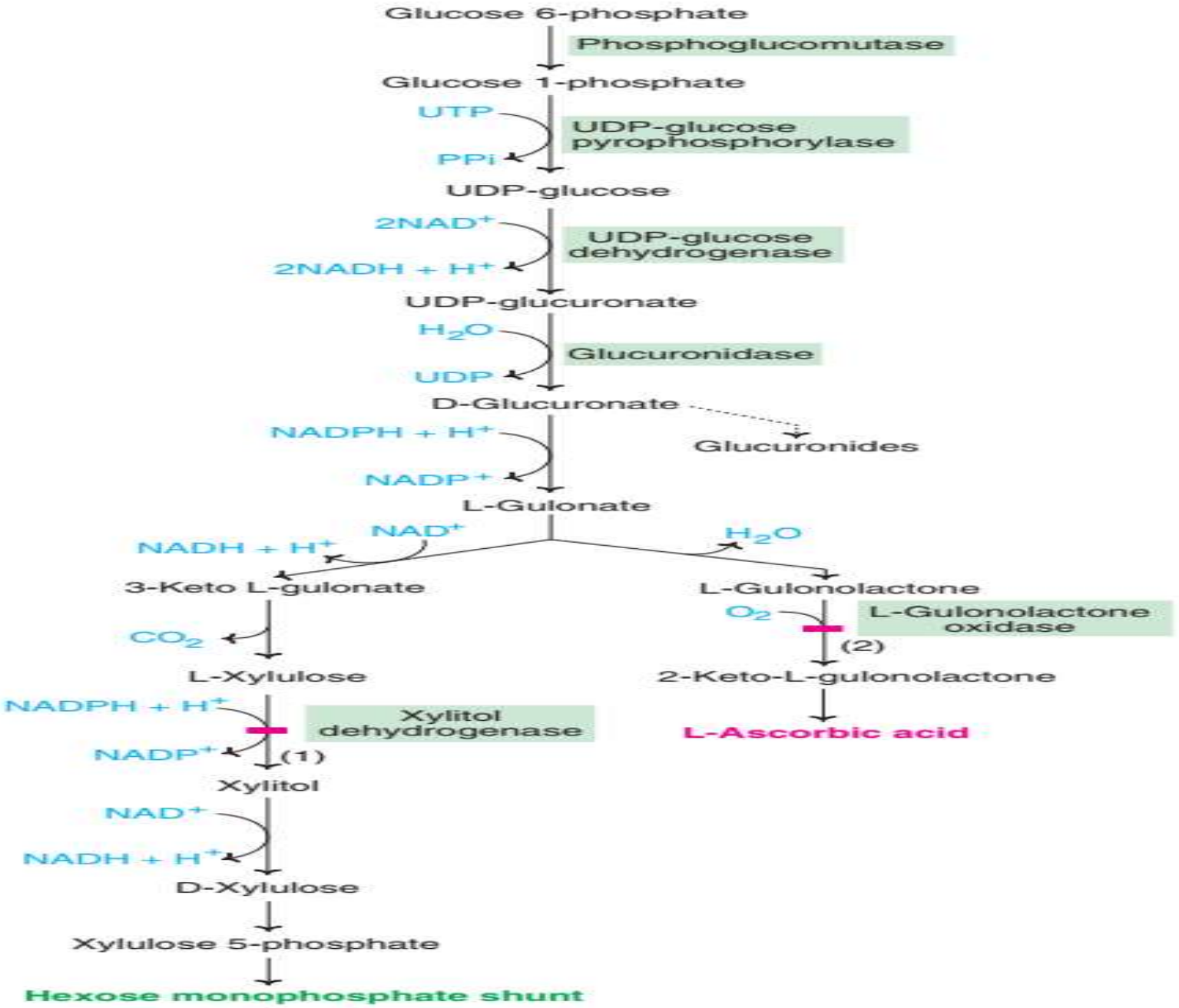


Fig.: Showing HMP Shunt pathway.

GLUCORONIC ACID PATHWAY

- Alternative oxidative pathway for glucose
- Concern with synthesis of glucuronic acid
- This is an oxidative pathway of glucose where glucose is converted into glucoronic acid, pentoses,vitamin & ascorbic acid
- but in primates ,guinea pigs , birds and bats ascorbic acid cannot be synthesized
- Instead of gluconic acid is converted to L-xylulose


Glucose 6-phosphate
Phosphoglucomutase
Glucose 1-phosphate
UTP
PPi
UDP-glucose pyrophosphorylase
UDP-glucose
2NAD+
2NADH + H+
UDP-glucose dehydrogenase
UDP-glucuronate
H2O
UDP
Glucuronidase
D-Glucuronate
Glucuronides
NADPH + H+
NADP+
L-Gulonate
NAD+
NADH + H+
H2O
3-Keto L-gulonate
L-Gulonolactone
CO2
O2
L-Gulonolactone oxidase
(2)
L-Xylulose
2-Keto-L-gulonolactone
NADPH + H+
Xylitol dehydrogenase
NADP+
(1)
L-Ascorbic acid
Xylitol
NAD+
NADH + H+
D-Xylulose
Xylulose 5-phosphate
Hexose monophosphate shunt

Thank you