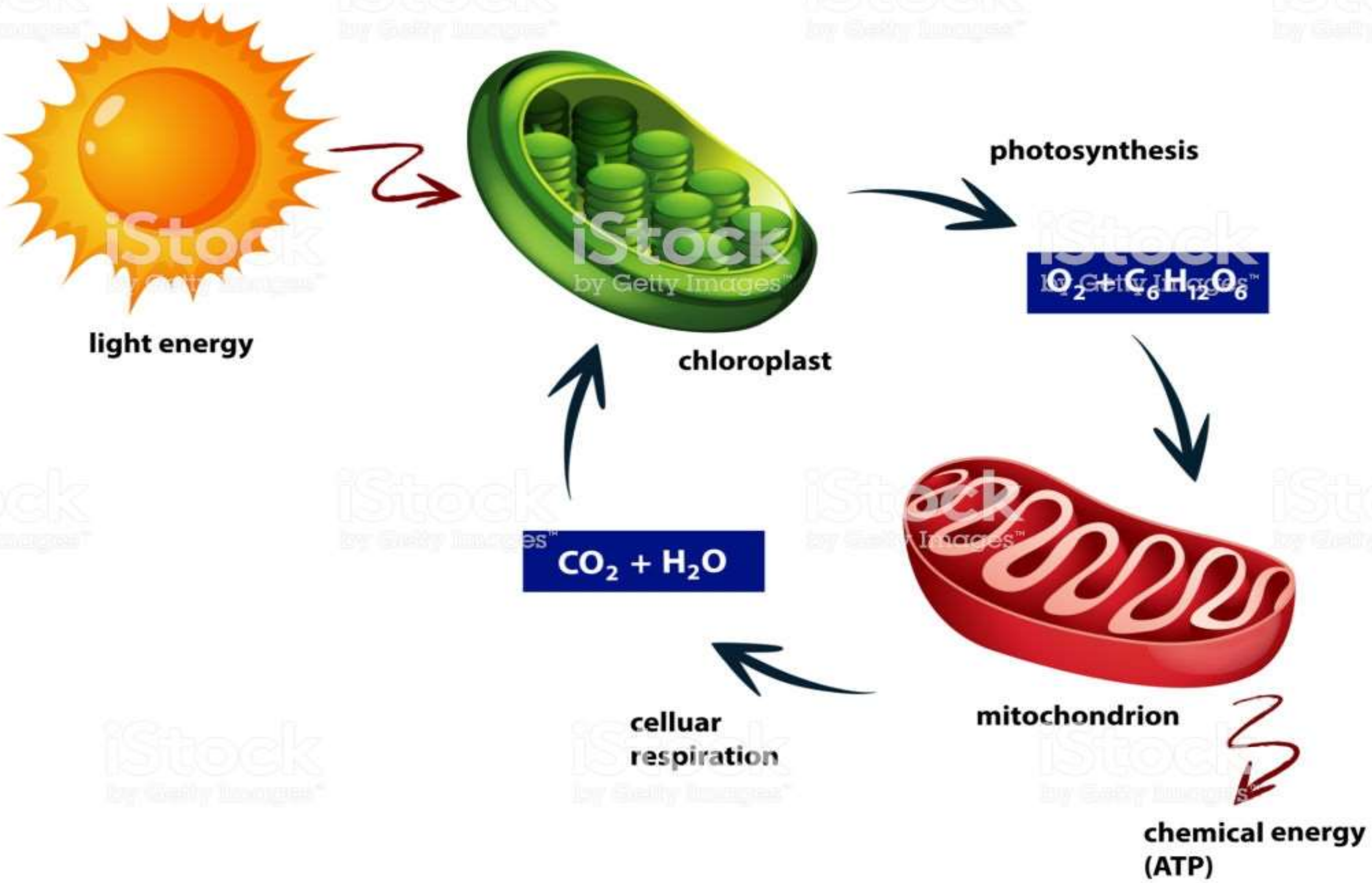
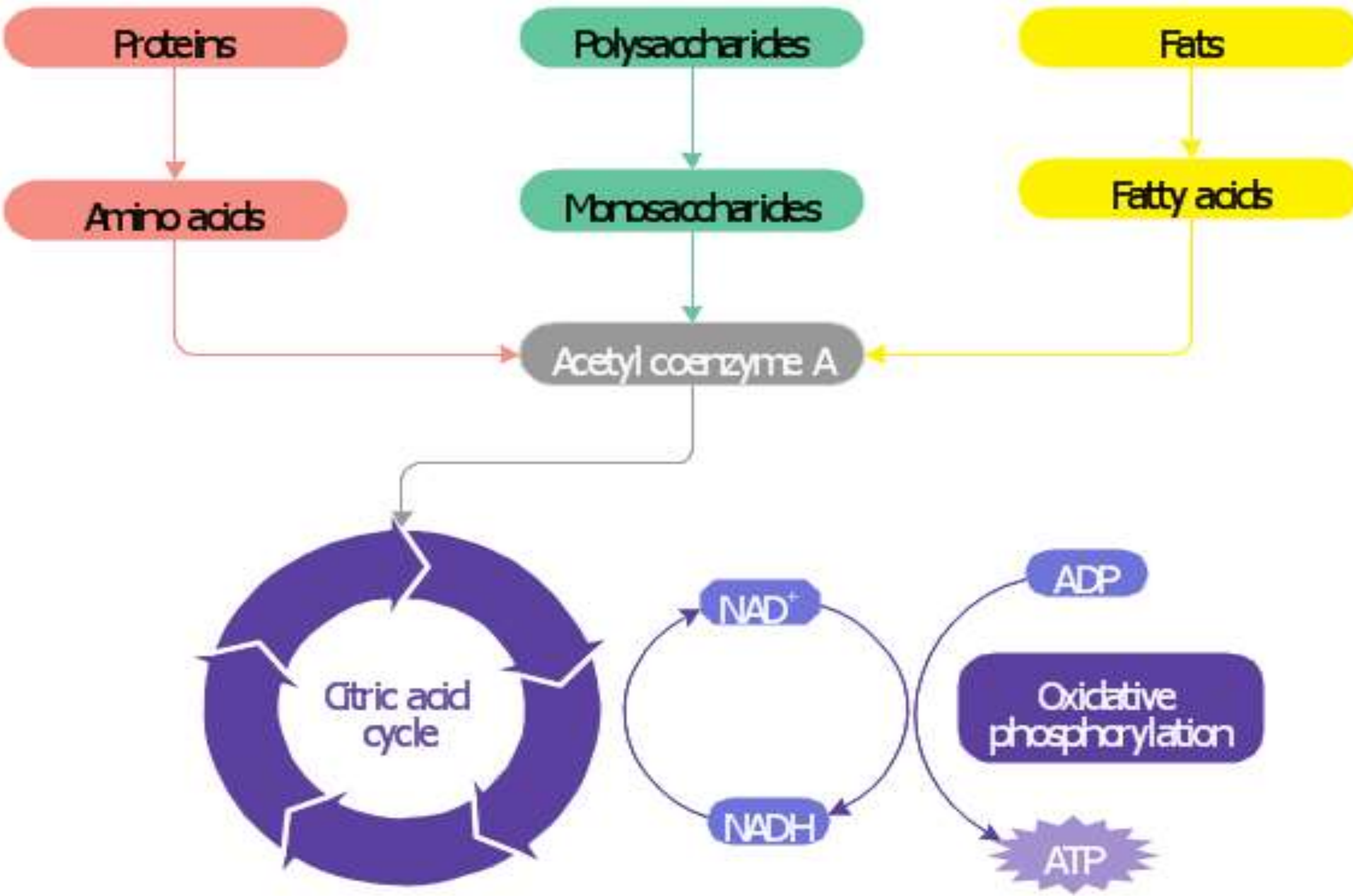
Catabolism

Cellular Respiration

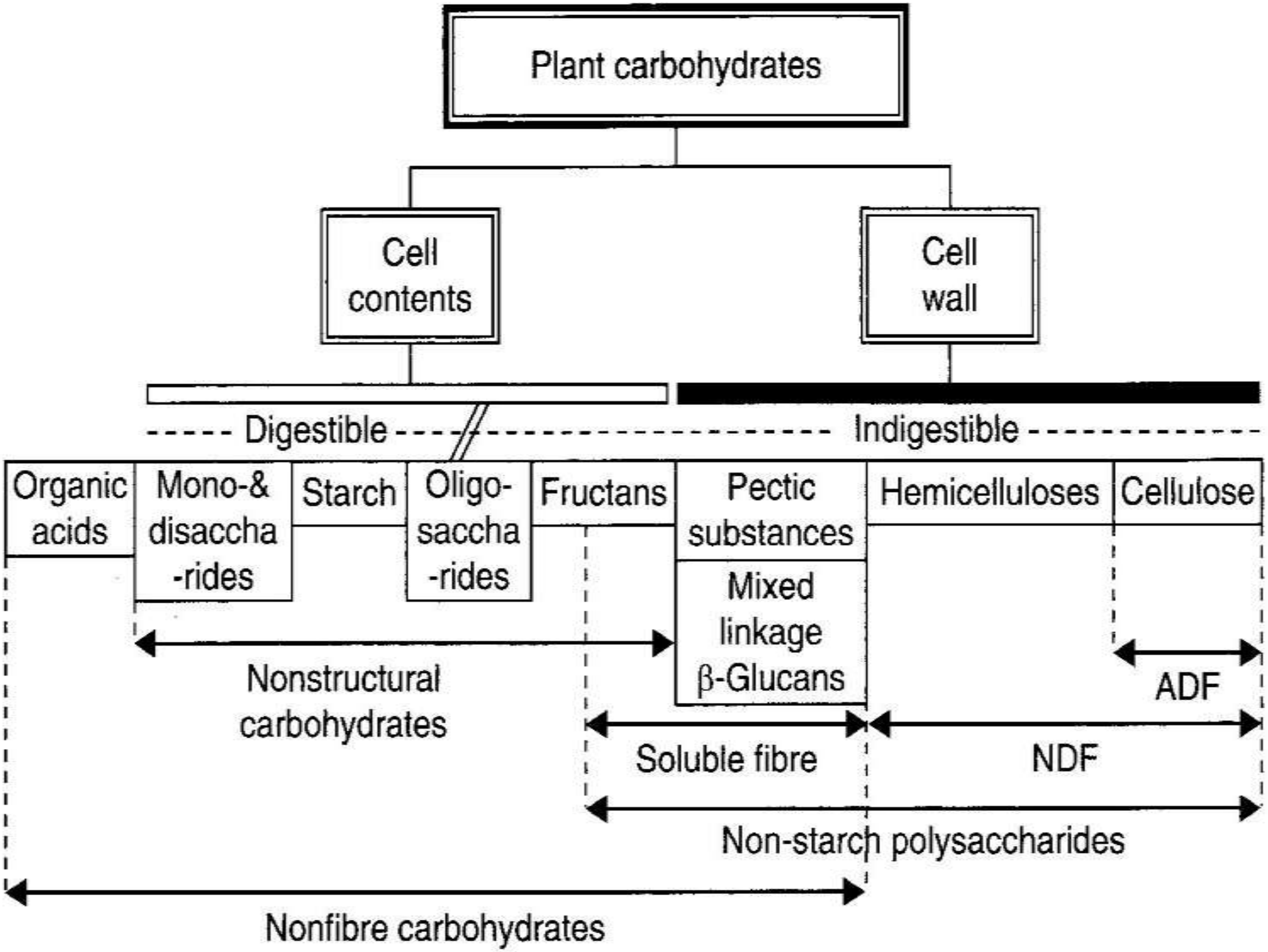


Catabolism schematic



Carbohydrate Digestion and Catabolism

Overview of Carbohydrate Digestion and Catabolism



Carbohydrates

- Carbohydrates are composed of carbon and water and have a composition of $(CH_2O)_{n.}$
- The major nutritional role of carbohydrates is to provide energy and digestible carbohydrates provide **4 kilocalories per gram**.

Simple Sugars

<u>Monosaccharides</u>

- Glucose
- Mannose
- Fructose
- Galactose

<u>Disaccharides</u>

- Lactose : Glucose + Galactose
- Maltose : Glucose + Glucose
- Sucrose : Glucose + Fructose

Complex carbohydrates

- Oligosaccharides
- Polysaccharides
  - Starch
  - Glycogen
  - Cellulose (Dietary fiber)

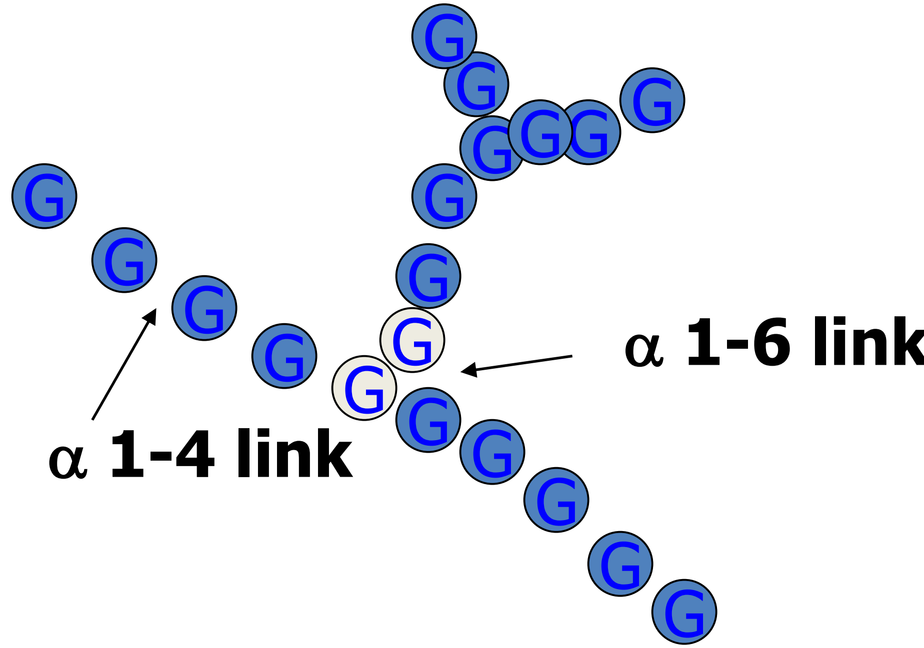
Starch

Major storage carbohydrate in higher plants

Amylose – long straight glucose chains (α1-4)

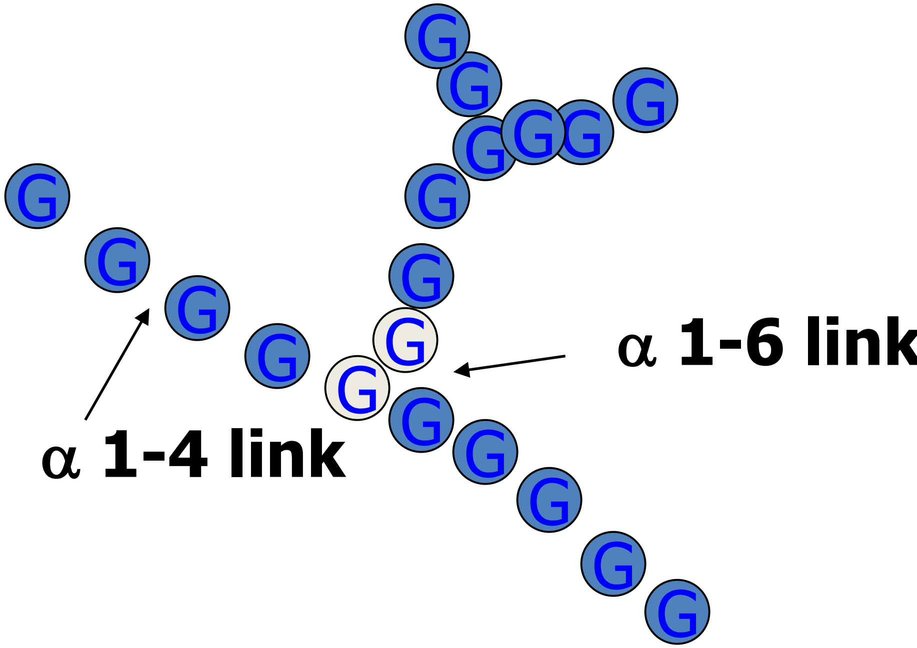
Amylopectin – branched every 24-30 glc residues (α 1-6)

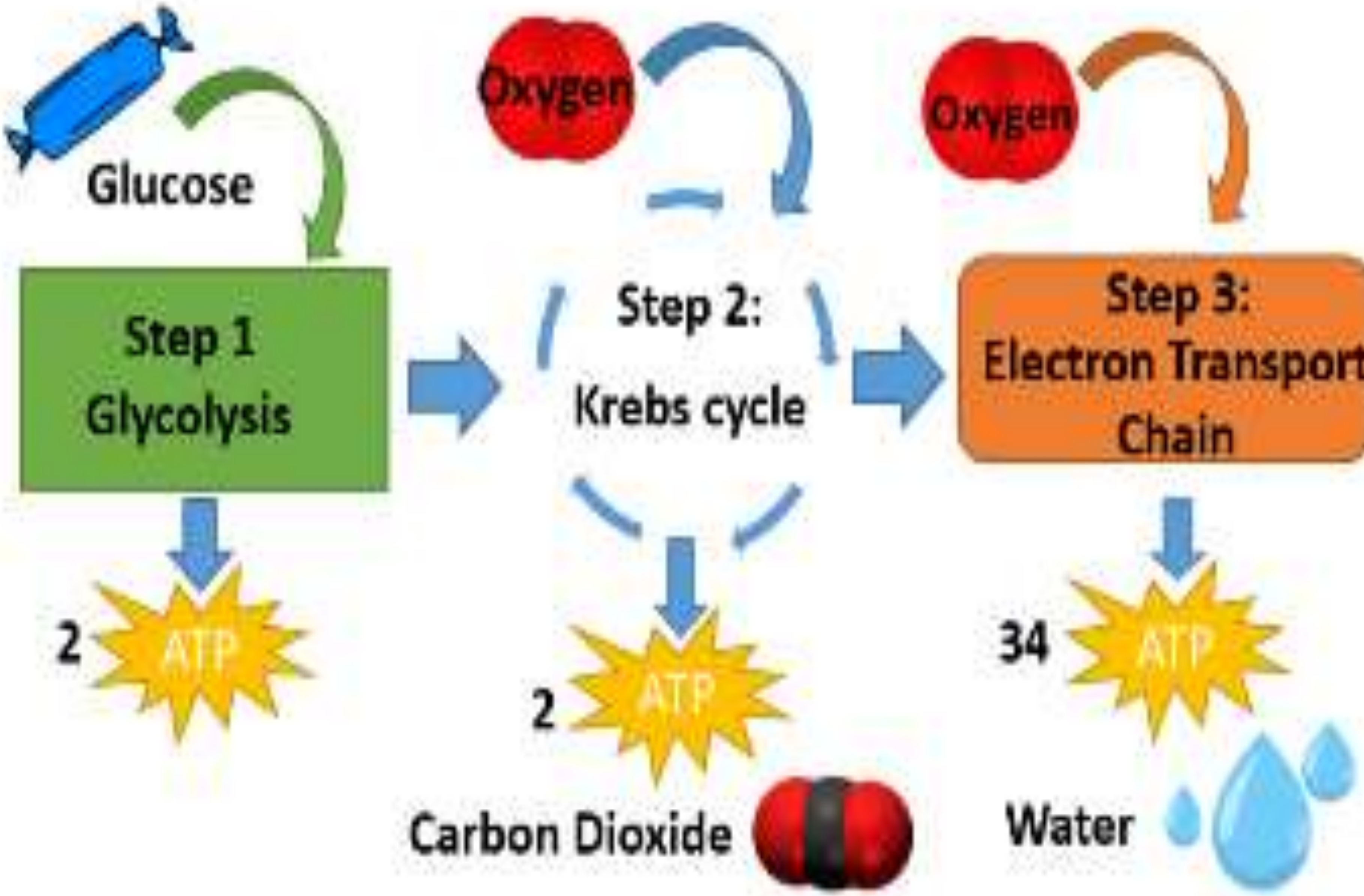
Provides 80% of dietary calories in humans worldwide



Glycogen

- Major storage carbohydrate in animals
- Long straight glucose chains (α 1-4)
- Branched every 4-8 glc residues (α 1-6)
- More branched than starch
- Less osmotic pressure
- Easily mobilized




Glucose
Step 1
Glycolysis
2
ATP
Oxygen
Step 2:
Krebs cycle
2
ATP
Carbon Dioxide
Oxygen
Step 3:
Electron Transport
Chain
34
ATP
Water

Stage 1: Digestion of Carbohydrates

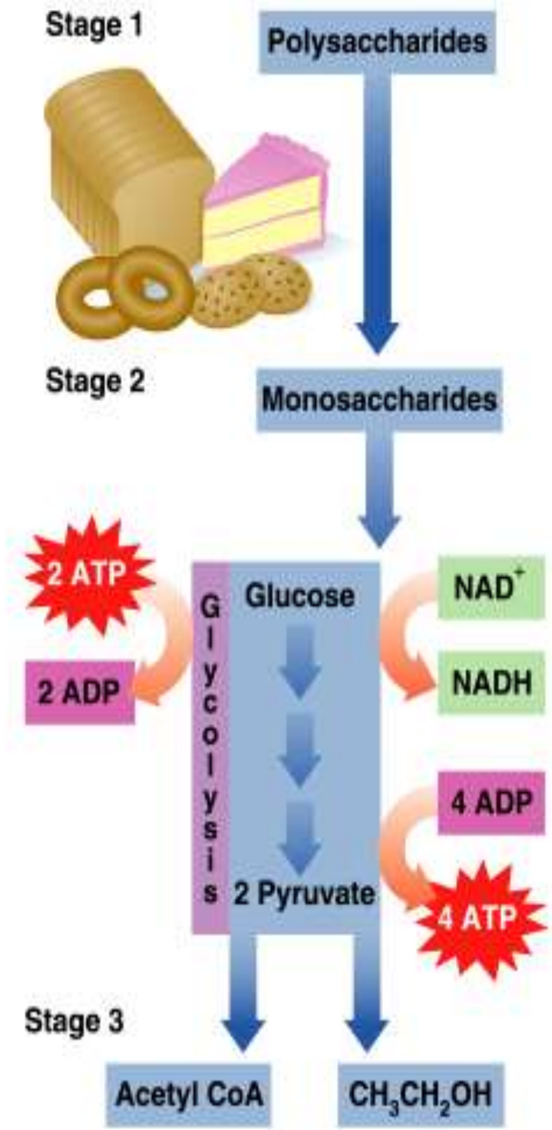
In Stage 1, the digestion of carbohydrates

- Begins in the mouth where salivary amylase breaks down polysaccharides to smaller polysaccharides (dextrins), maltose, and some glucose.
- Continues in the small intestine where pancreatic amylase hydrolyzes dextrins to maltose and glucose.
- Hydrolyzes maltose, lactose, and sucrose to monosaccharides, mostly glucose, which enter the bloodstream for transport to the cells.

Stage 2: Glycolysis

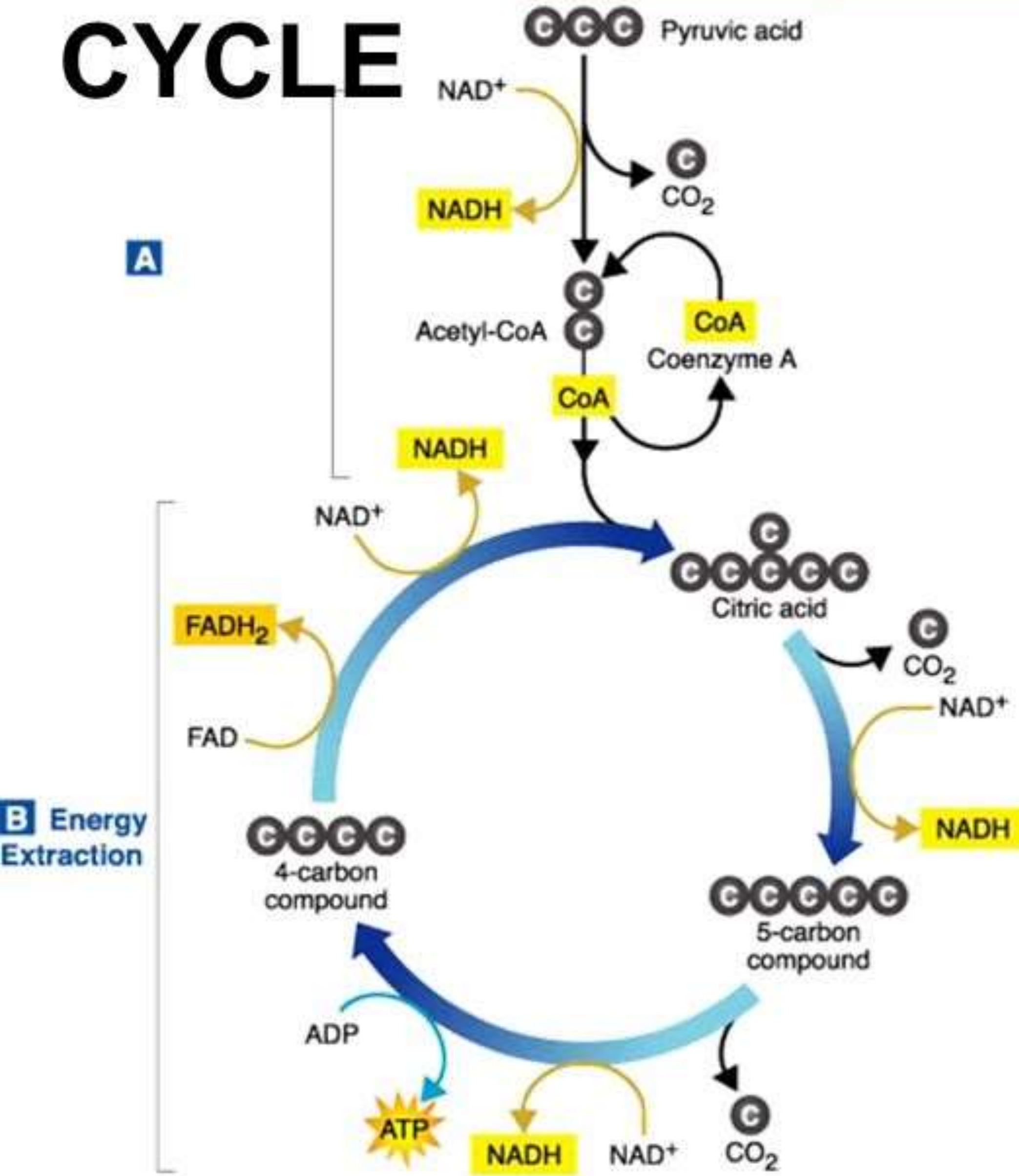
Stage 2: Glycolysis

- Is a metabolic pathway that uses glucose, a digestion product.
- Degrades six-carbon glucose molecules to three-carbon. pyruvate molecules.
- Is an anaerobic (no oxygen) process.

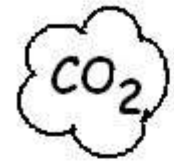


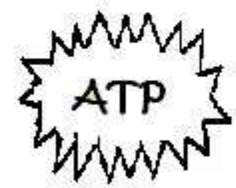
KREBS CYCLE

Krebs Cycle Animation-(select #3)



KREBS CYCLE PRODUCES

______ 

______ 

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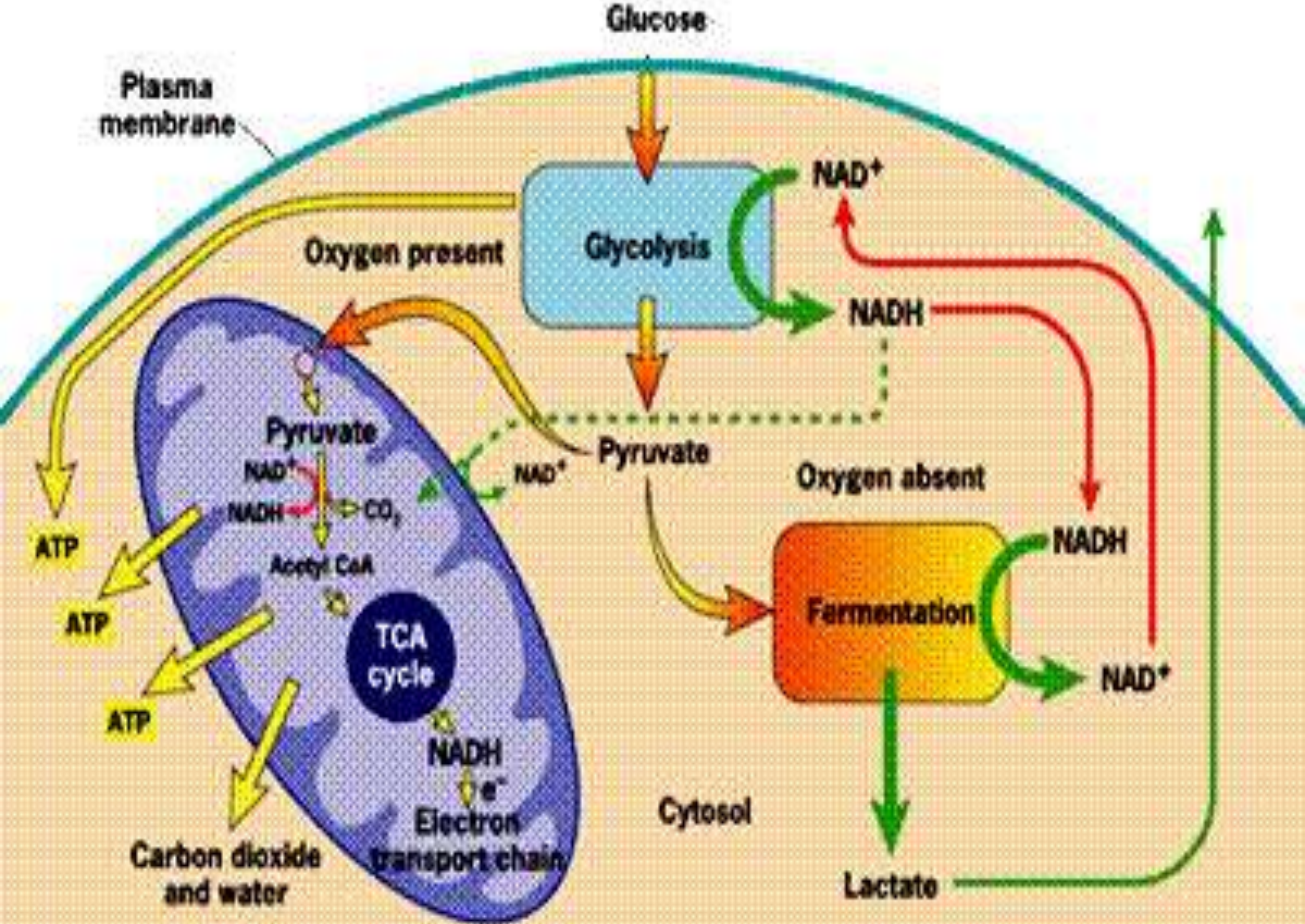
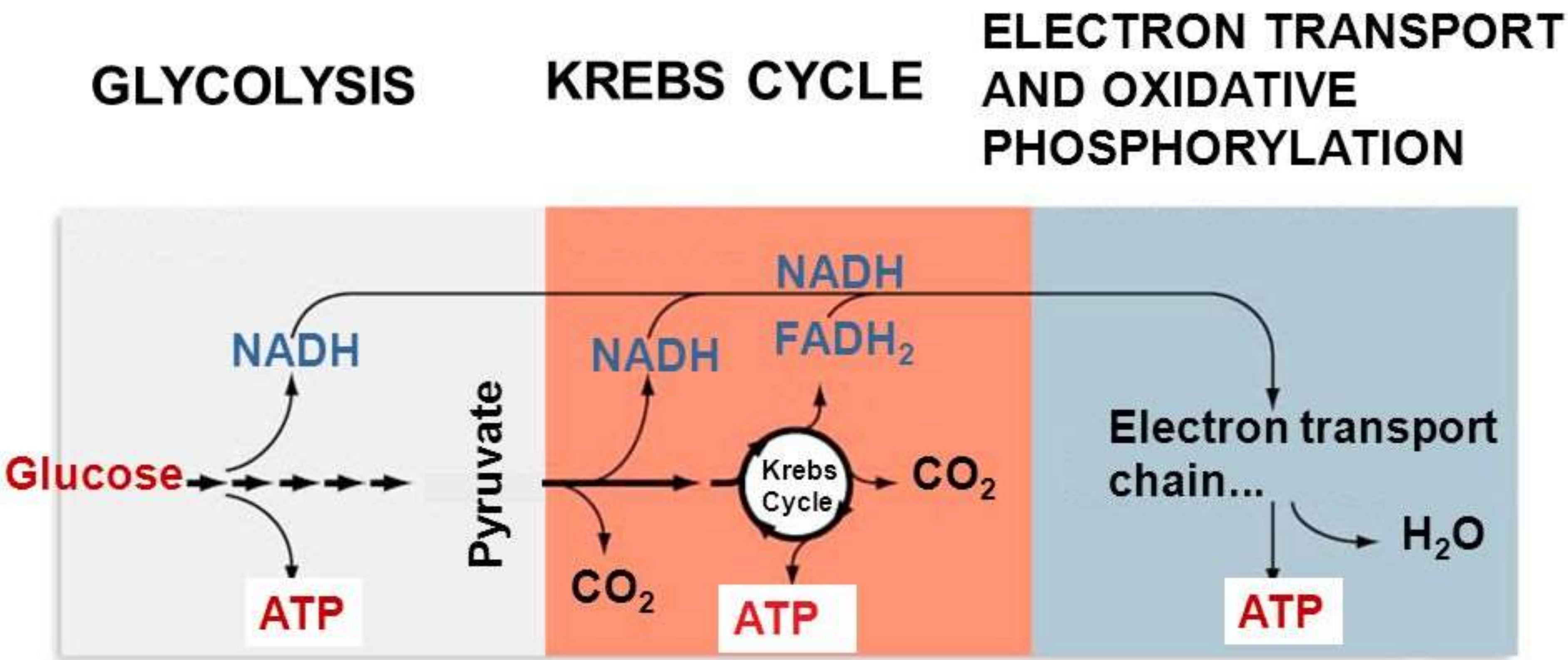


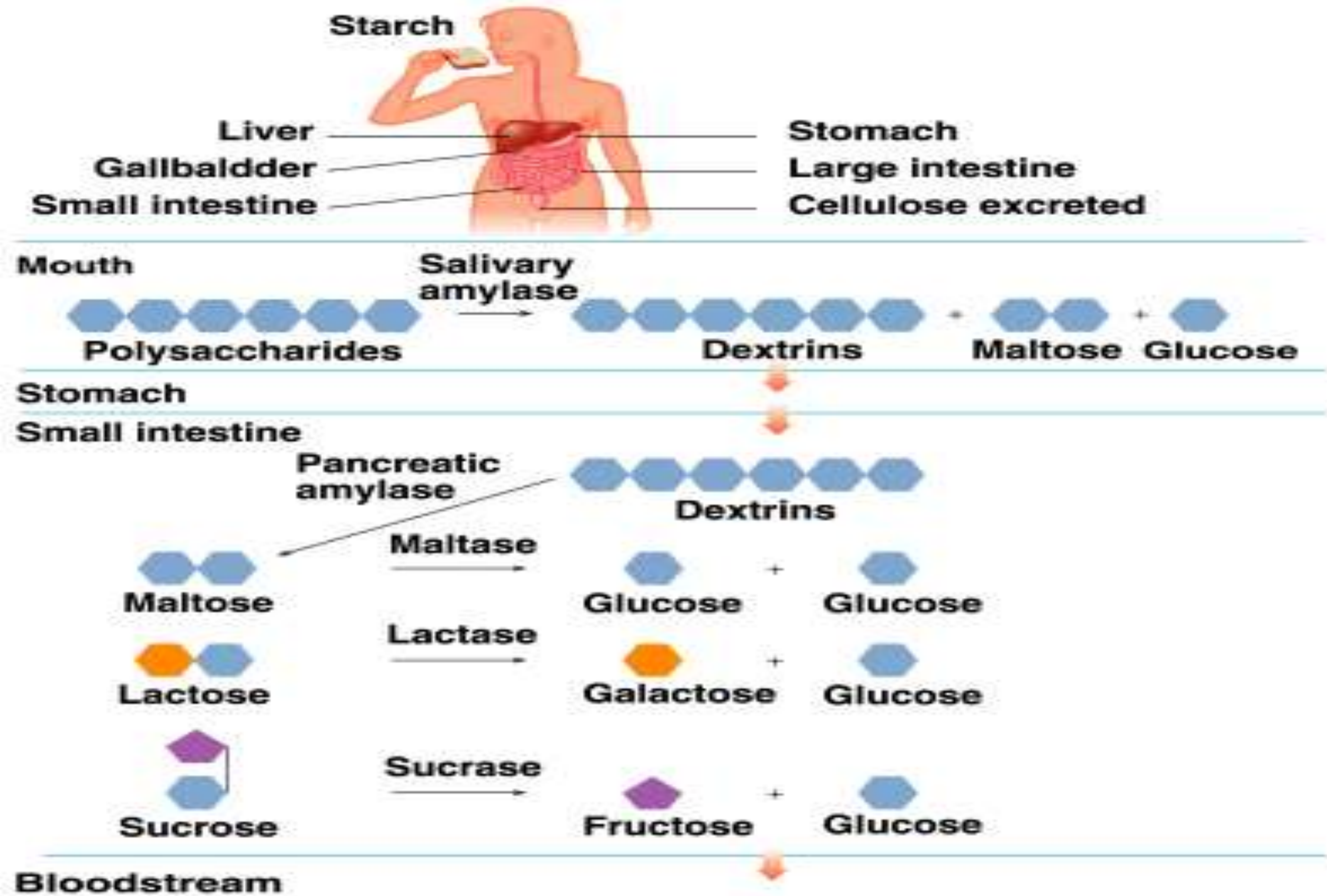
Glucose
Plasma membrane
Glycolysis
NAD+
NADH
Oxygen present
Pyruvate
NAD+
NADH
CO2
Acetyl CoA
TCA cycle
NADH
e-
Electron transport chain
ATP
ATP
ATP
Carbon dioxide and water
NAD+
Pyruvate
Oxygen absent
NADH
Fermentation
NAD+
Cytosol
Lactate

Cell Respiration is separated into 3 stages



Energy/electrons are transferred from glucose to convert NAD^+ to NADH, which is used in the ETC to make ATP

Digestion of Carbohydrates



Digestion of Carbohydrates

- Monosaccharides
  - Do not need hydrolysis before absorption
  - Very little (if any) in most feeds
- Di- and poly-saccharides
  - Relatively large molecules
  - Must be hydrolyzed prior to absorption
  - Hydrolyzed to monosaccharides

Only monosaccharides can be absorbed

Carbohydrate Digestion

- Mouth

  - Salivary amylase

- Breaks starches down to maltose
- Plays only a small role in breakdown because of the short time food is in the mouth
- Ruminants do not have this enzyme
- Not all monogastrics secrete it in saliva

Stomach

- Not much carbohydrate digestion
- Acid and pepsin to unfold proteins
- Ruminants have forestomachs with extensive microbial populations to breakdown and anaerobically ferment feed

Digestion in Small Intestine

- Digestion mediated by enzymes synthesized by cells lining the small intestine (brush border)

$$\text{Disaccharides} \xrightarrow{\text{Brush Border Enzymes}} \text{Monosaccharides}$$

* Exception is β-1,4 bonds in cellulose

Small intestine

Portal for transport of virtually all nutrients
Water and electrolyte balance

Enzymes associated with intestinal surface membranes

- Sucrase
- α dextrinase
- Glucoamylase (maltase)
- Lactase
- peptidases

Digestion in Small Intestine

$$\text{Sucrose} \xrightarrow{\text{Sucrase}} \text{Glucose + Fructose}$$

* Ruminants do not have sucrase

$$\text{Maltose} \xrightarrow{\text{Maltase}} \text{Glucose + Glucose}$$

$$\text{Lactose} \xrightarrow{\text{Lactase}} \text{Glucose + Galactose}$$

* Poultry do not have lactase

Carbohydrate Digestion

- Pancreas
  - ➢ Pancreatic amylase
    - Hydrolyzes alpha 1-4 linkages
    - Produces monosaccharides, disaccharides, and polysaccharides
    - Major importance in hydrolyzing starch and glycogen to maltose

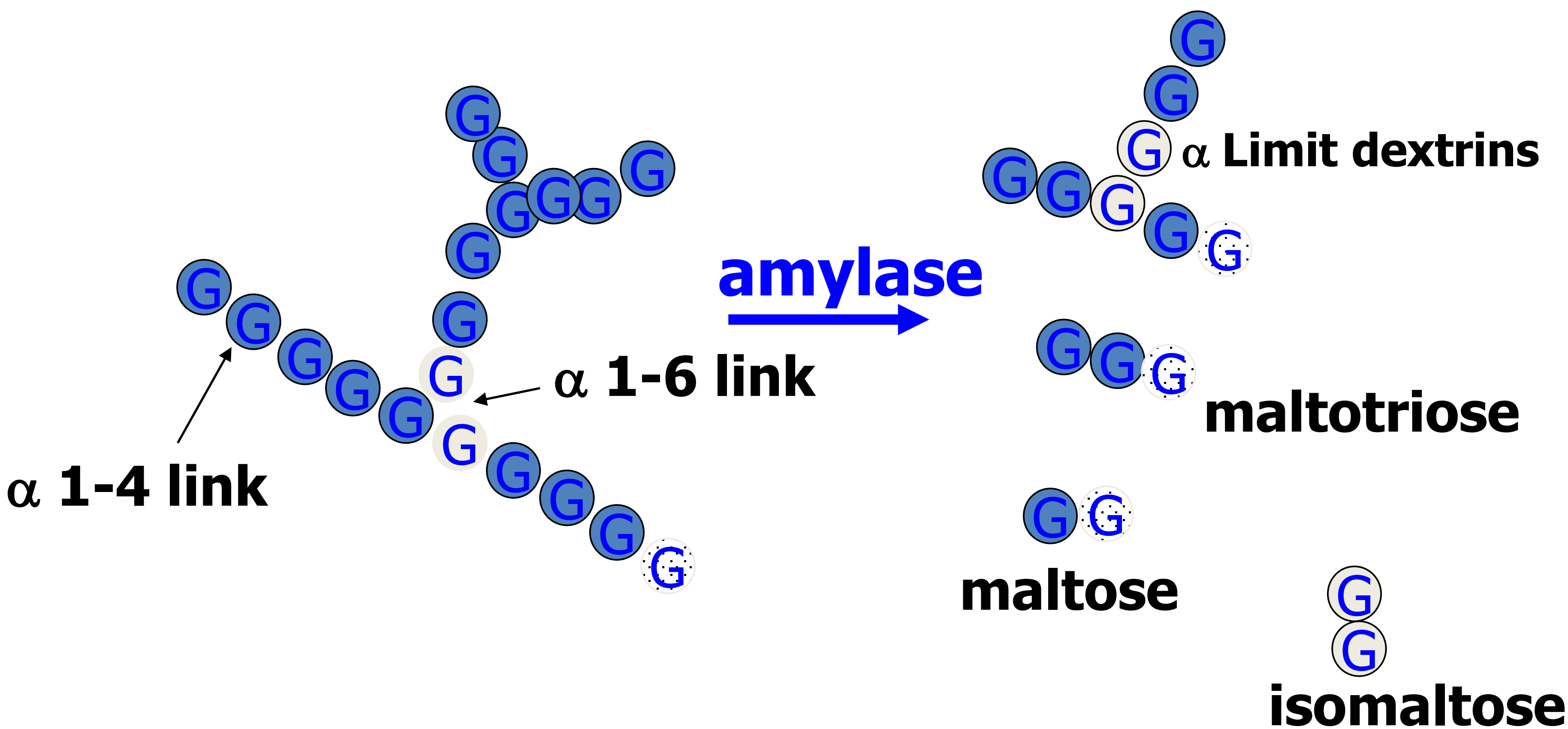
$$\text{Polysaccharides} \xrightarrow{\text{Amylase}} \text{Disaccharides}$$

Digestion in Large Intestine

- Carnivores and omnivores
  - Limited anaerobic fermentation
  - Bacteria produce small quantities of cellulase
  - SOME volatile fatty acids (VFA) produced by microbial digestion of fibers
    - Propionate
    - Butyrate
    - Acetate

Digestion

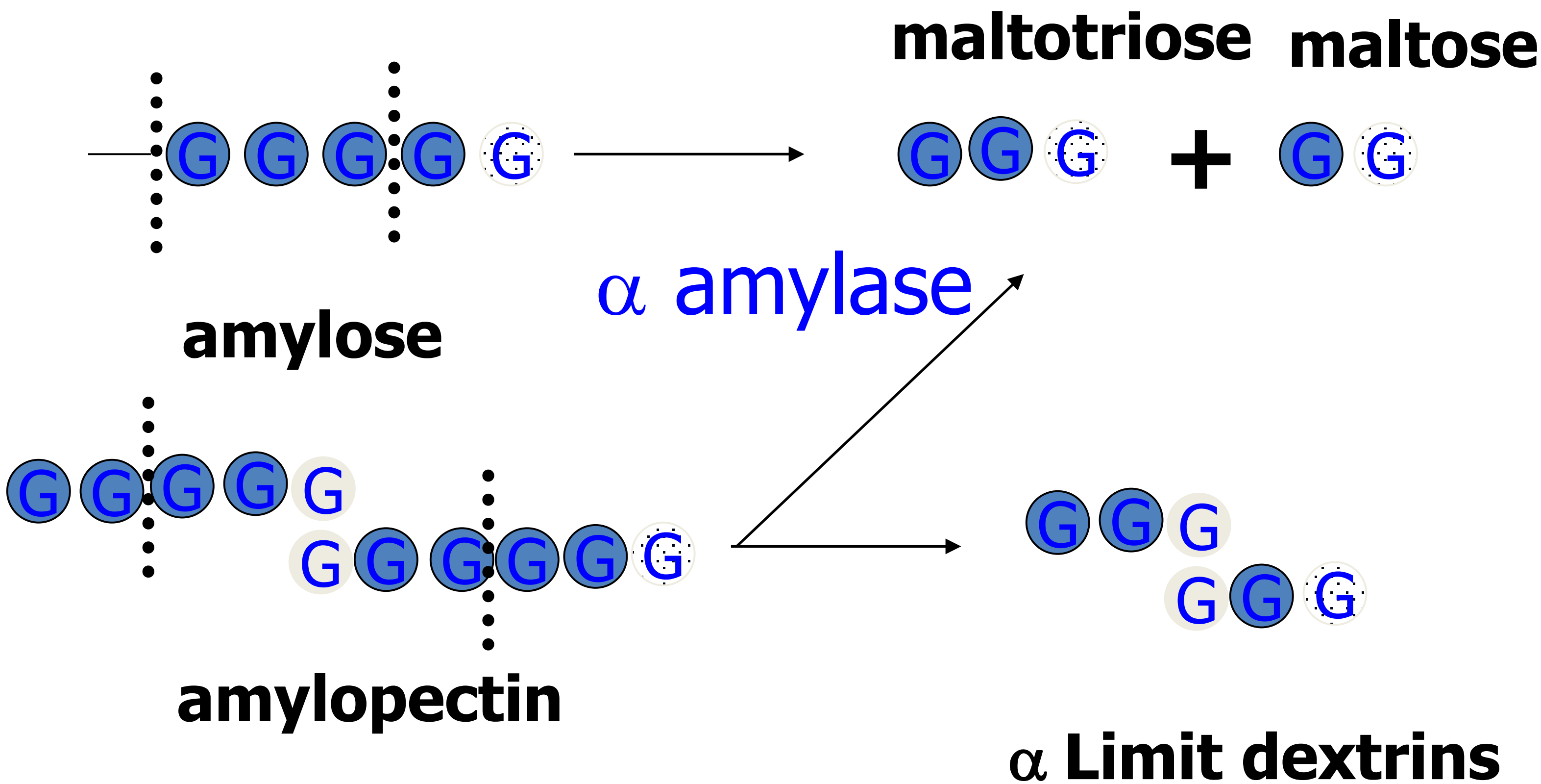
- Pre-stomach – Salivary amylase : α 1-4 endoglycosidase



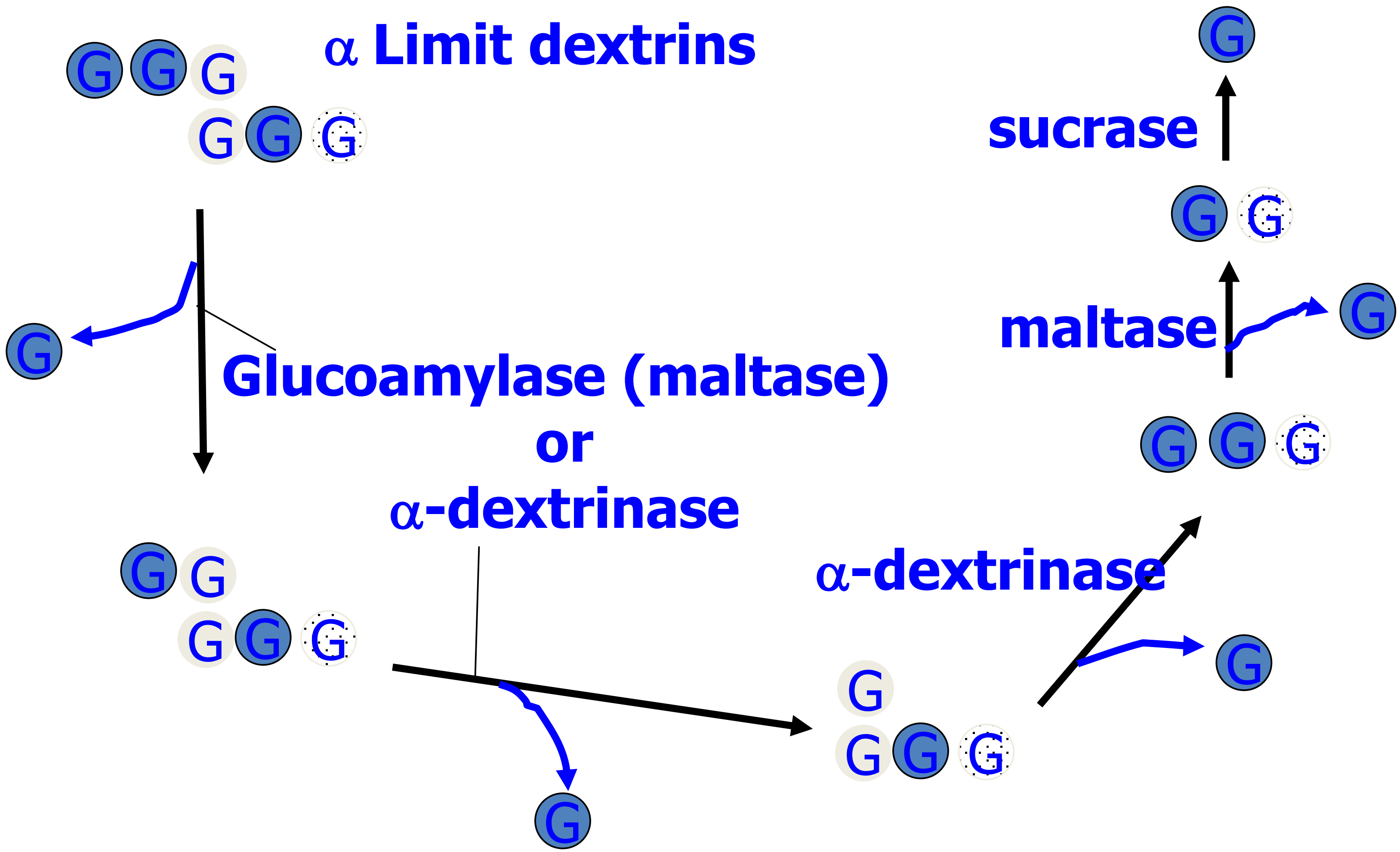
Small Intestine

- Pancreatic enzymes

α-amylase

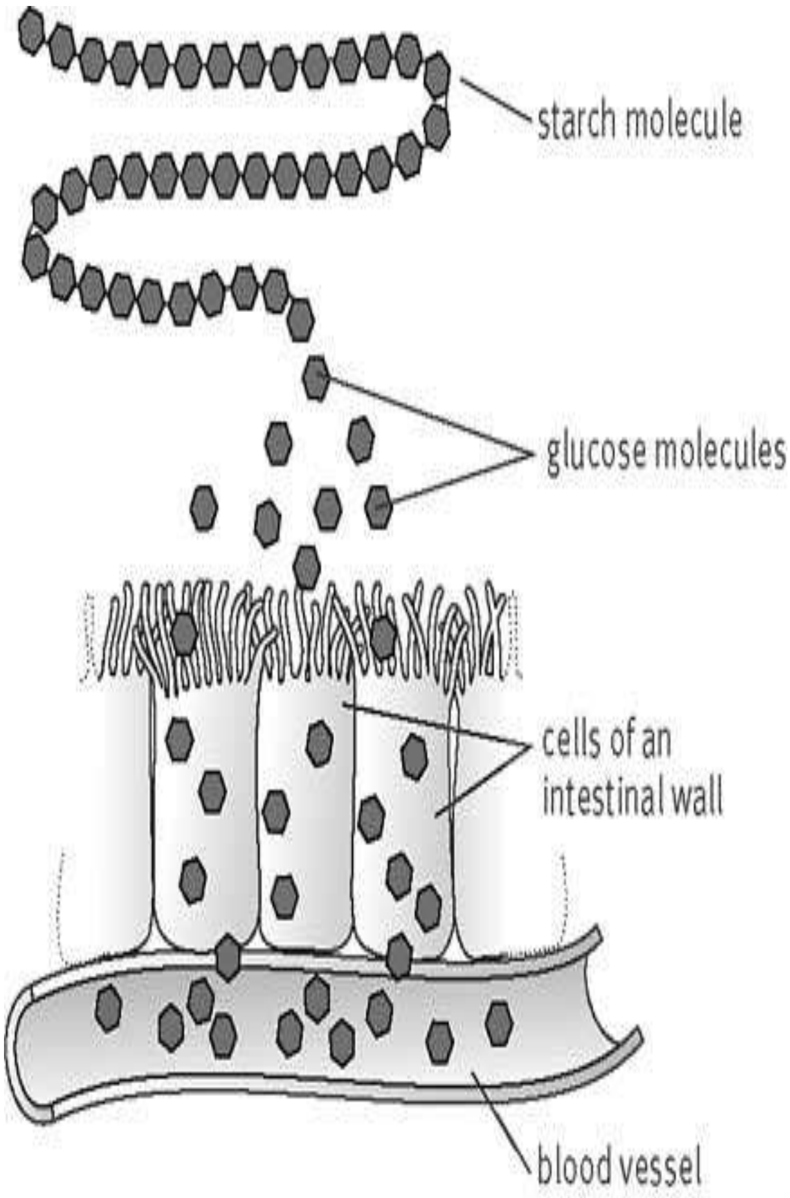


Oligosaccharide digestion..cont

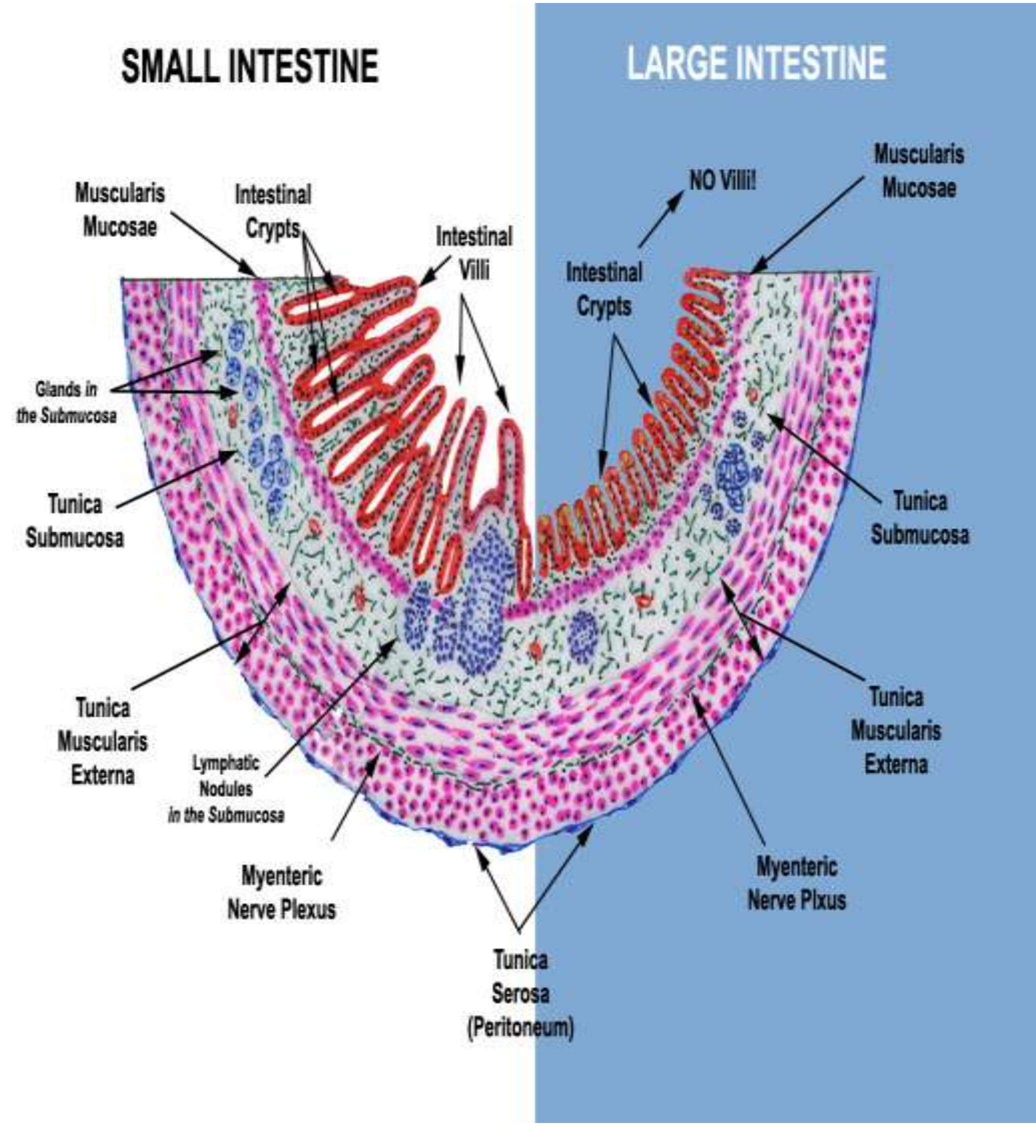


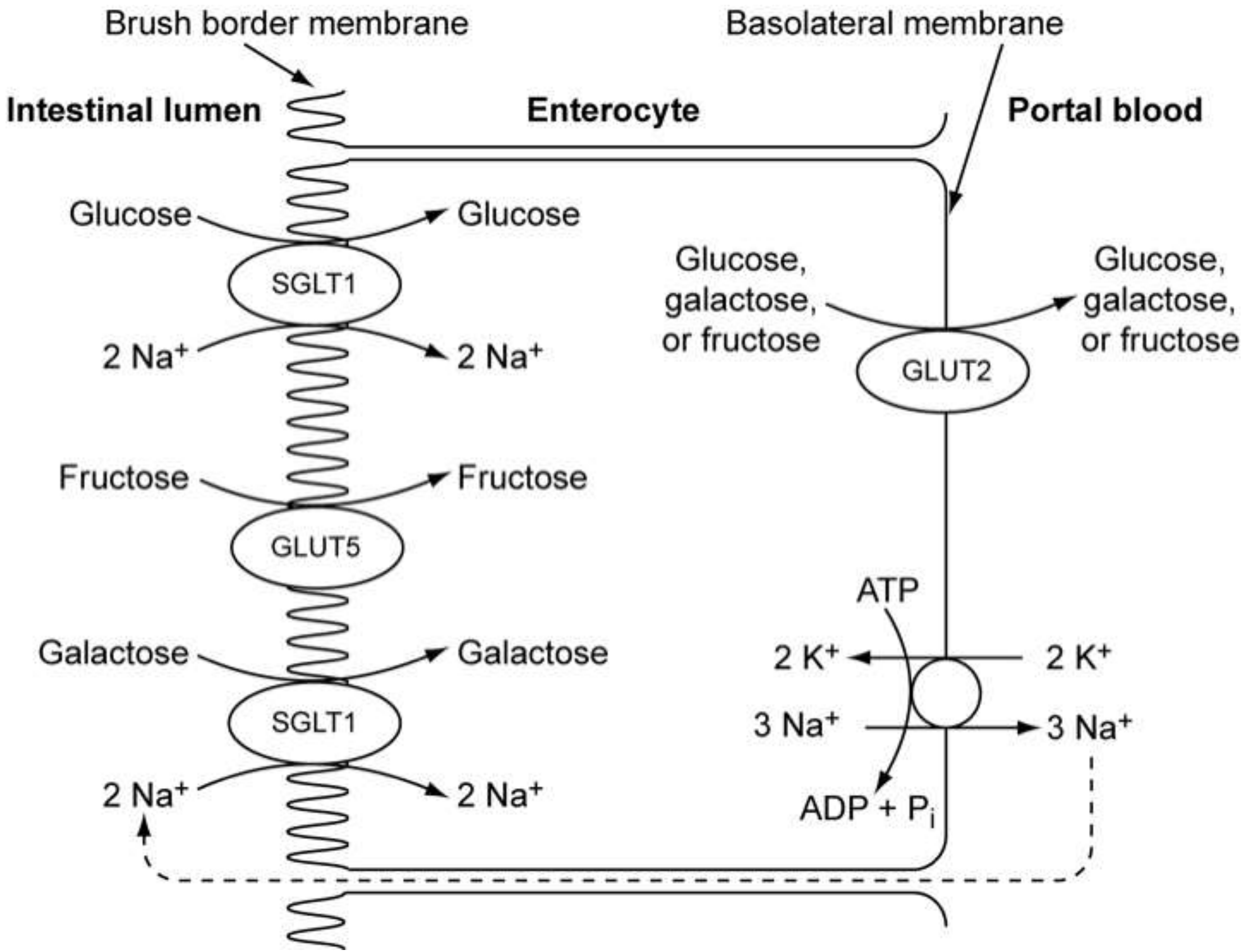
Overview Monogastric Carbohydrate Digestion

Location	**Enzymes**	**Form of Dietary CHO**
Mouth	Salivary Amylase	Starch Maltose Sucrose Lactose
Stomach	(amylase from saliva)	Dextrin→Maltose
Small Intestine	Pancreatic Amylase	Maltose
	Brush Border Enzymes	Glucose + Glucose, Fructose + Glucose, Galactose + Glucose
Large Intestine	None	Bacterial Microflora Ferment Cellulose

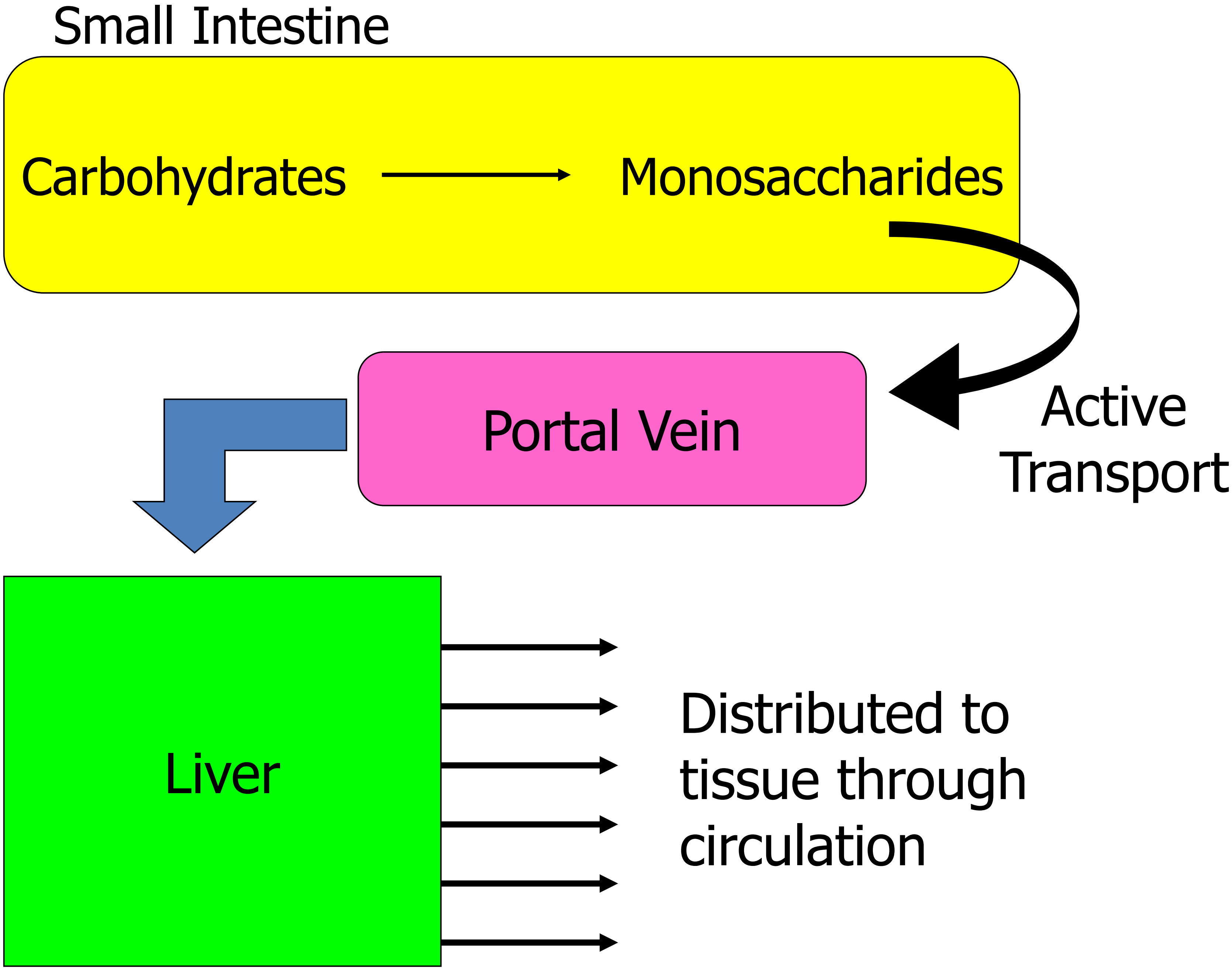


Elizabeth Morales

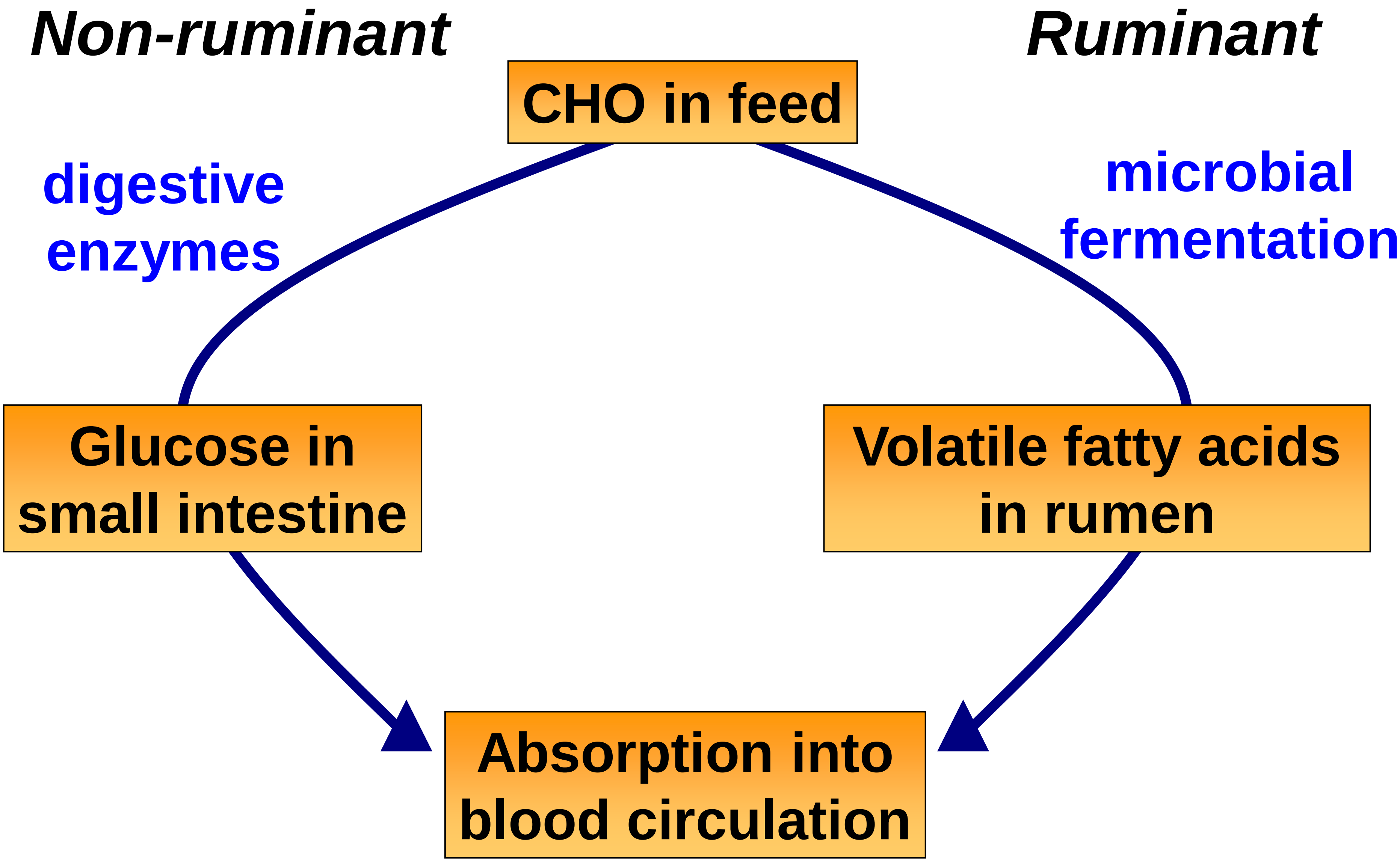




Brush border membrane
Basolateral membrane
Intestinal lumen
Enterocyte
Portal blood
Glucose
Glucose
SGLT1
2 Na+
2 Na+
Glucose, galactose, or fructose
Glucose, galactose, or fructose
GLUT2
Fructose
Fructose
GLUT5
ATP
2 K+
2 K+
3 Na+
3 Na+
Galactose
Galactose
SGLT1
2 Na+
2 Na+
ADP + Pi


Small Intestine
Carbohydrates
Monosaccharides
Active Transport
Portal Vein
Liver
Distributed to tissue through circulation

Digestion and Absorption



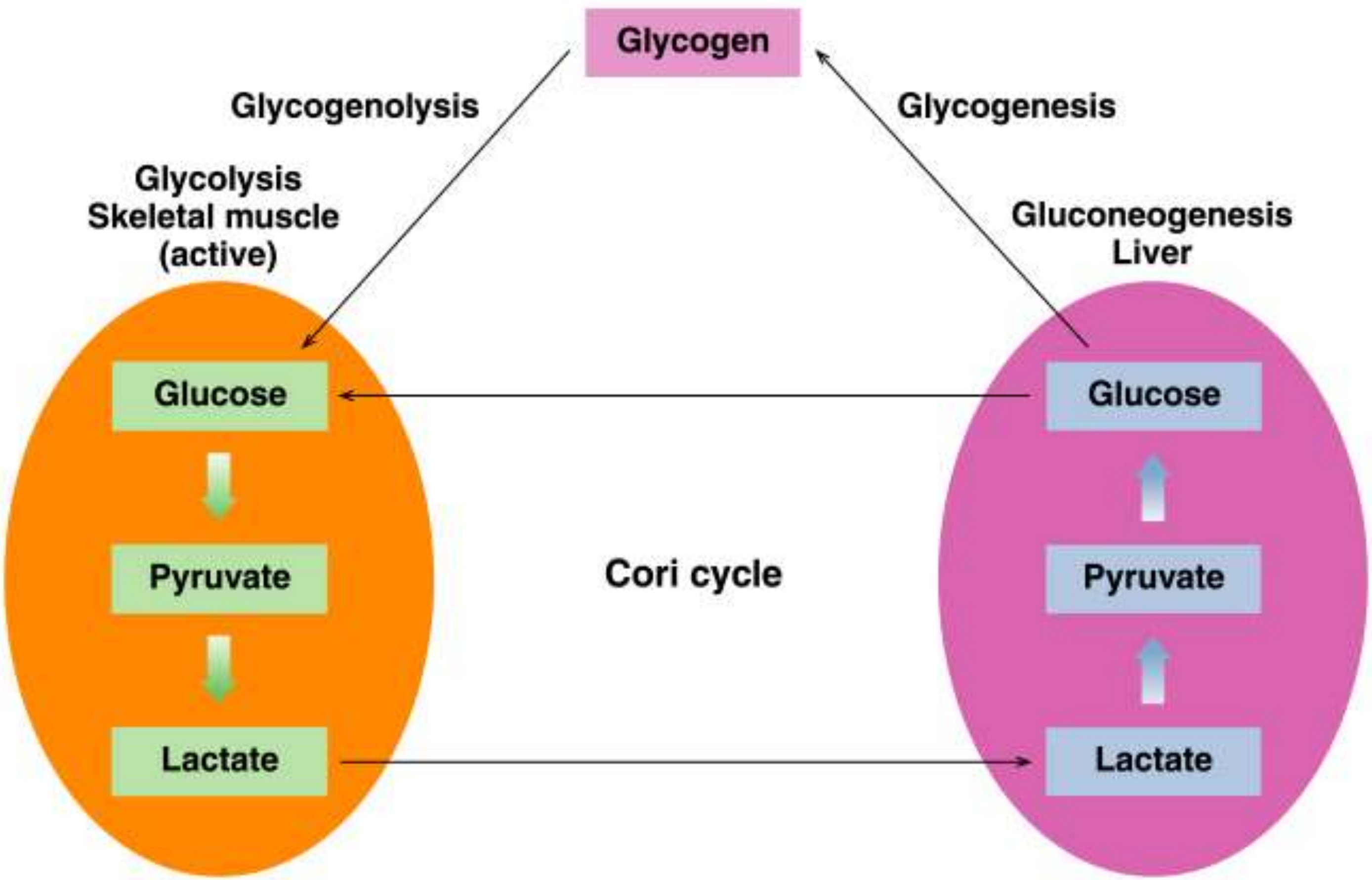
Microbial Populations

- Cellulolytic bacteria (fiber digesters)
  - Produce cellulase - cleaves $\beta 1 \rightarrow 4$ linkages
  - Primary substrates are cellulose and hemicellulose
  - Prefer pH 6-7
  - Produce acetate, propionate, little butyrate, CO_2
  - Predominate in animals fed roughage diets

Summary of Carbohydrate in Monogastrics

- Polysaccharides broken down to monosaccharides
- Monosaccharides taken up by active transport or facilitated diffusion and carried to liver
- Glucose is transported to cells requiring energy
  - Insulin influences rate of cellular uptake

Glycogen Metabolism



Regulation of Glycolysis and Gluconeogenesis

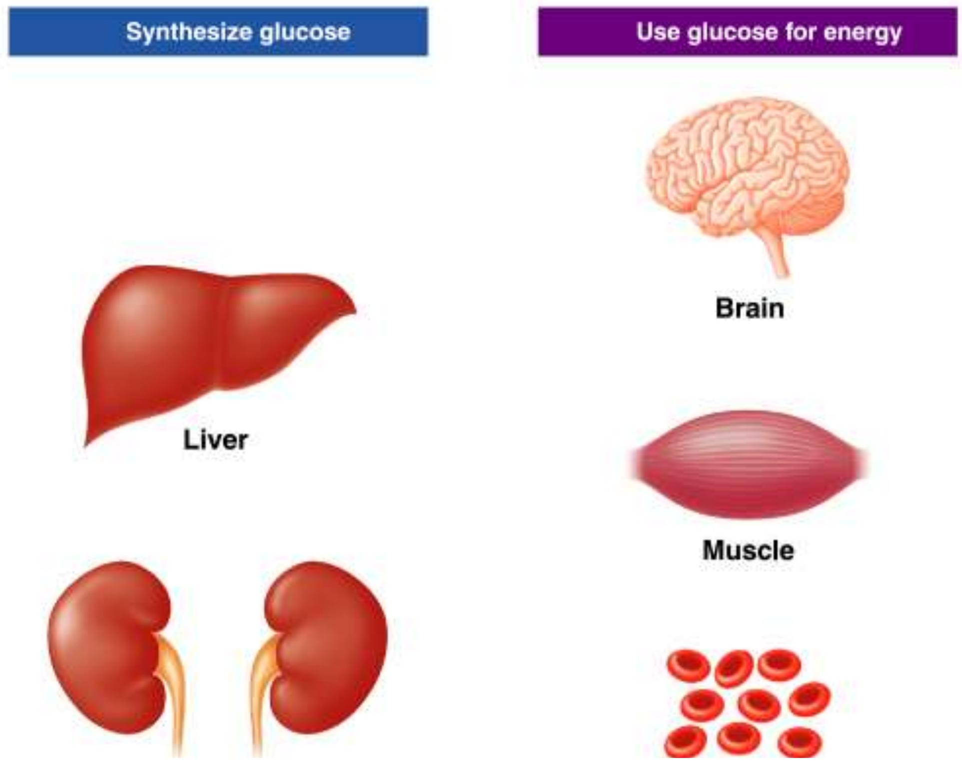
Regulation occurs as

- High glucose levels and insulin promote glycolysis.
- Low glucose levels and glucagon promote gluconeogenesis.

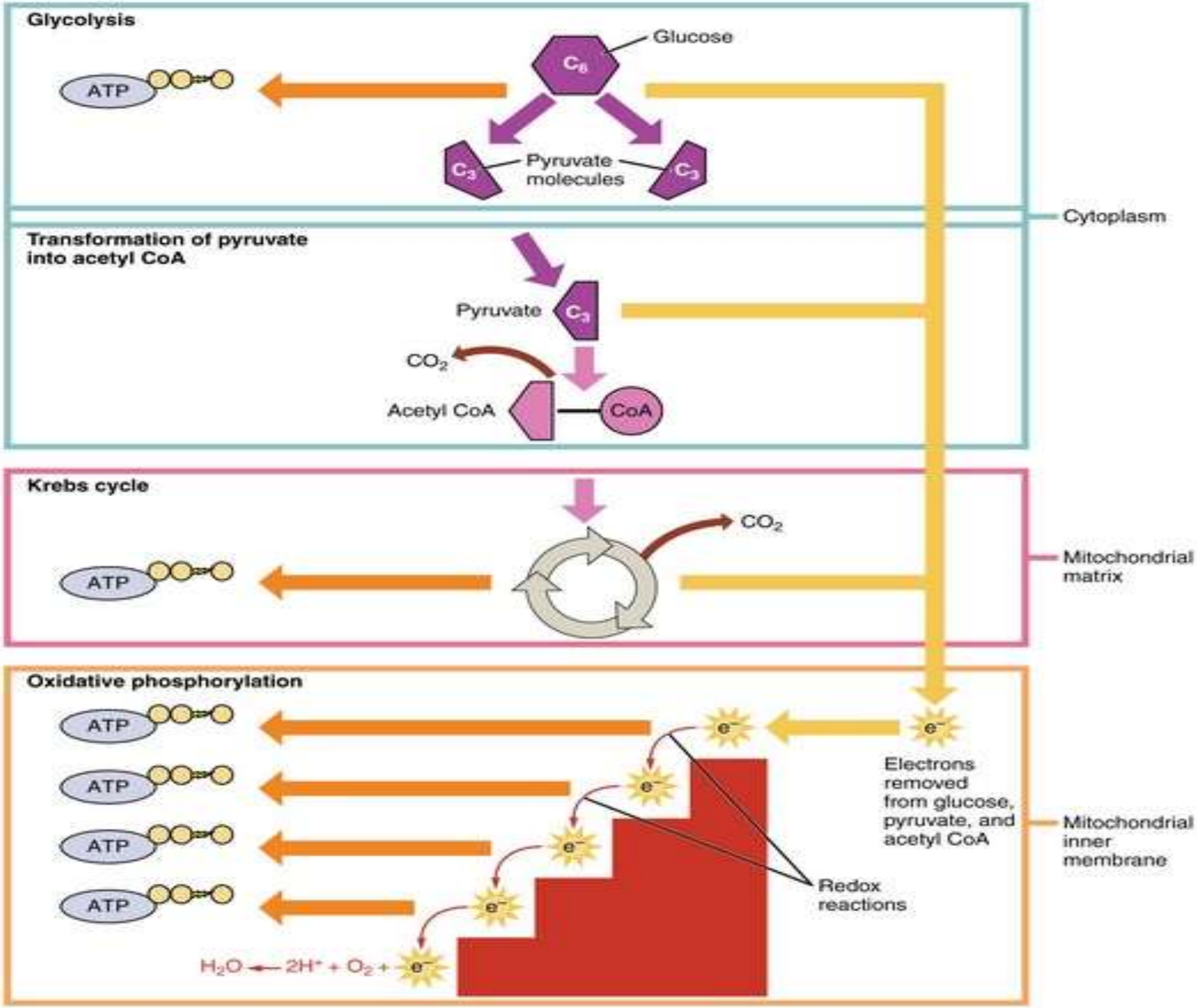
Utilization of Glucose

Glucose

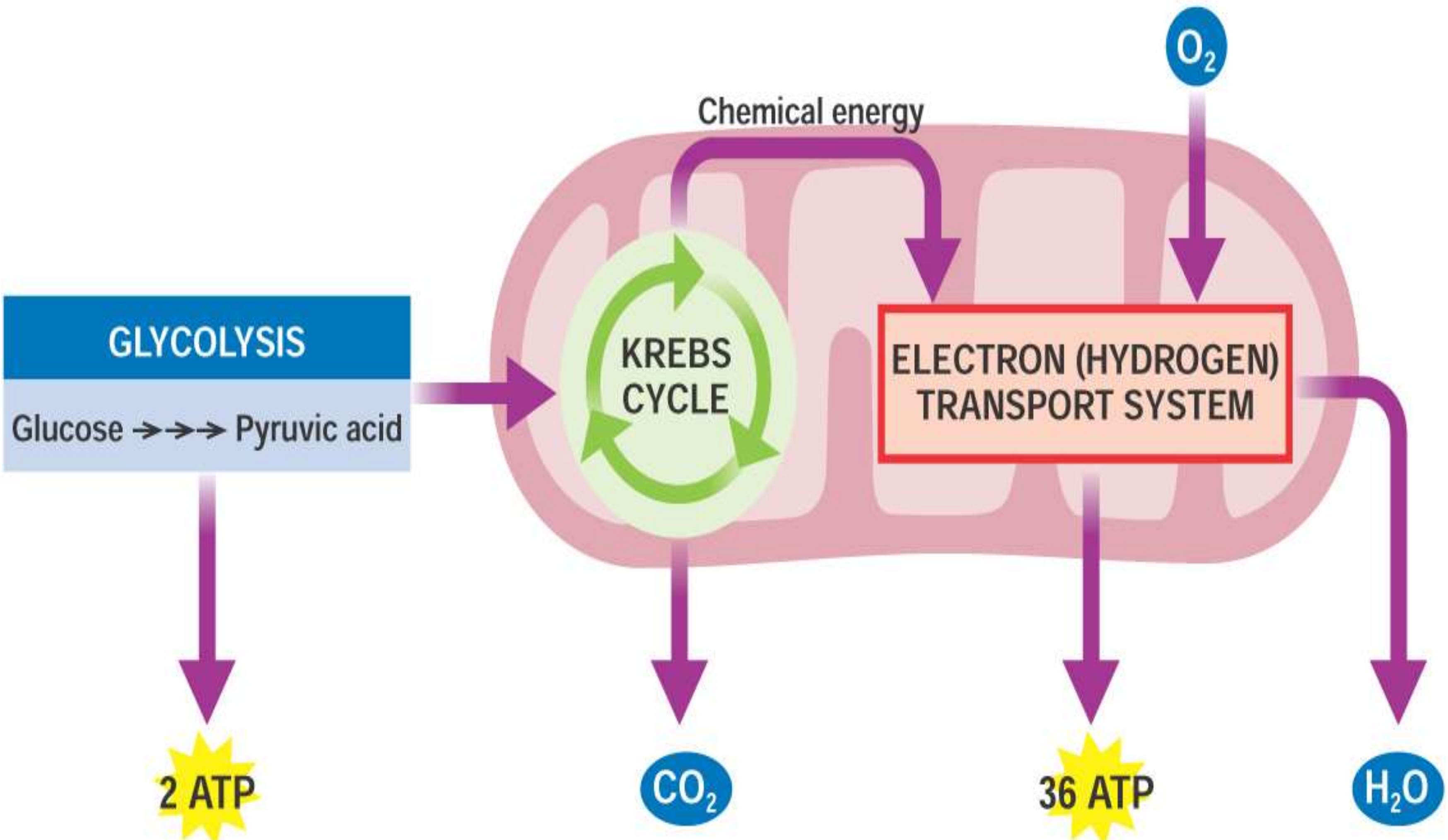
- Is the primary energy source for the brain, skeletal muscle, and red blood cells.
- Deficiency can impair the brain and nervous system.

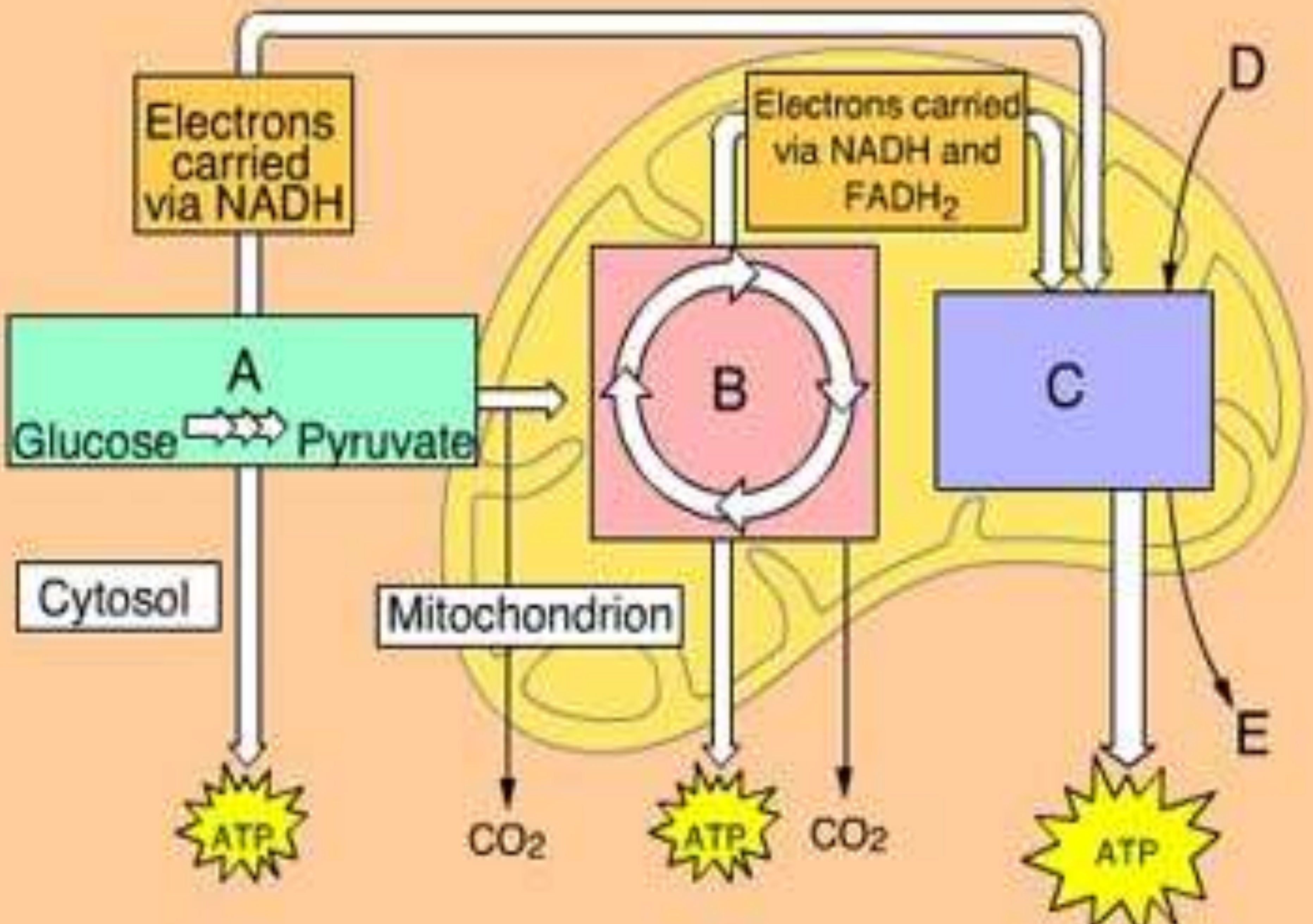


Cellular Respiration

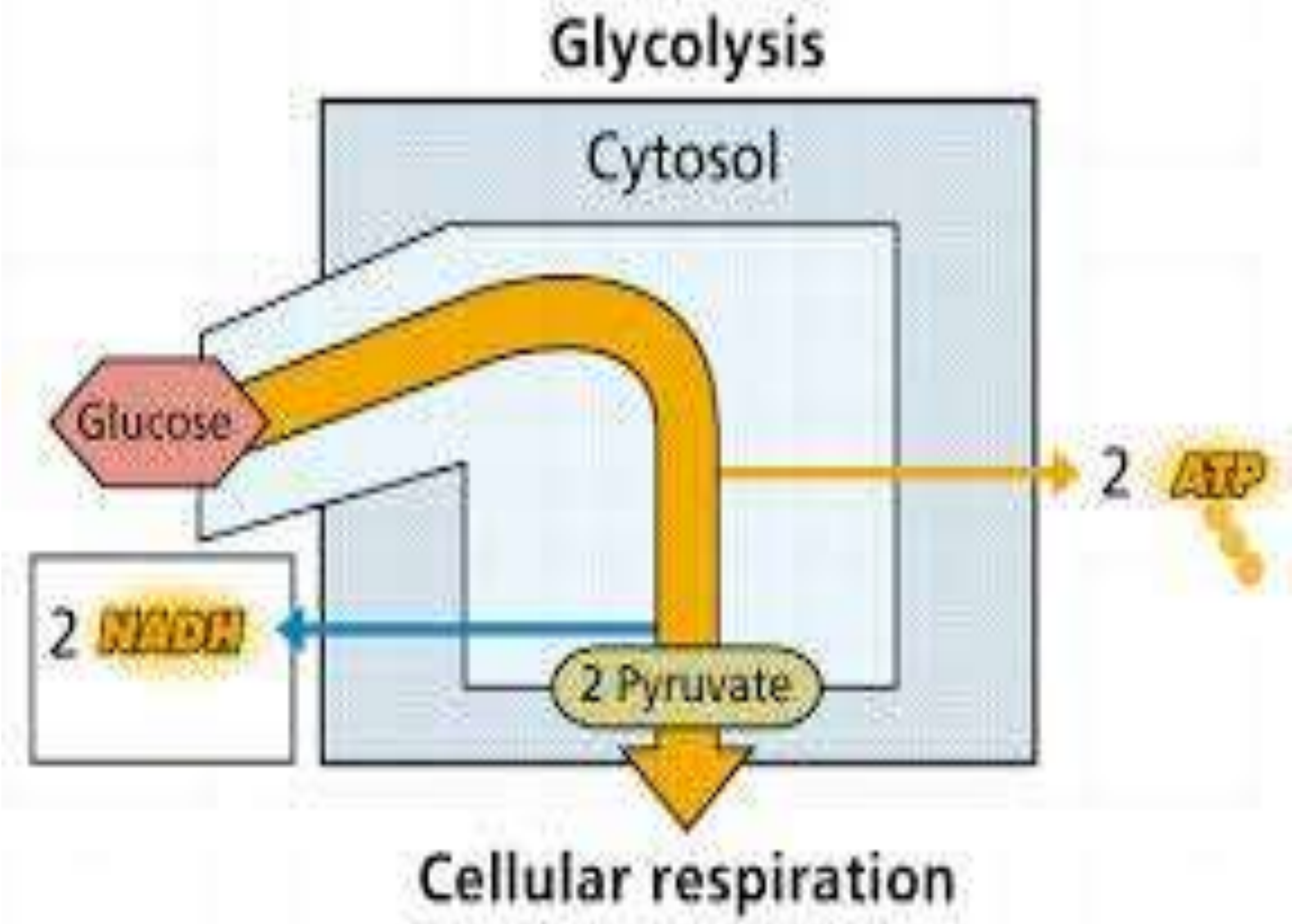


AEROBIC RESPIRATION -- SUMMARY





Electrons carried via NADH
Electrons carried via NADH and $FADH_2$
D
A
Glucose
Pyruvate
B
C
Cytosol
Mitochondrion
E
ATP
CO_2
ATP
CO_2
ATP


Glycolysis
Cytosol
Glucose
2 ATP
2 NADH
2 Pyruvate
Cellular respiration

End products of glycolysis

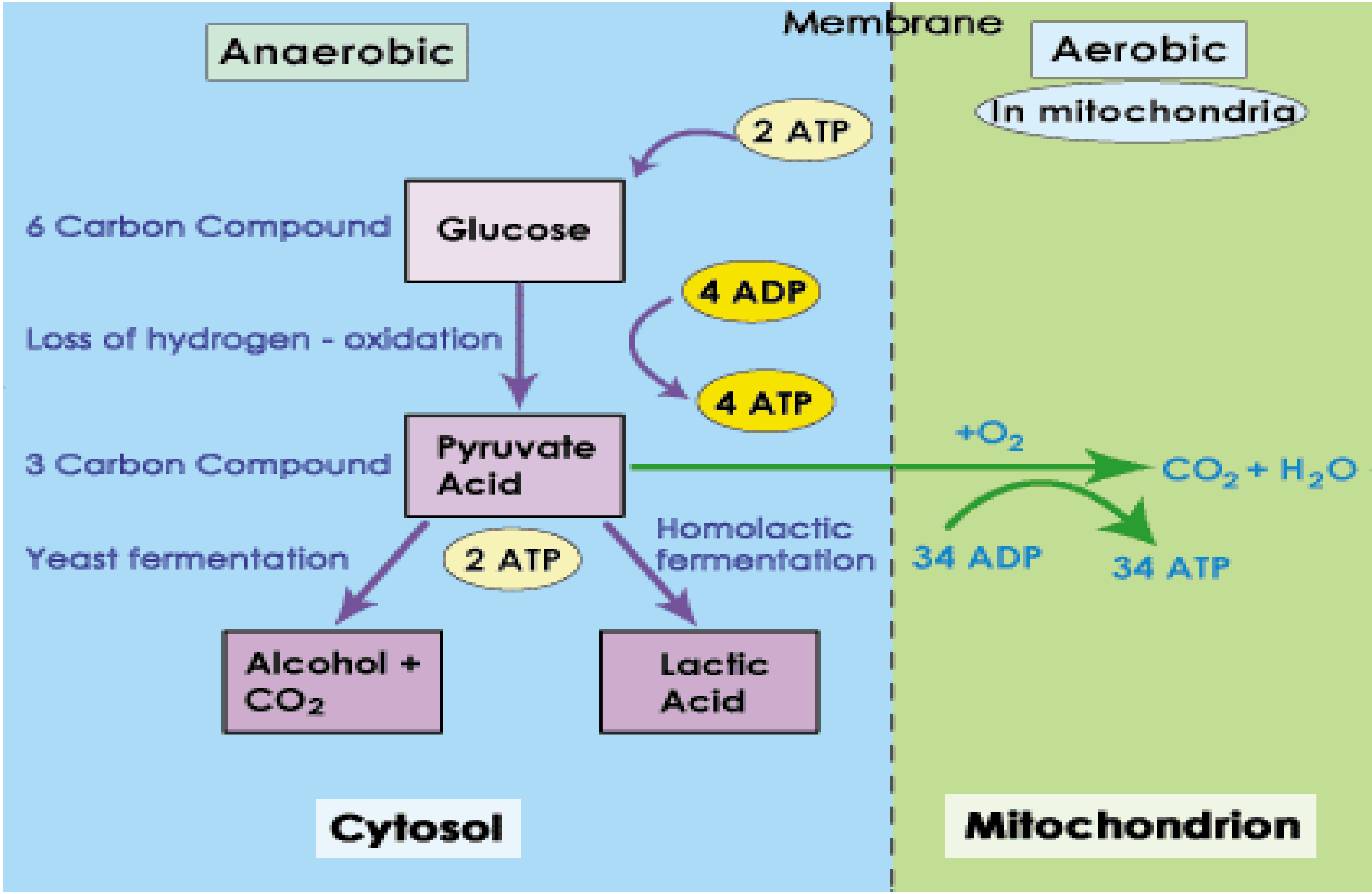
1- In cells with mitochondria & an adequate supply of oxygen
(***Aerobic glycolysis***)

- ***Pyruvate***: enters the mitochondria & is converted into acetyl CoA.
  Acetyl CoA enters citric acid cycle (Krebs cycle) to yield energy in the form of ATP

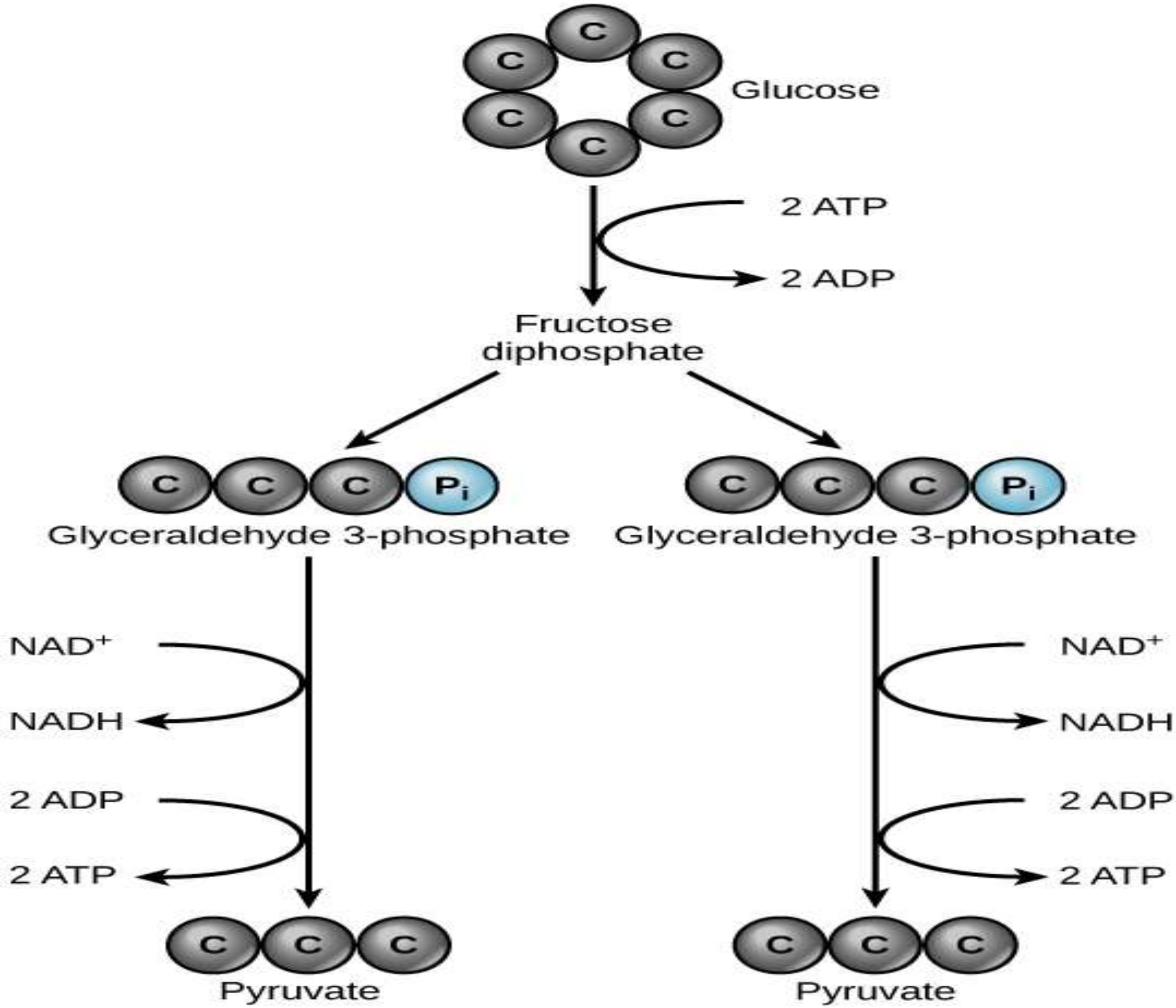
- ***NADH***: utilizes mitochondria & oxygen to yield energy

2- *In cells with no mitochondria or adequate oxygen (or Both)*
(***Anaerobic glycolysis***)

Lactate: formed from pyruvate (by utilizing NADH)

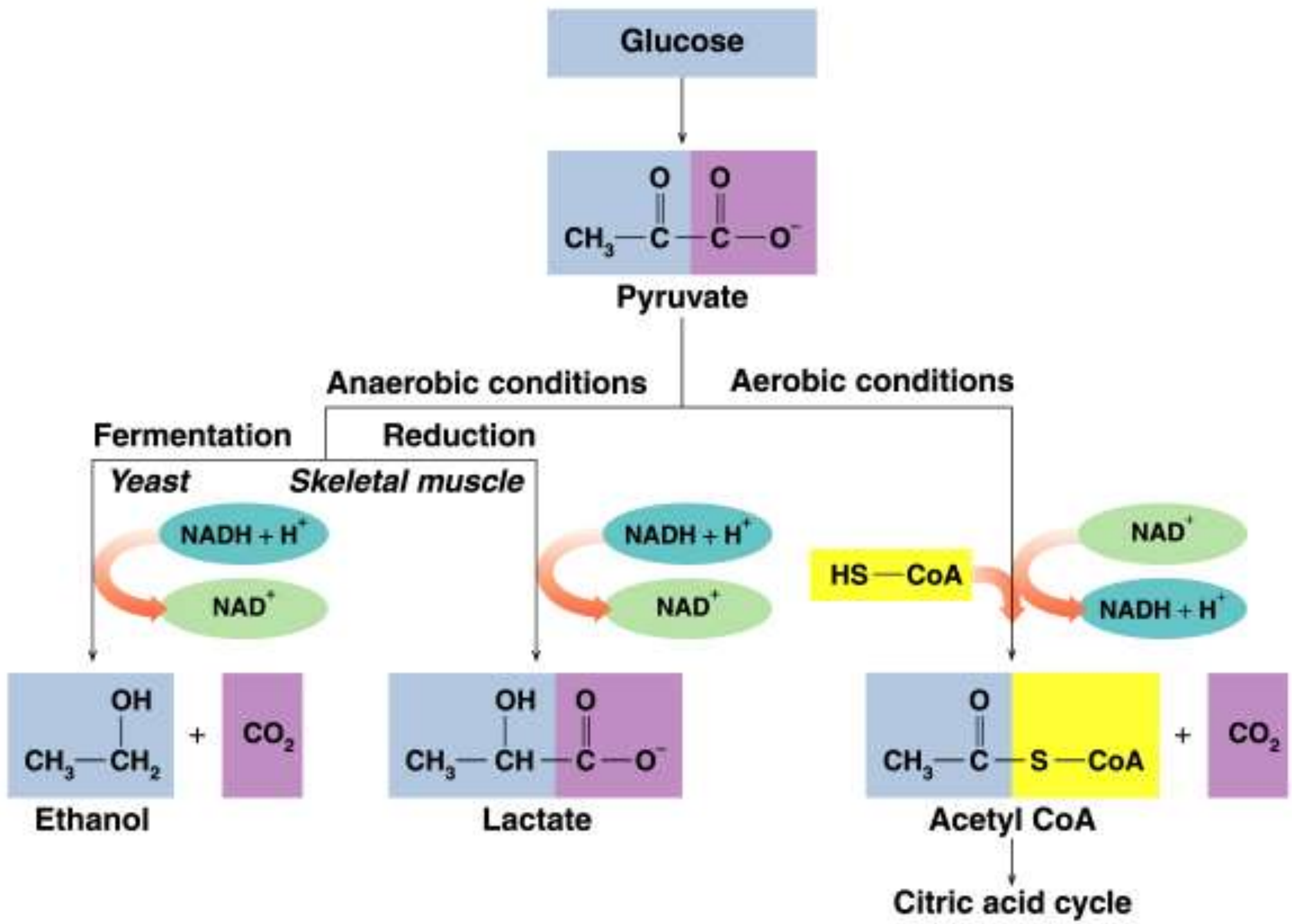


Anaerobic
Membrane
Aerobic
In mitochondria
2 ATP
6 Carbon Compound
Glucose
4 ADP
Loss of hydrogen - oxidation
4 ATP
3 Carbon Compound
Pyruvate Acid
$+O_2$
$CO_2 + H_2O$
Yeast fermentation
2 ATP
Homolactic fermentation
34 ADP
34 ATP
Alcohol + CO_2
Lactic Acid
Cytosol
Mitochondrion

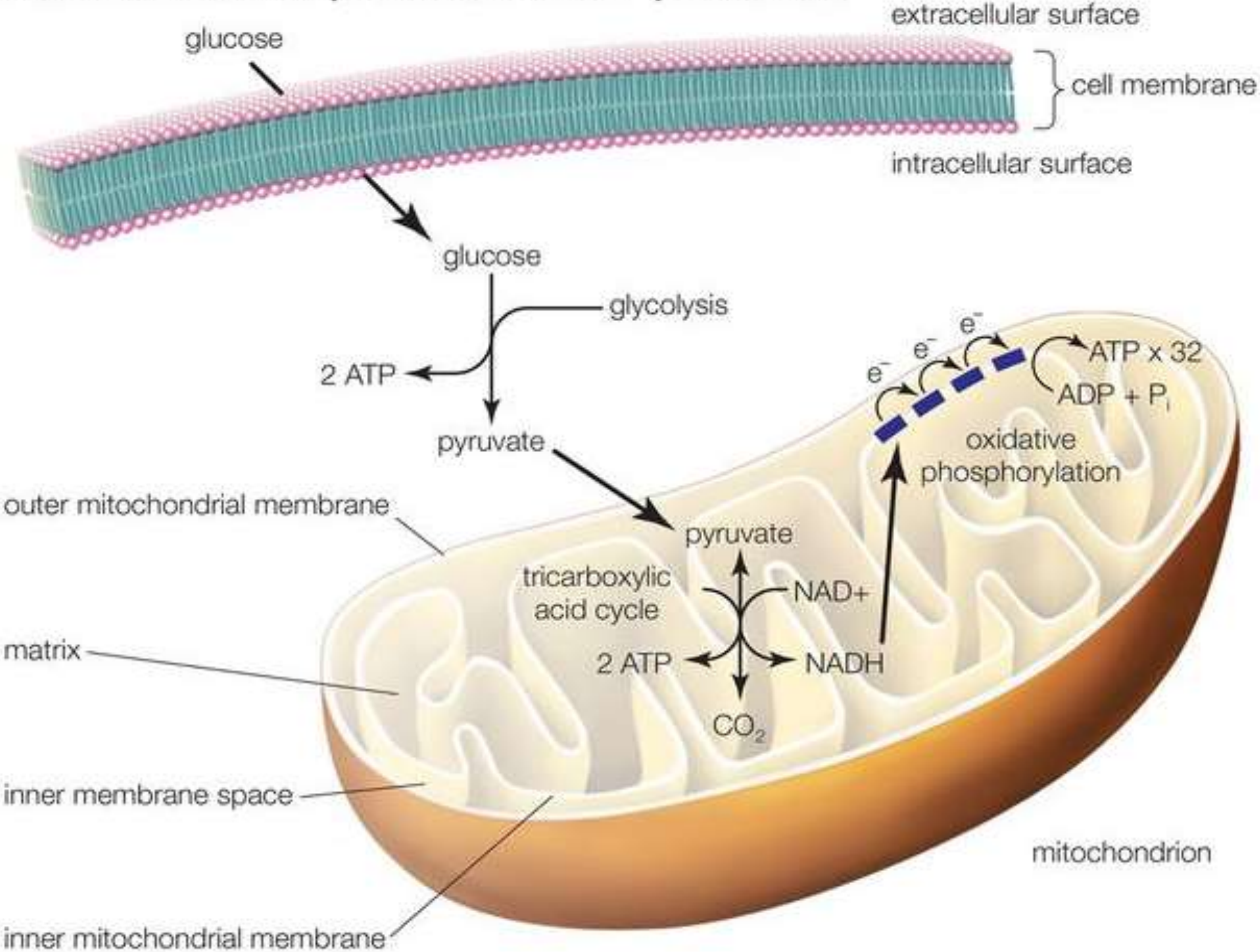


C
C
C
C
C
C
Glucose
2 ATP
2 ADP
Fructose diphosphate
C C C P_i
Glyceraldehyde 3-phosphate
C C C P_i
Glyceraldehyde 3-phosphate
NAD^+
NADH
2 ADP
2 ATP
NAD^+
NADH
2 ADP
2 ATP
C C C
Pyruvate
C C C
Pyruvate

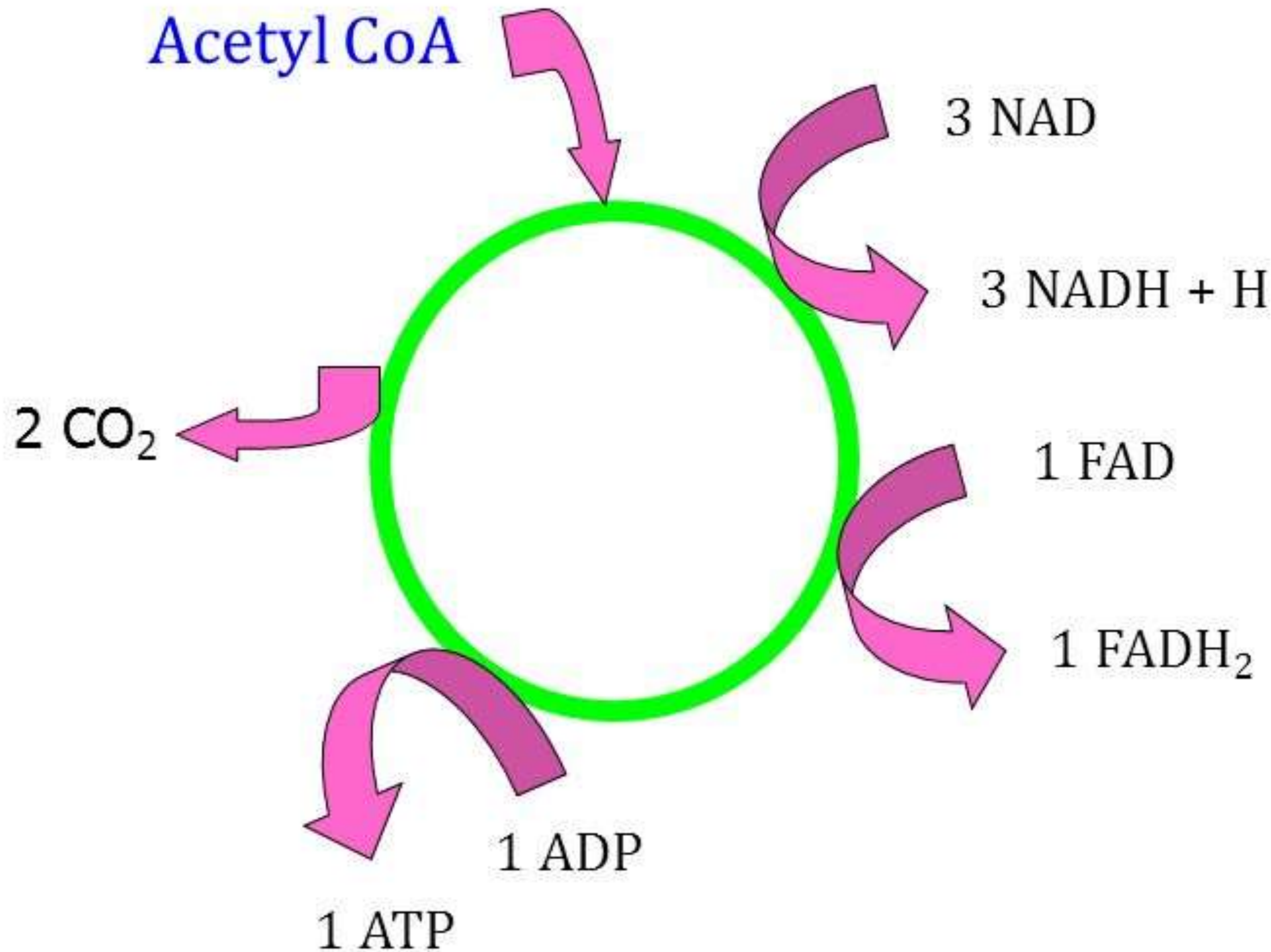
Pathways for Pyruvate

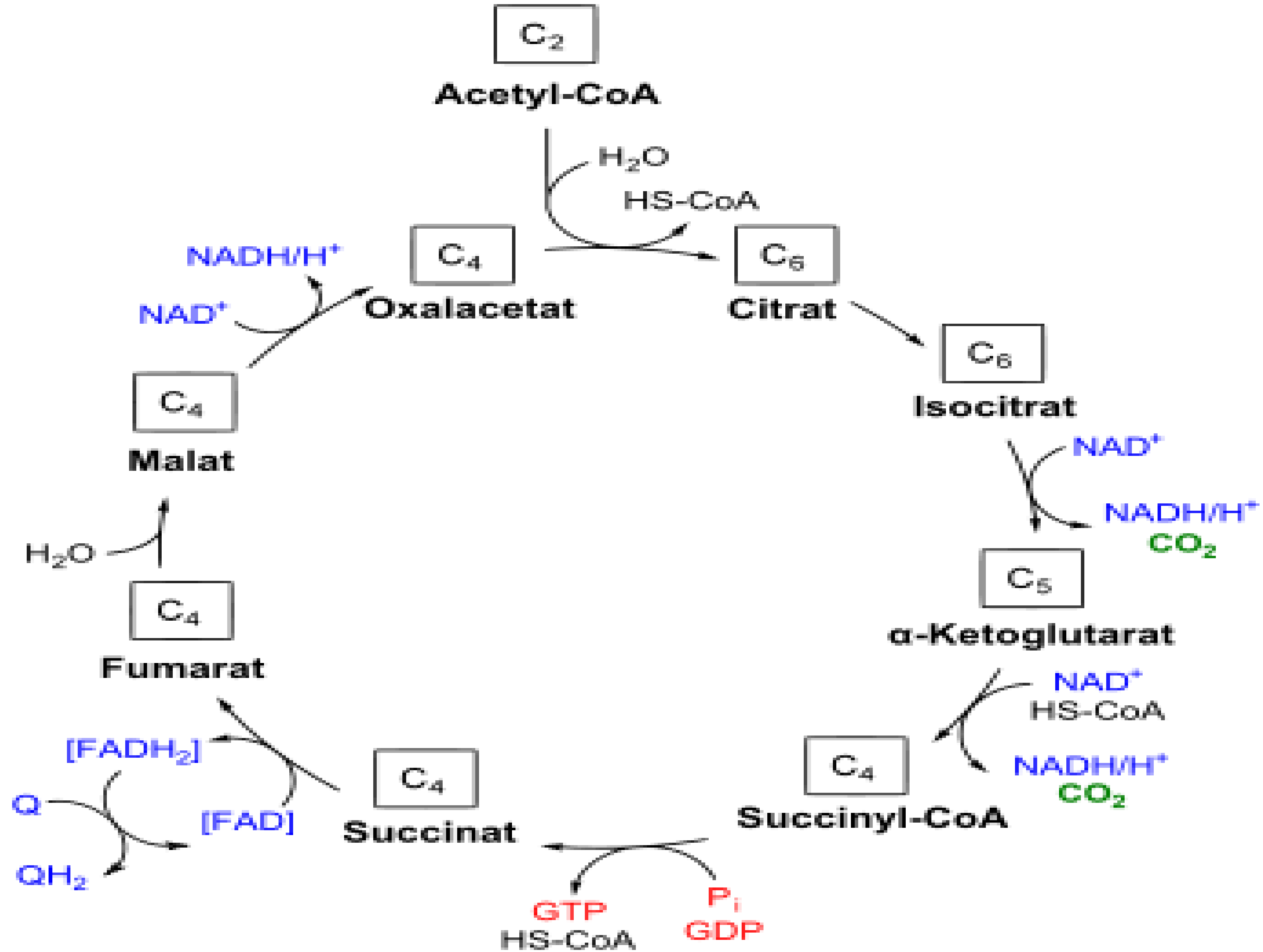


Basic overview of processes of ATP production



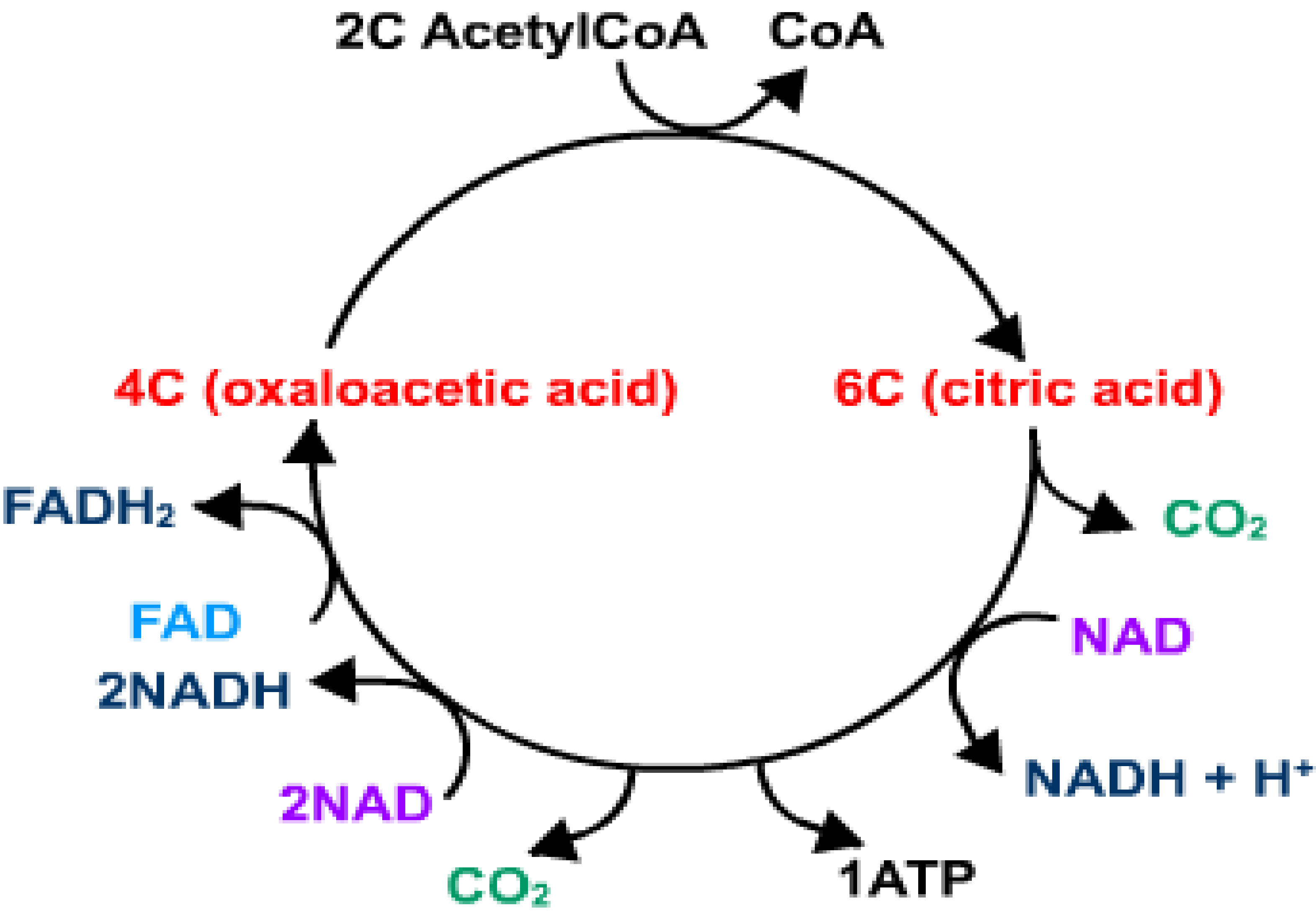
Citric Acid Cycle CYCLE - SUMMARY



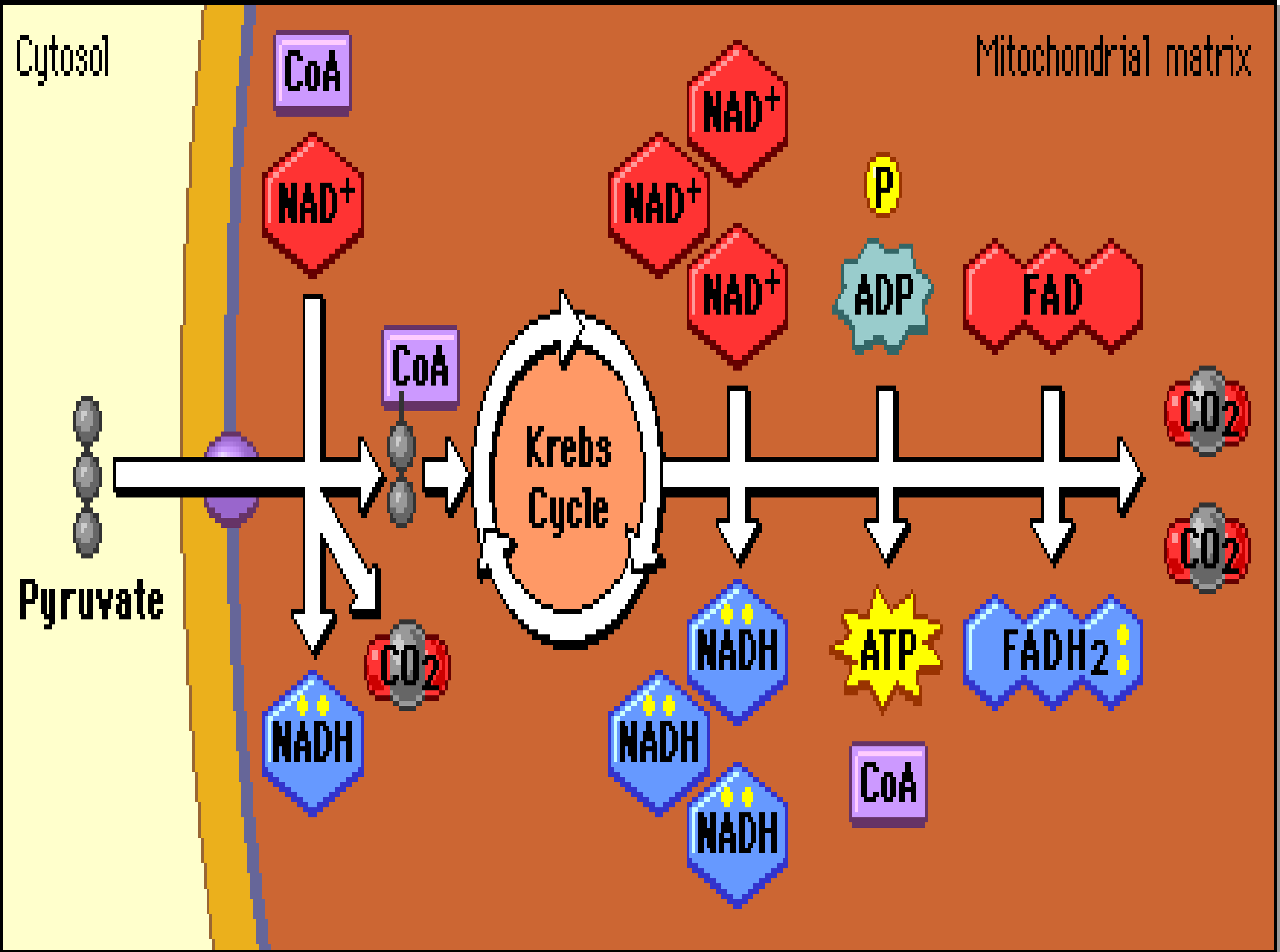


C_2
Acetyl-CoA
H_2O
HS-CoA
C_4
Oxalacetat
C_6
Citrat
C_6
Isocitrat
NAD^+
$NADH/H^+$
CO_2
C_5
α-Ketoglutarat
NAD^+
HS-CoA
$NADH/H^+$
CO_2
C_4
Succinyl-CoA
P_i
GDP
GTP
HS-CoA
C_4
Succinat
[FAD]
[$FADH_2$]
Q
QH_2
C_4
Fumarat
H_2O
C_4
Malat
NAD^+
$NADH/H^+$

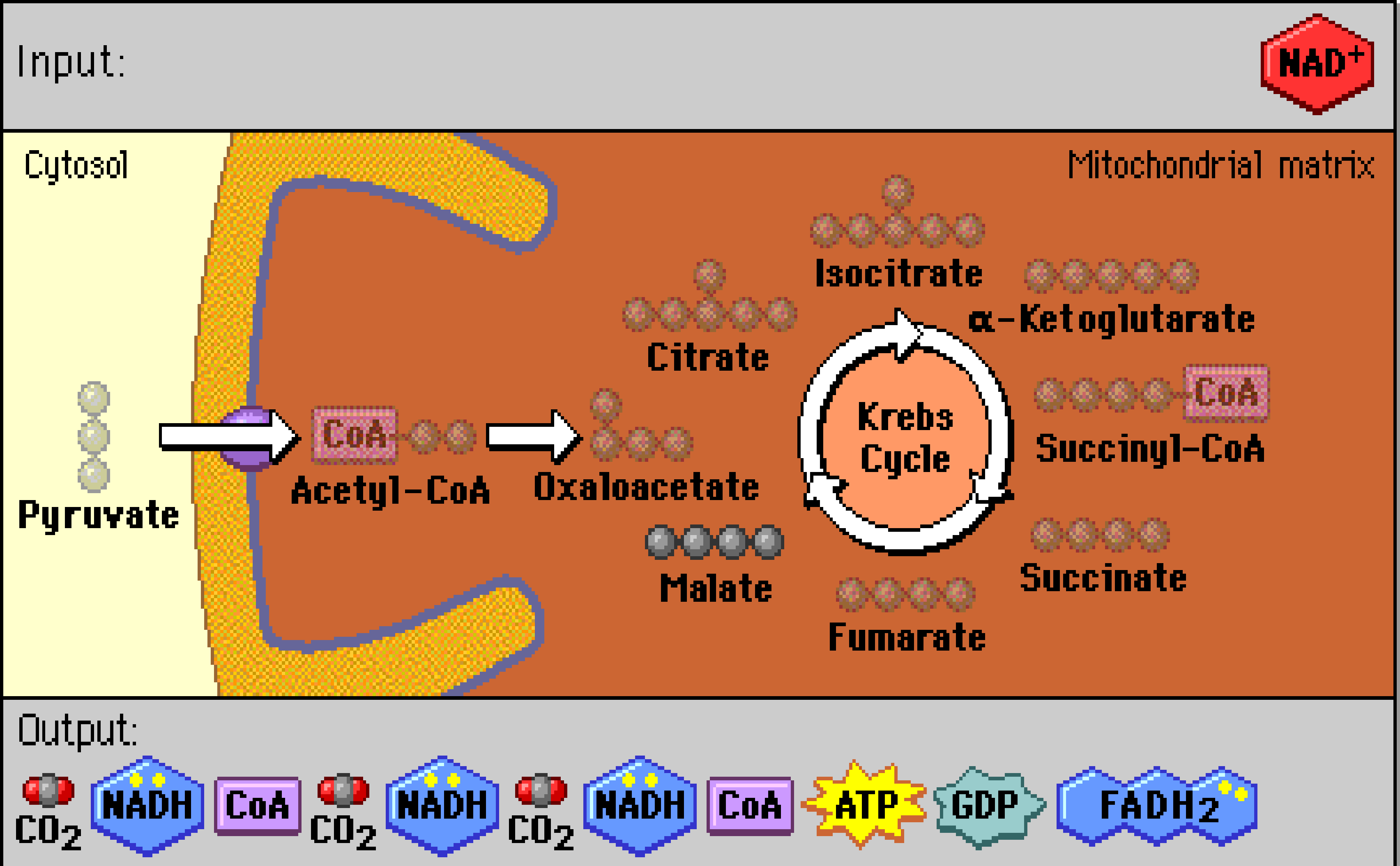
Krebs cycle



2C AcetylCoA
CoA
4C (oxaloacetic acid)
6C (citric acid)
FADH₂
CO₂
FAD
NAD
2NADH
NADH + H⁺
2NAD
CO₂
1ATP

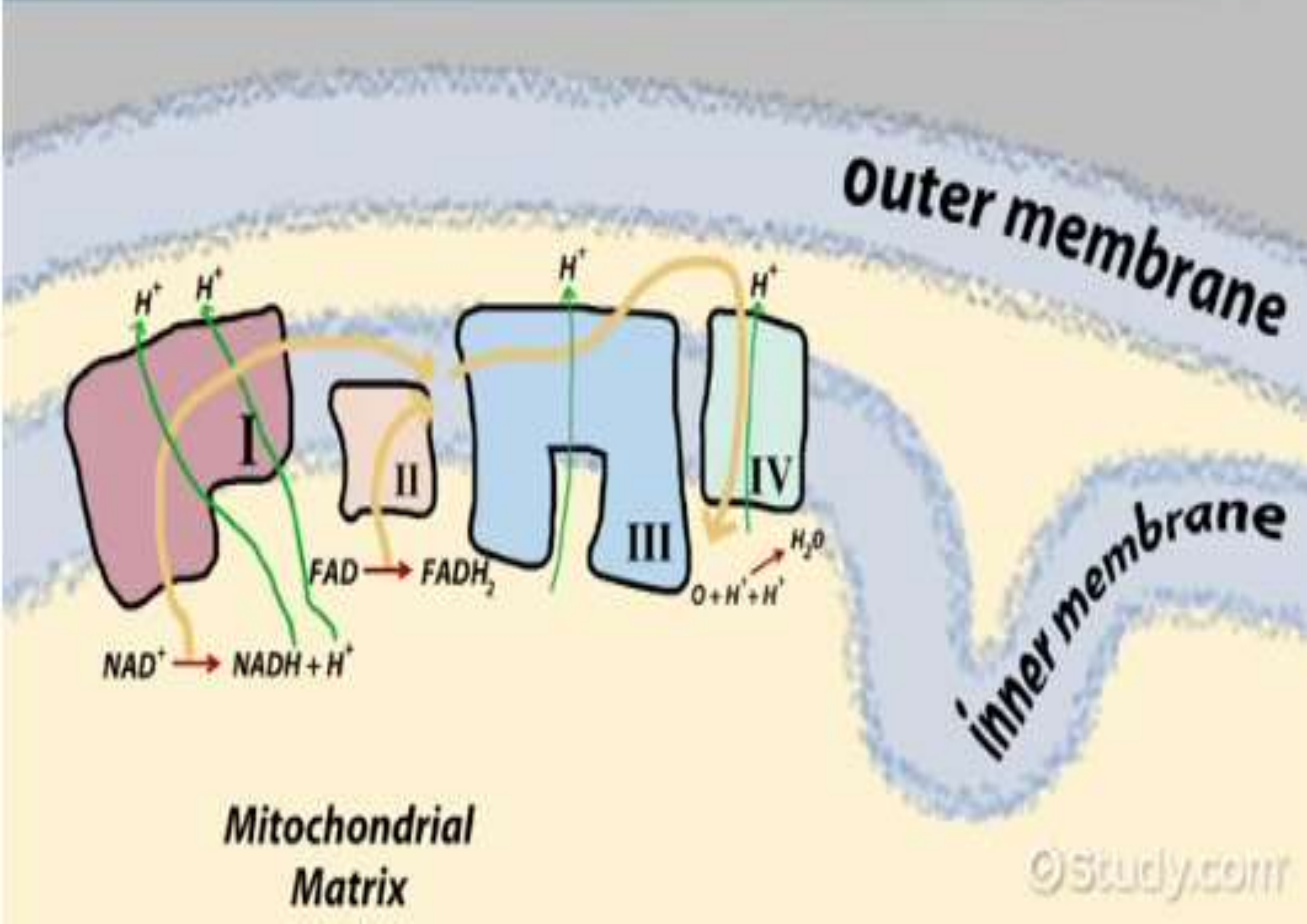


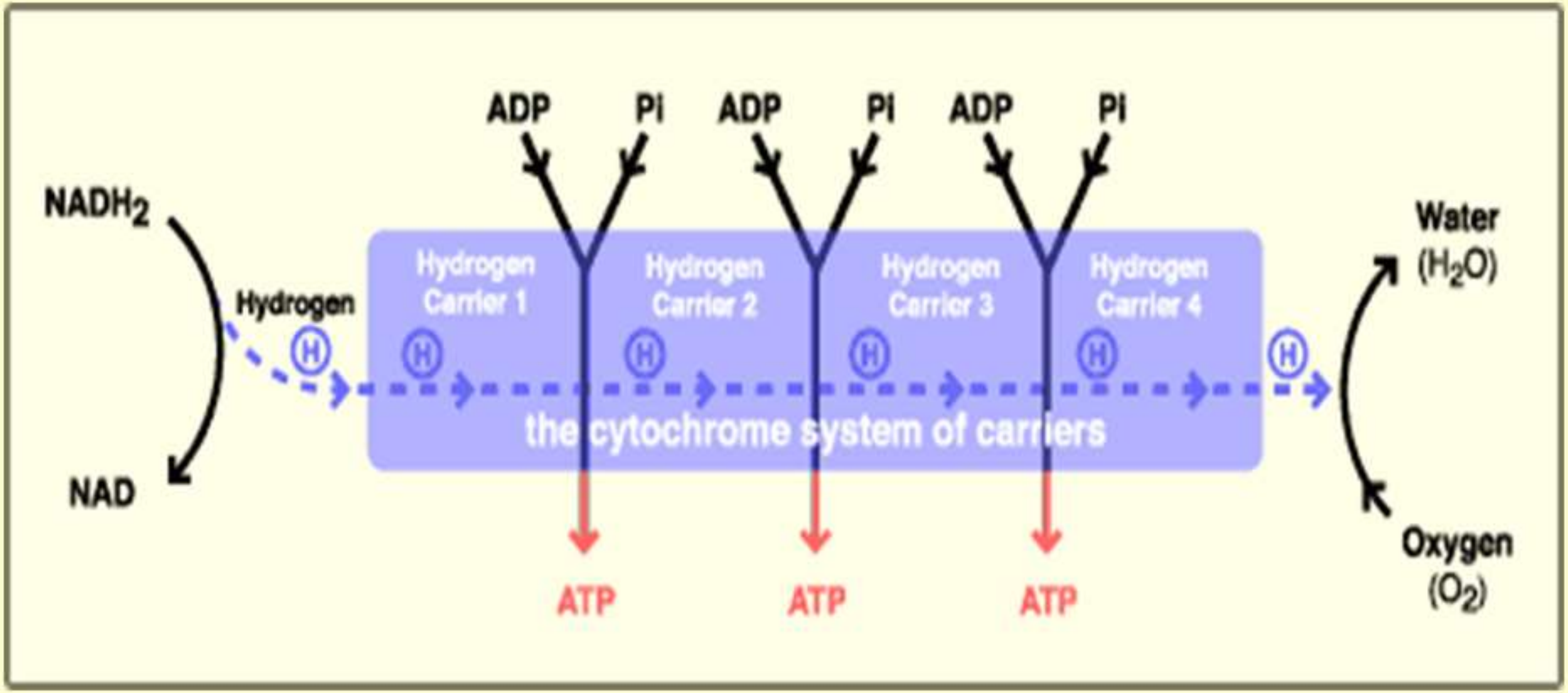
Cytosol
Mitochondrial matrix
CoA
NAD+
NAD+
NAD+
NAD+
P
ADP
FAD
CoA
Krebs Cycle
CO2
CO2
Pyruvate
CO2
NADH
NADH
ATP
FADH2
NADH
NADH
CoA



Succinate is oxidized by FAD to produce FADH2 and fumarate.

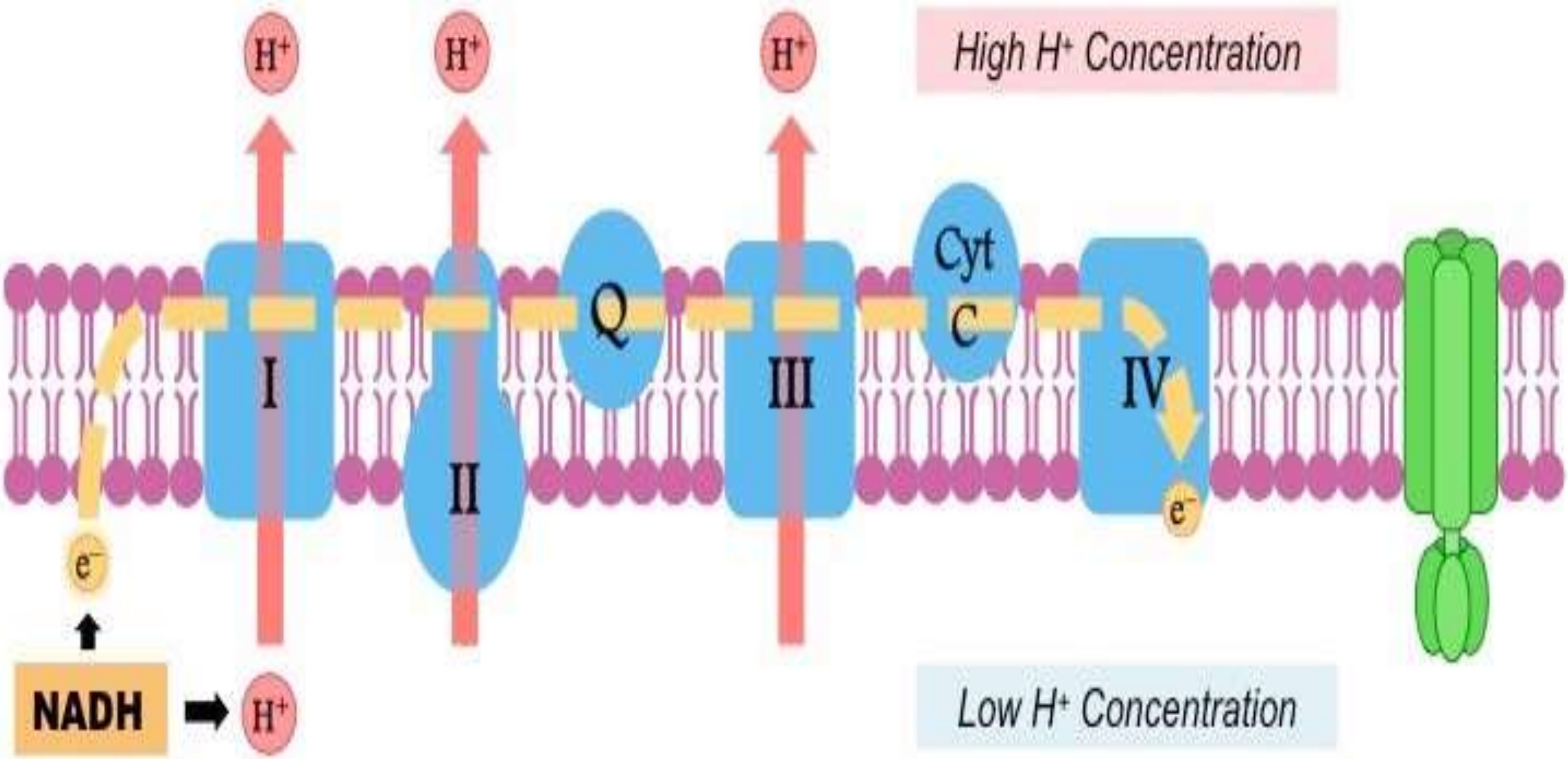
STEPS OF THE ELECTRON TRANSPORT CHAIN





ADP
Pi
ADP
Pi
ADP
Pi
NADH2
NAD
Hydrogen
Hydrogen Carrier 1
Hydrogen Carrier 2
Hydrogen Carrier 3
Hydrogen Carrier 4
H
the cytochrome system of carriers
ATP
ATP
ATP
Water (H2O)
Oxygen (O2)

Step One: Generating a Proton Motive Force (PMF)



High energy electrons released by hydrogen carriers are shuttled through the electron transport chain
The released energy is used to translocate H^+ ions from the matrix, creating an electrochemical gradient

Summary of Cellular Respiration p.16

Reaction	***Location***	***Purpose***	***ATP YIELD***
Glycolysis	CYTOPLASM	SPLIT Glucose into 2 Pyruvate	2 ATP
Kreb Cycle	MATRIX	USE PYRUVATE YIELDS CO2 FILLS ELECTRON CARRIERS	2 ATP
Electron Transport Chain	CRISTAE INNER MEMBRANE	CONVERT ELECTRONS TO ATP, O2 accepts electrons = WATER	32 ATP