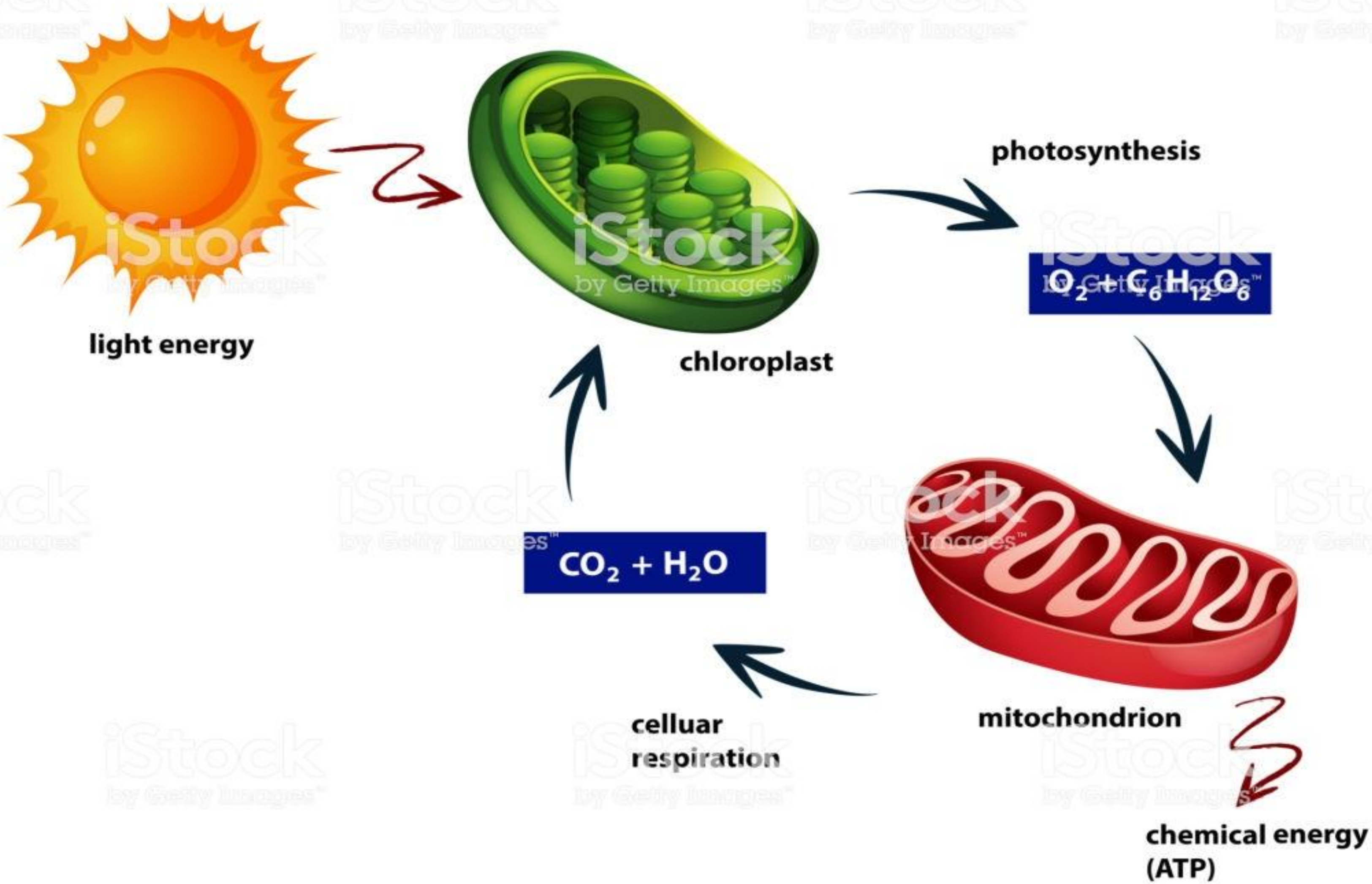
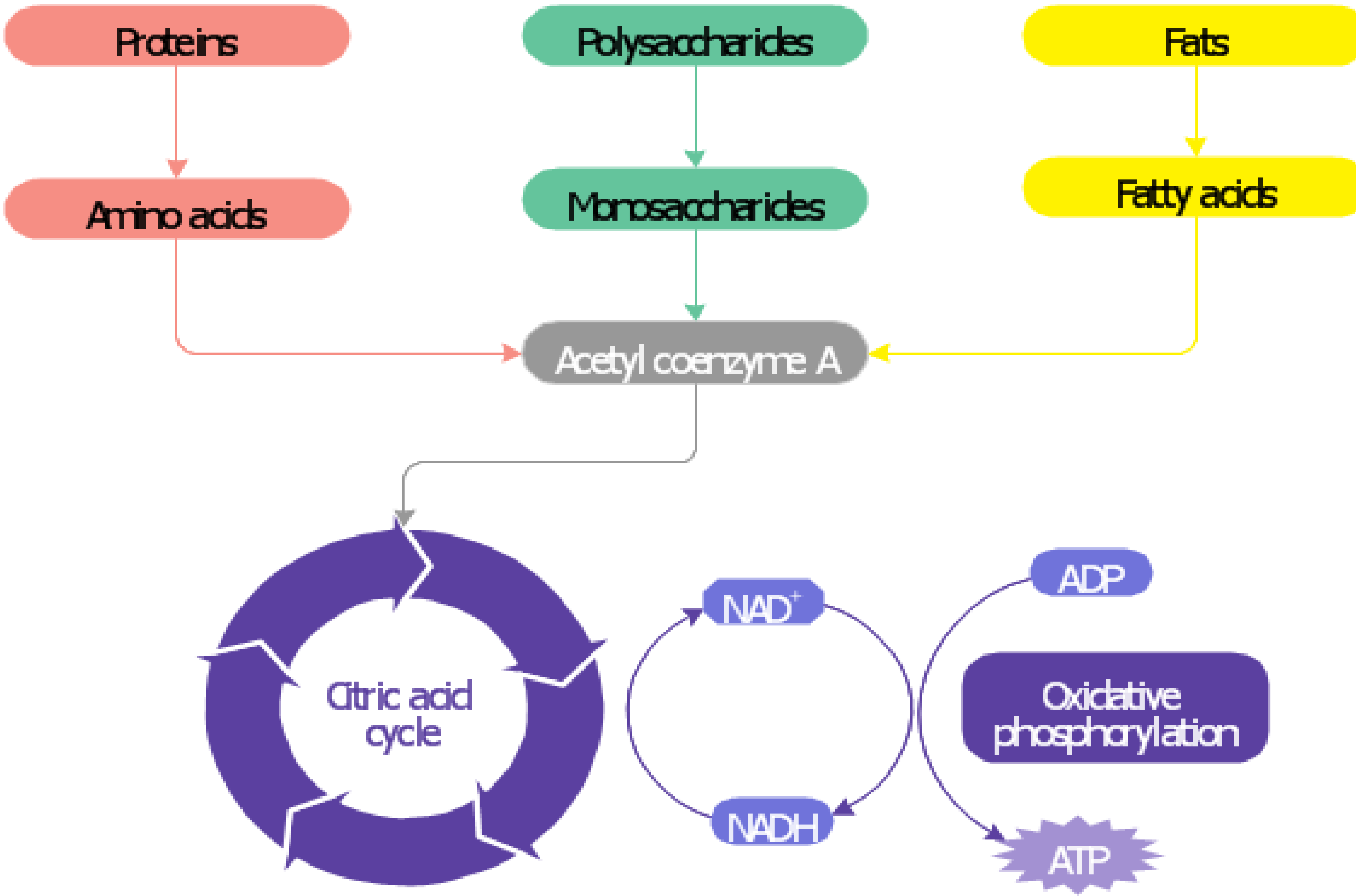
Catabolism

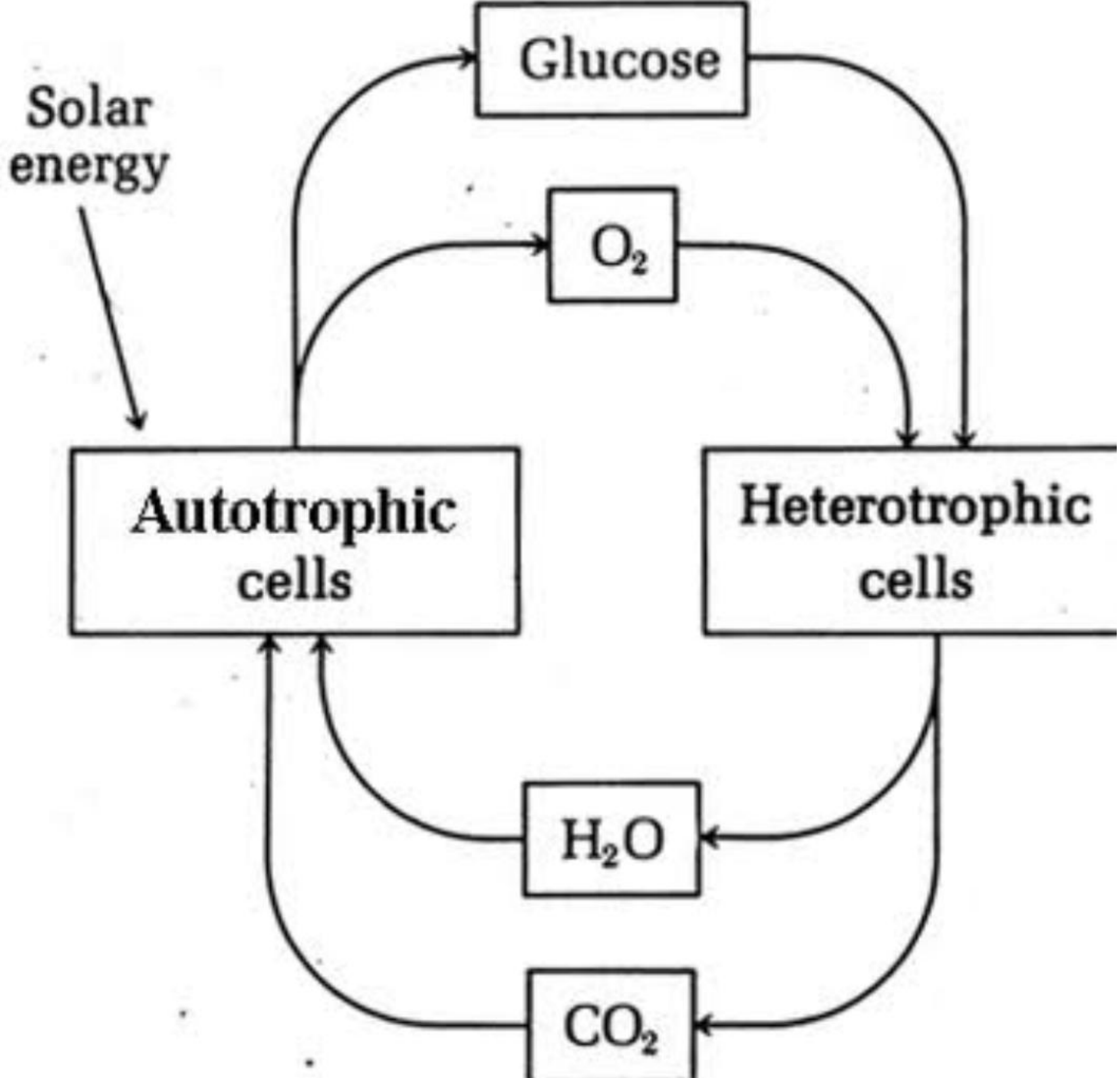
Lecture 9

Cellular Respiration



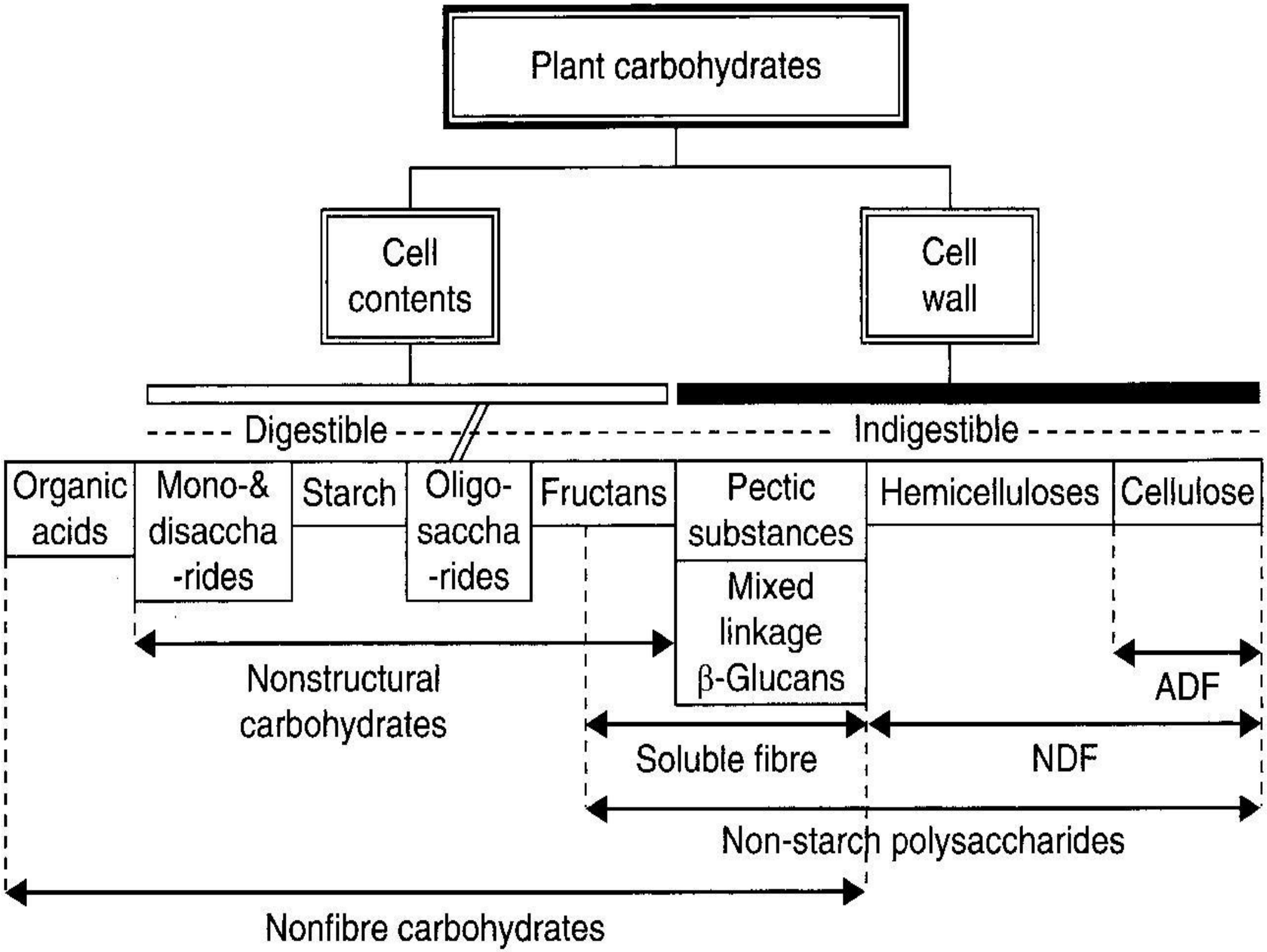
Schematic of catabolism




Glucose
Solar energy
O_2
Autotrophic cells
Heterotrophic cells
H_2O
CO_2

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)

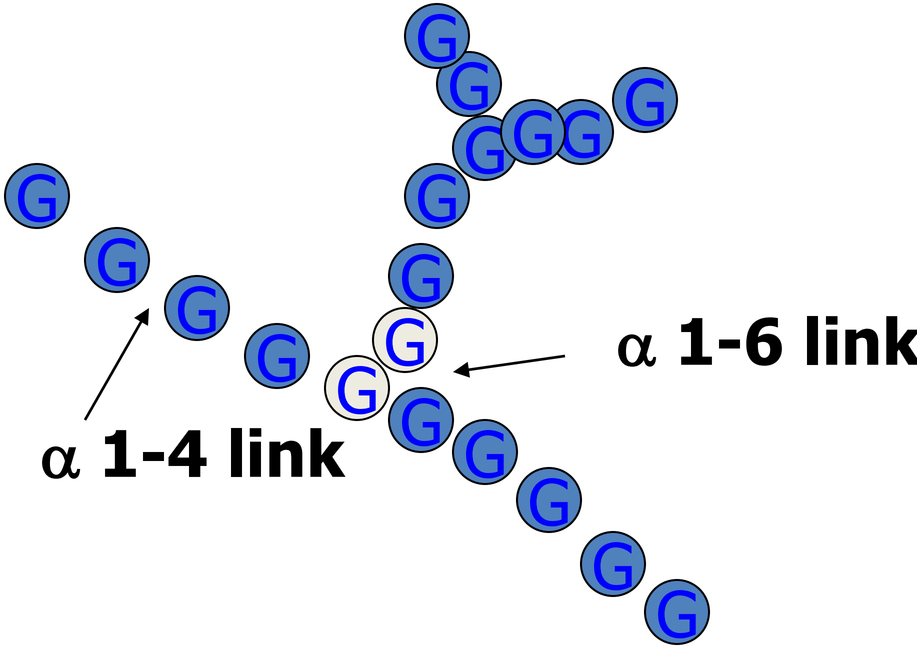
Starch

Major storage carbohydrate in higher plants

Amylose – long straight glucose chains (α1-4)

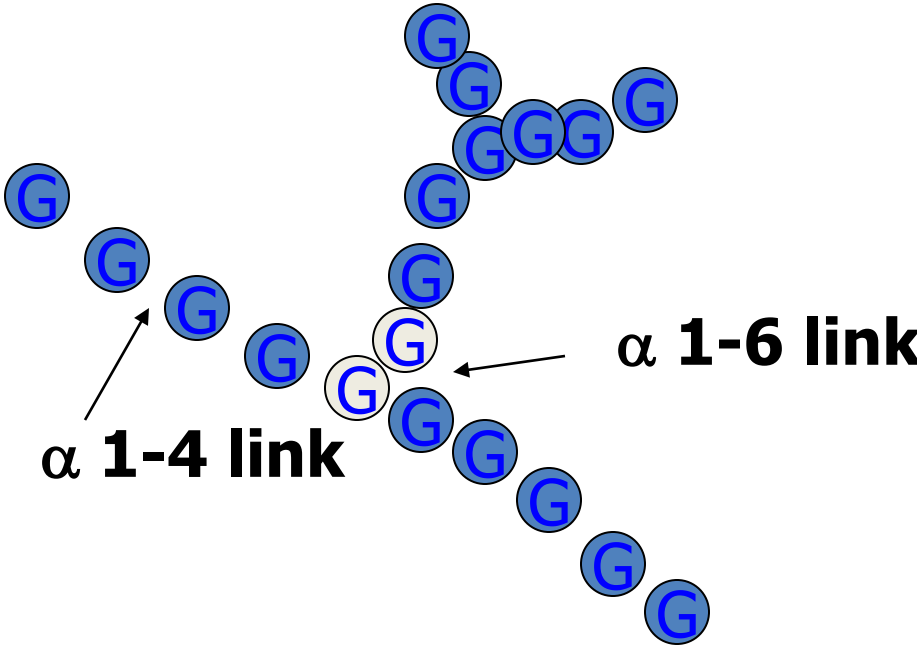
Amylopectin – branched every 24-30 glucose residues (α 1-6)

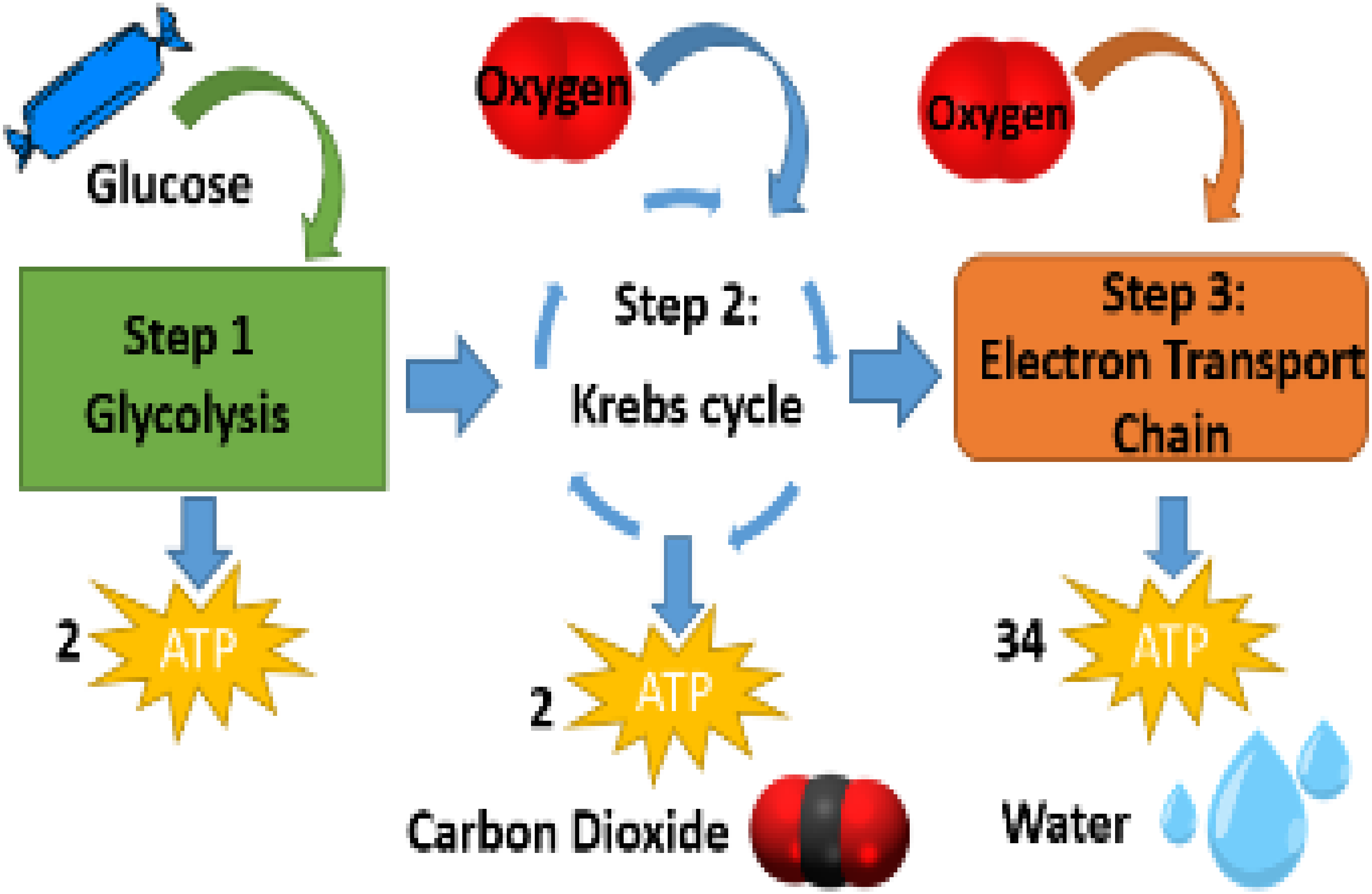
Provides 80% of dietary calories in humans worldwide



Glycogen

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




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

Stage 1: Digestion of Carbohydrates

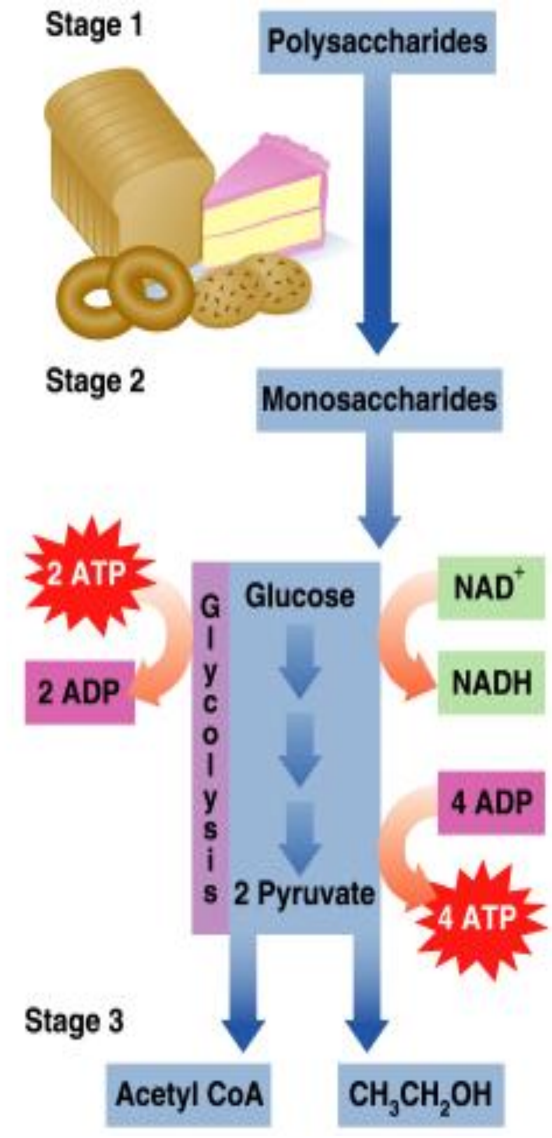
In Stage 1, the digestion of carbohydrates

- 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.

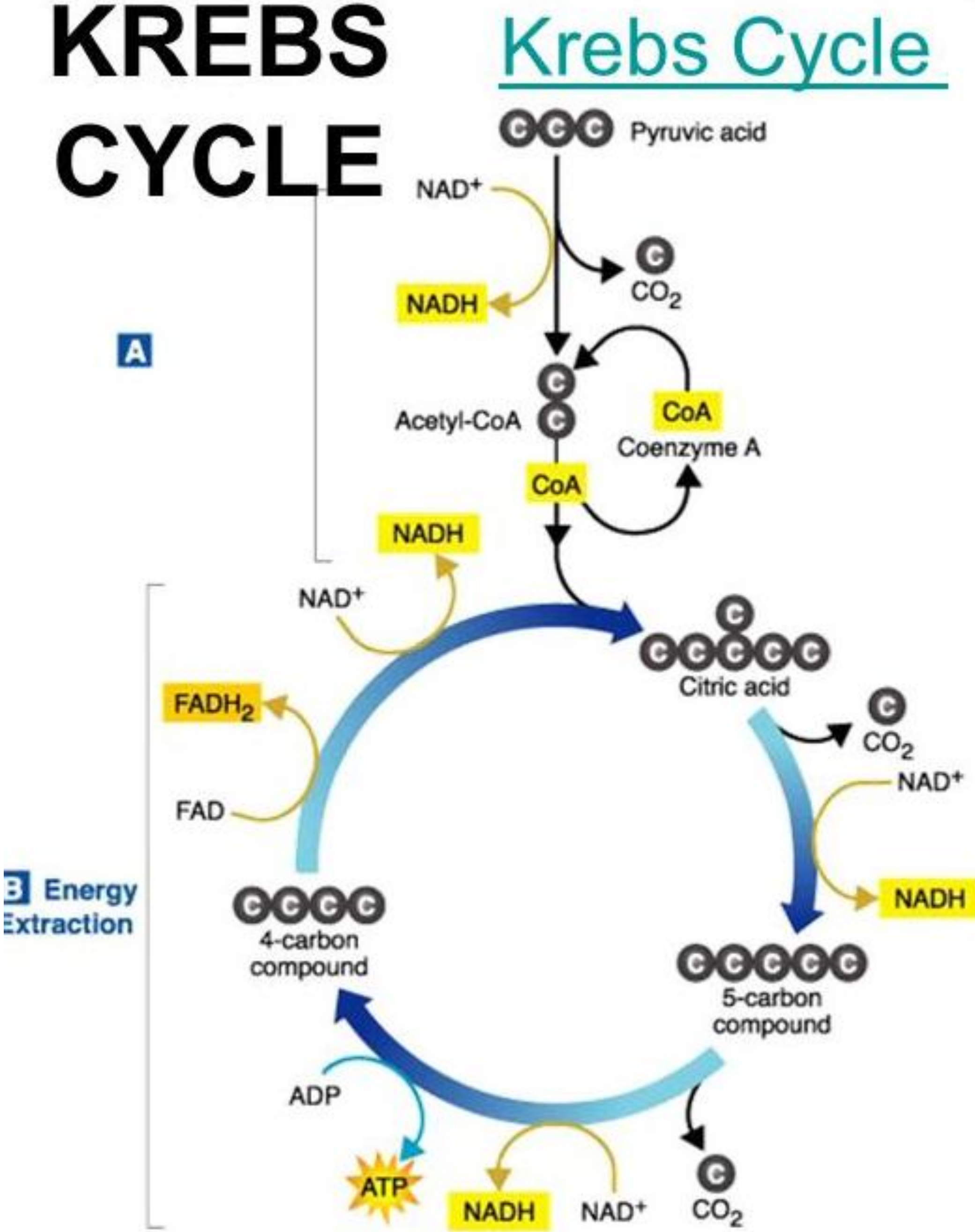
Stage 2: Glycolysis

Stage 2: Glycolysis

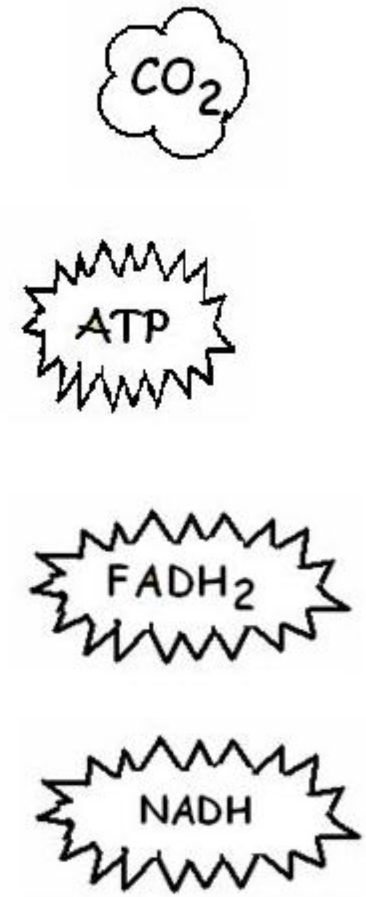
- Is a metabolic pathway that uses glucose, a digestion product.
- Degrades six-carbon glucose molecules to three-carbon. pyruvate molecules.
- Is an anaerobic (no oxygen) process.

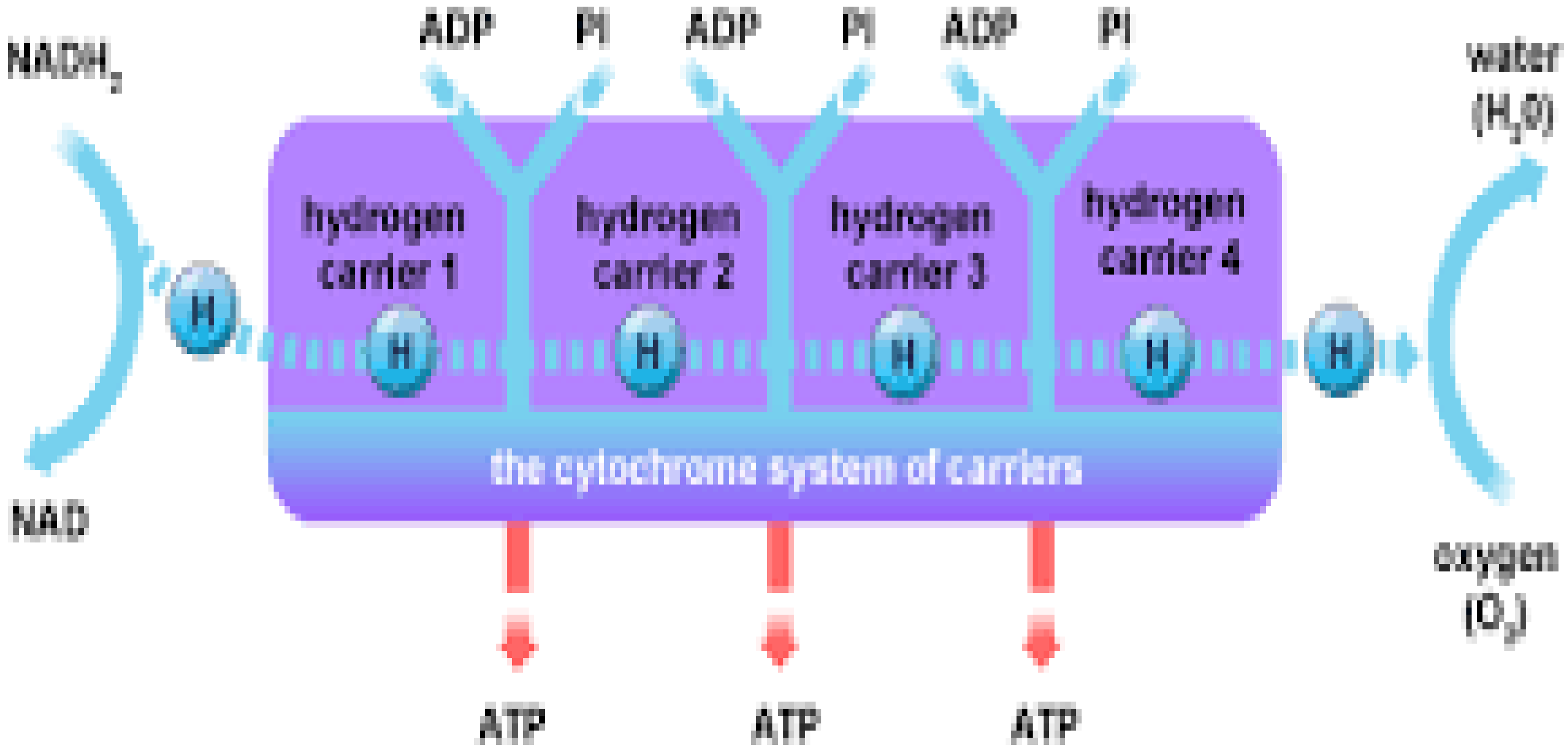


KREBS CYCLE

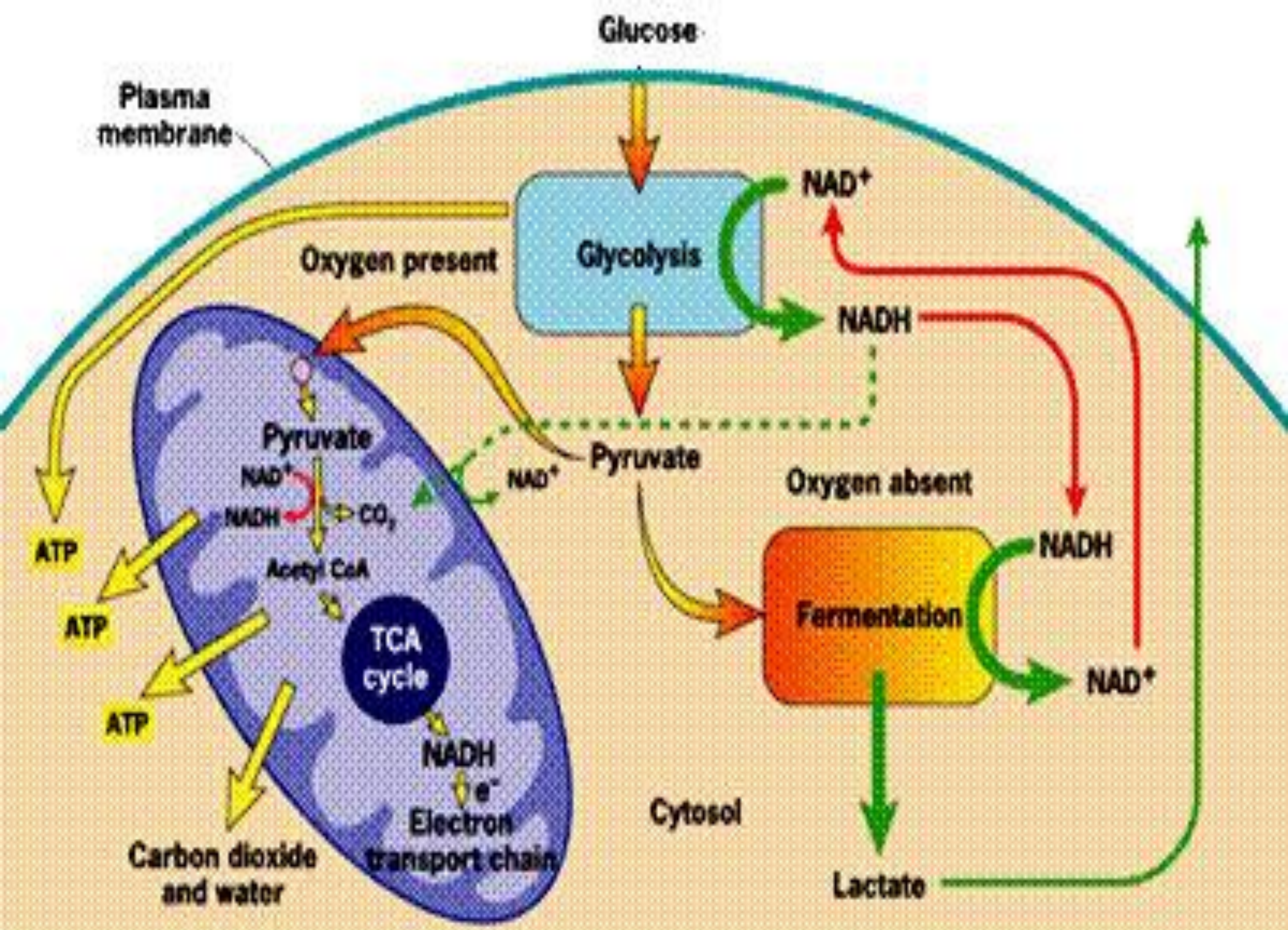


KREBS CYCLE PRODUCES



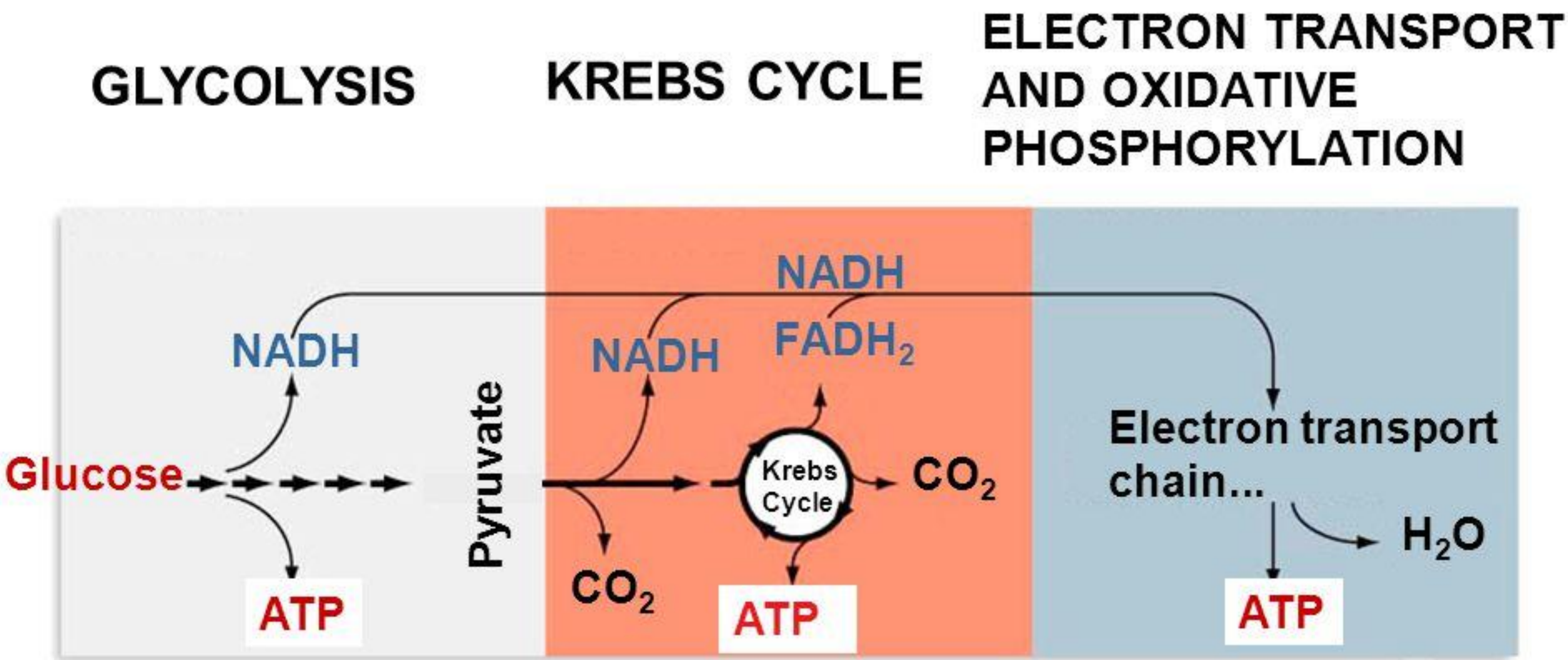


ADP
Pi
ADP
Pi
ADP
Pi
$NADH_2$
water
(H_2O)
hydrogen carrier 1
hydrogen carrier 2
hydrogen carrier 3
hydrogen carrier 4
H
H
H
H
H
H
NAD
the cytochrome system of carriers
oxygen
(O_2)
ATP
ATP
ATP



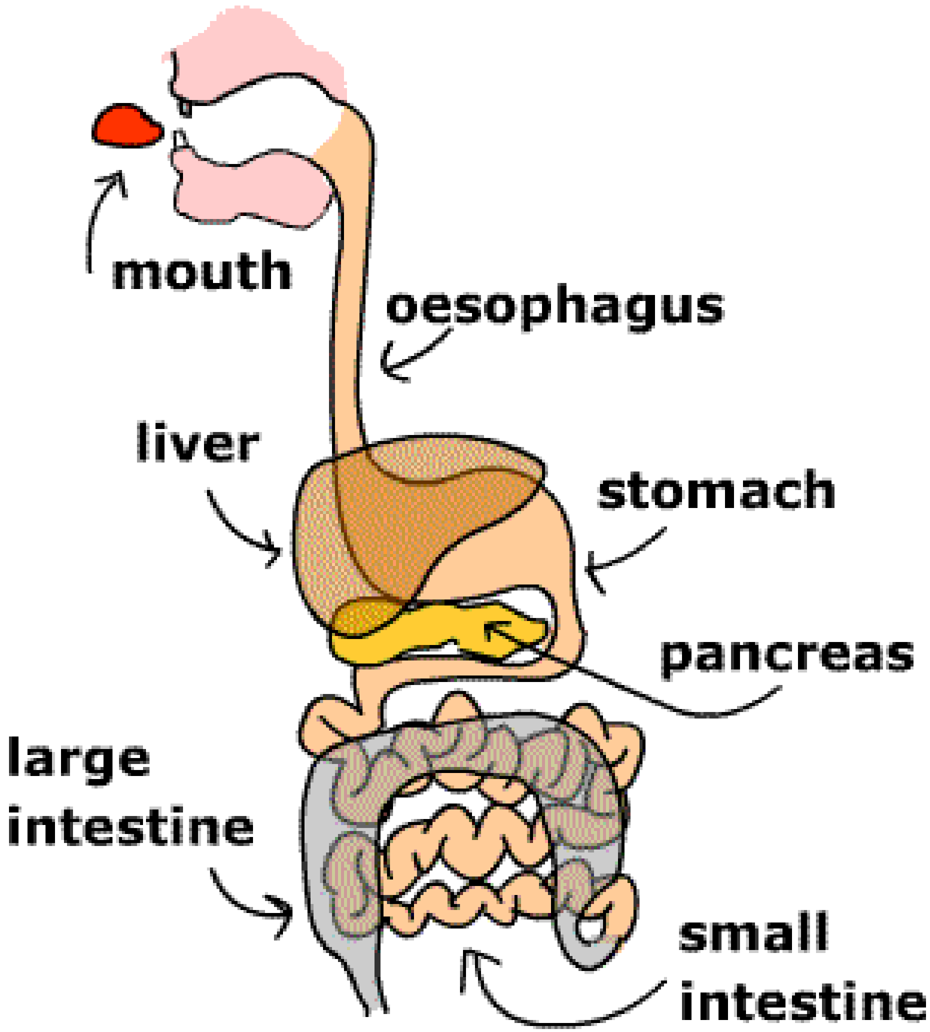
Glucose
Plasma membrane
Glycolysis
NAD+
NADH
Oxygen present
Pyruvate
NAD+
NADH
CO_2
Acetyl CoA
TCA cycle
NADH
e-
Electron transport chain
ATP
ATP
ATP
Carbon dioxide and water
NAD+
Pyruvate
Oxygen absent
NADH
Fermentation
NAD+
Cytosol
Lactate

Cell Respiration is separated into 3 stages

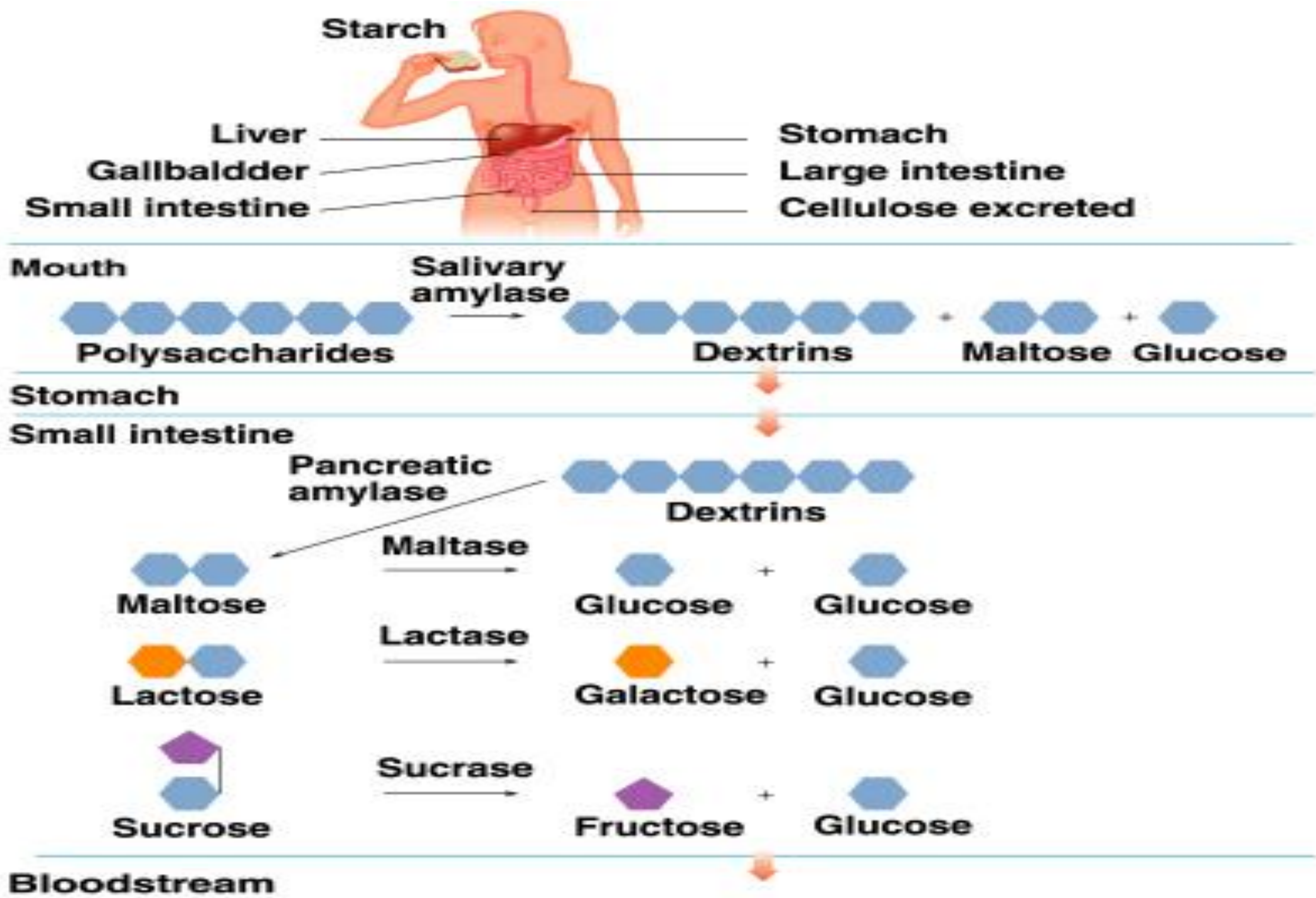


Energy/electrons are transferred from glucose to convert NAD^+ to NADH, which is used in the ETC to make ATP

Nutrition and digestion



Digestion of Carbohydrates

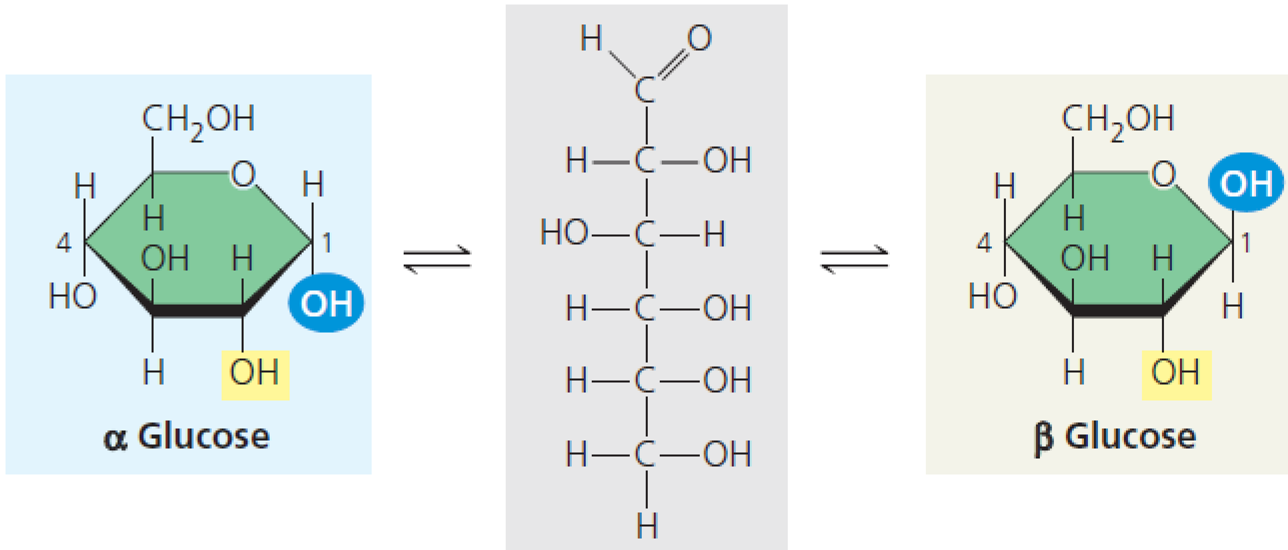


Digestion of Carbohydrates

- 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

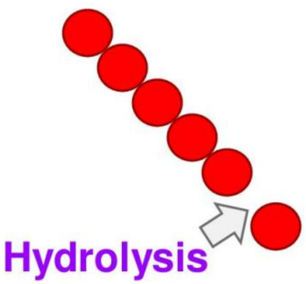
α and β glucose ring structures. These two interconvertible forms of glucose differ in the placement of the hydroxyl group (highlighted in blue) attached to the number 1 carbon.



Starch: Amylose and Amylopectin

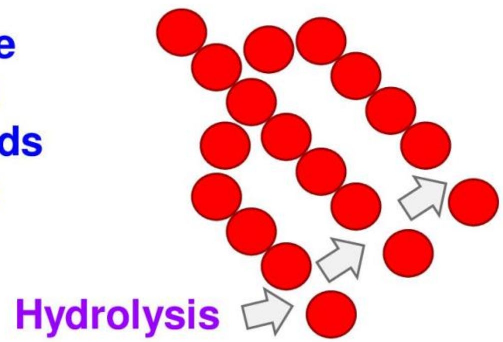
Starch is synthesised in plant in two main compounds, amylose and amylopectin. These types of starch have quite different structures, and this affects the rate of digestion, and can have a profound affect on the glycaemic index of the food containing the starch.

Amylose



Amylose is structured as straight chains of glucose units. Glucose is hydrolysed one at a time from the open ends during digestion. This produces a slow digestion rate.

Amylopectin



Amylopectin is a branched structure, similar to animal glycogen. The branched structure allows more than one glucose to be hydrolysed at a time, thus increasing the rate of digestion significantly.

Legumes contain a high content of amylose which may explain their slow rate of digestion. However, there may be other reasons to explain why legumes are resistant to digestion, including a high protein content and as the presence of enzyme inhibitors.

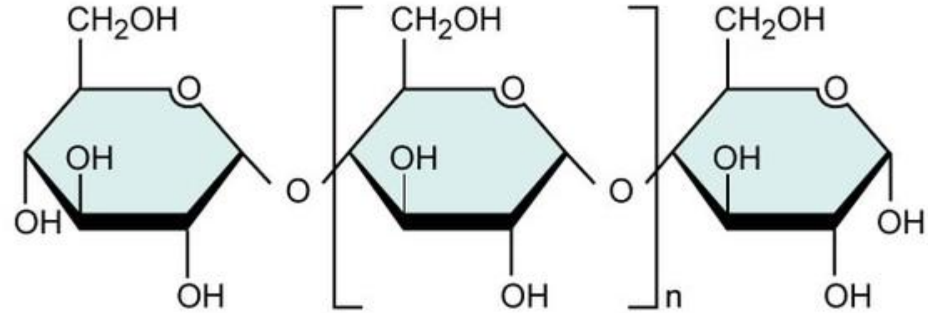
Amylose and amylopectin

- Two different glucose polysaccharides can be isolated from most starches: amylose and amylopectin.
- Amylose is a straight chain glucose polymer and usually accounts for 15-20% of the starch.
- Amylopectin is a highly branched glucose polymer and accounts for about 80-85% of the starch.

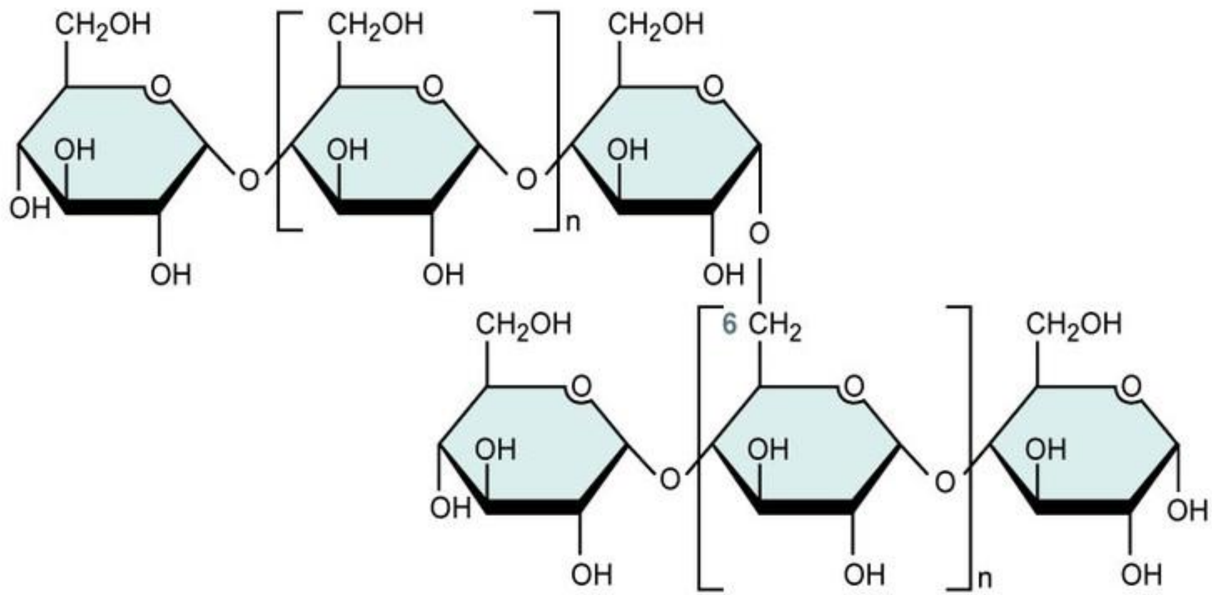
Amylose and amylopectin

- The glycosidic linkages in amylose are α 1-4, but in amylopectin they are α 1-4 and α 1-6.
- These alpha linkages can be broken down in the human digestive tract by the enzyme amylase.
- Starches contained in potatoes, rice, corn, wheat, etc. are major food sources.

Amylose



Amylopectin



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

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

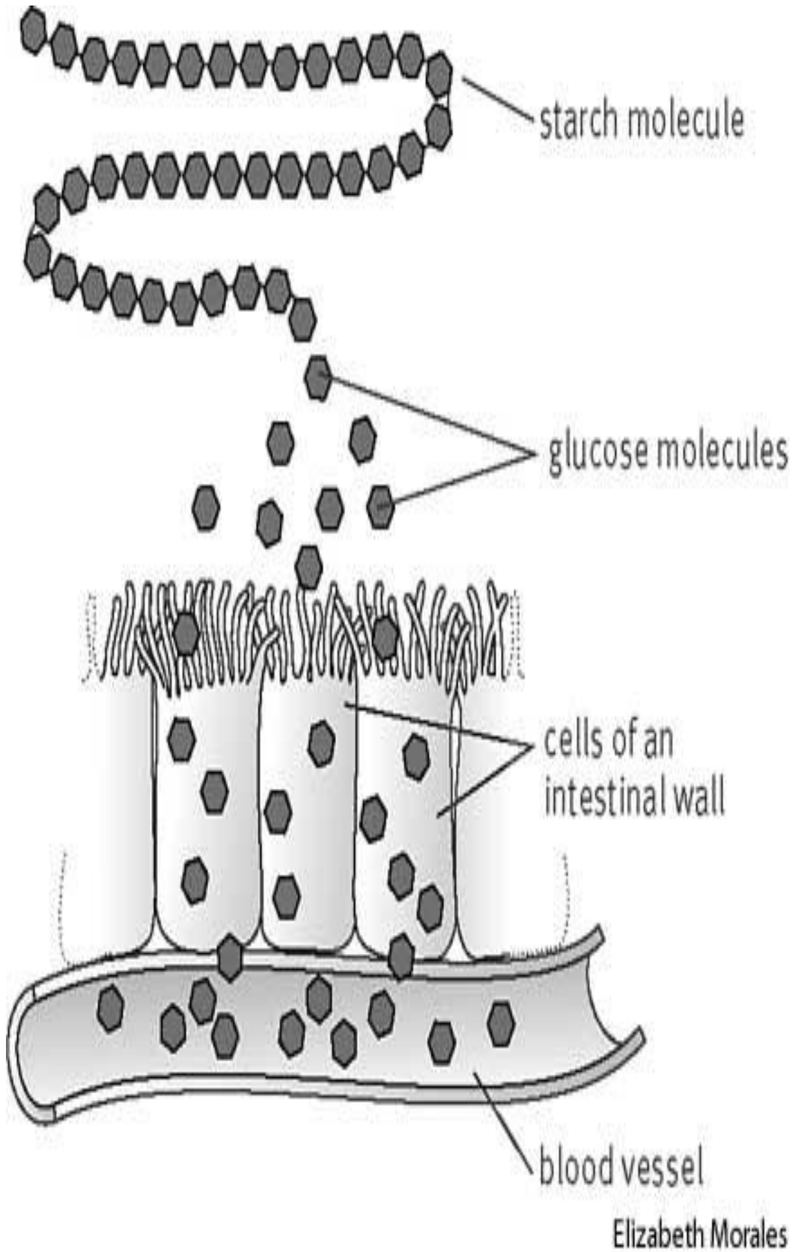
Digestion in Large Intestine

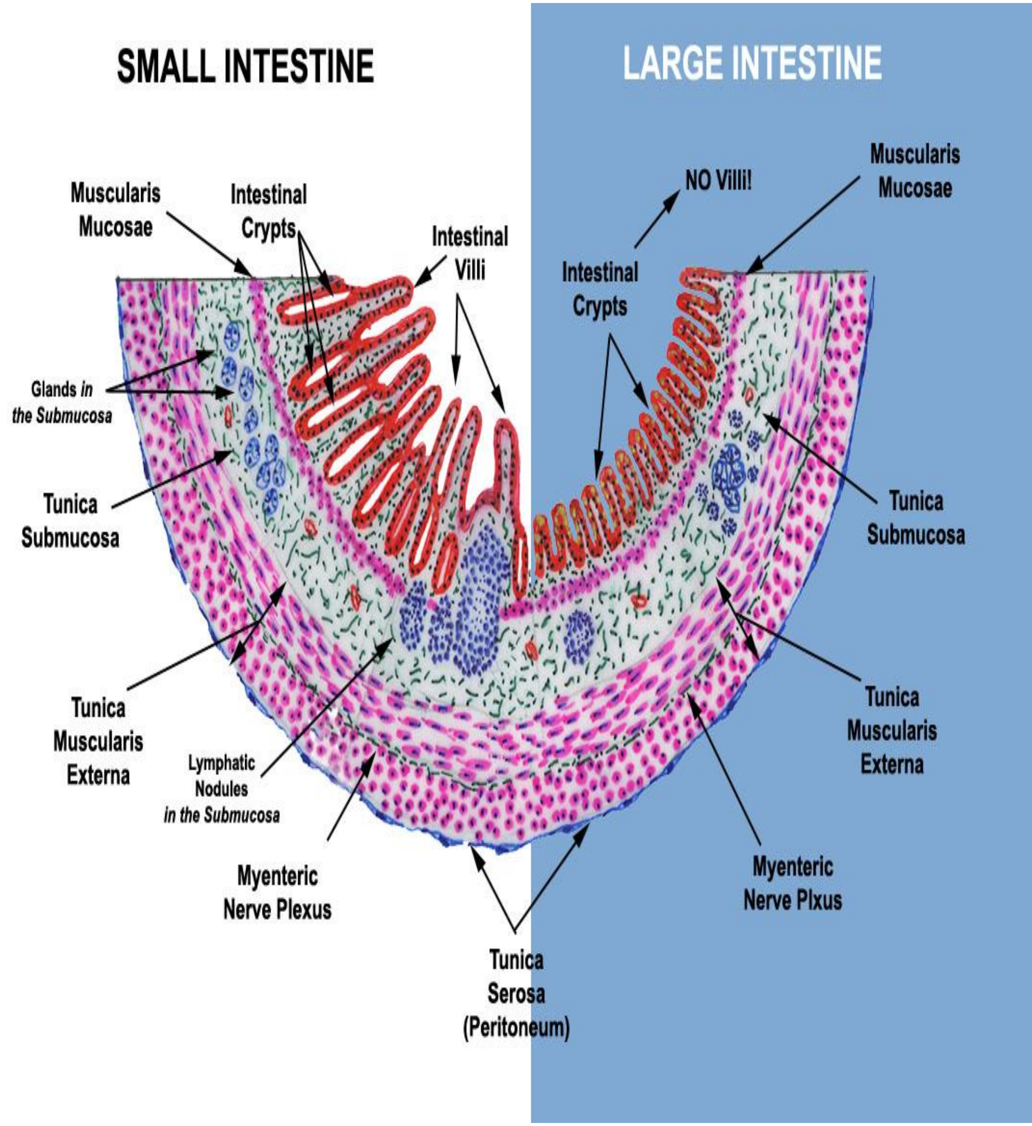
- Carnivores and omnivores
  - Limited anaerobic fermentation
  - Bacteria produce small quantities of cellulase
  - SOME volatile fatty acids (VFA) produced by microbial digestion of fibers
    - Propionate
    - Butyrate
    - Acetate

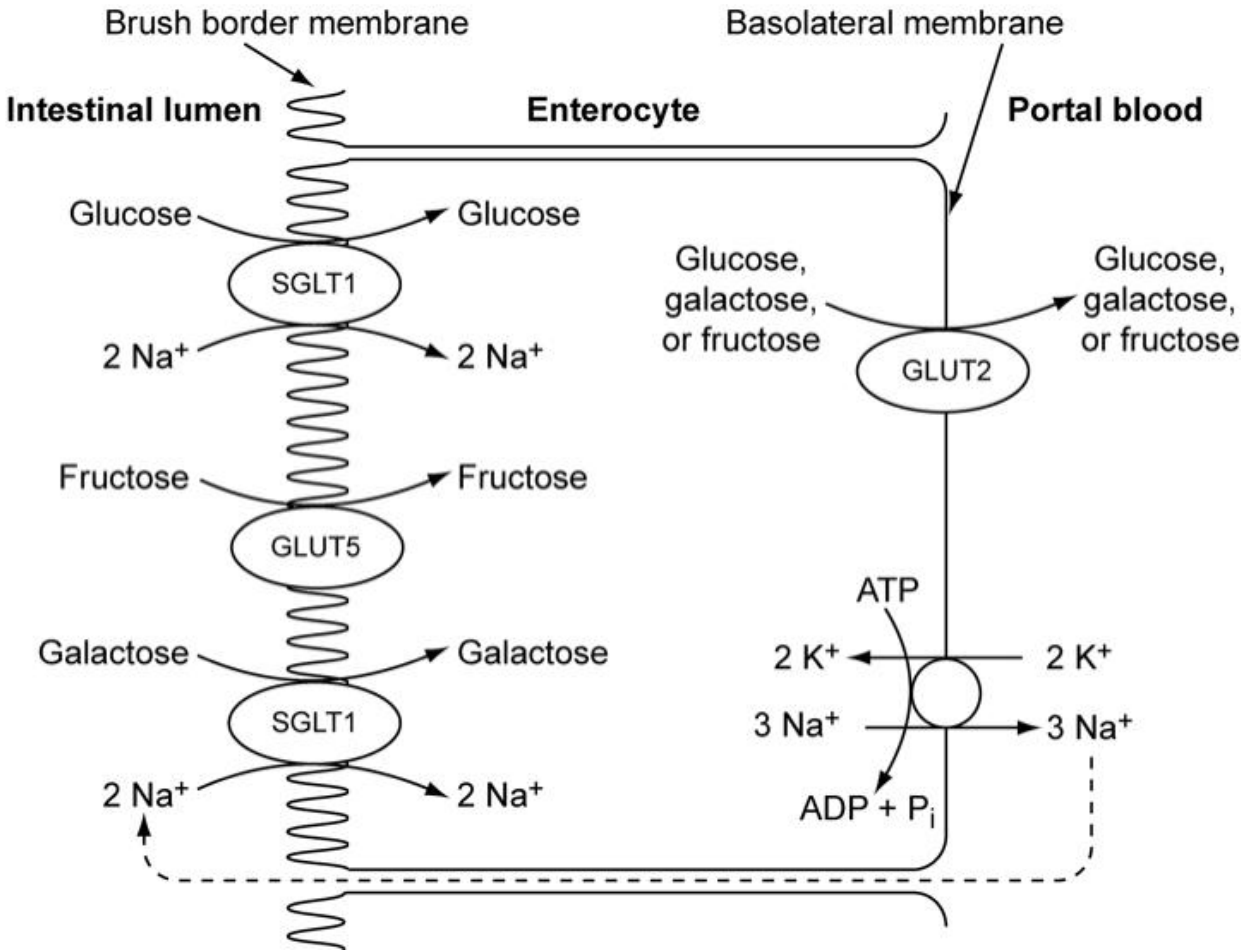
Overview Monogastric Carbohydrate Digestion

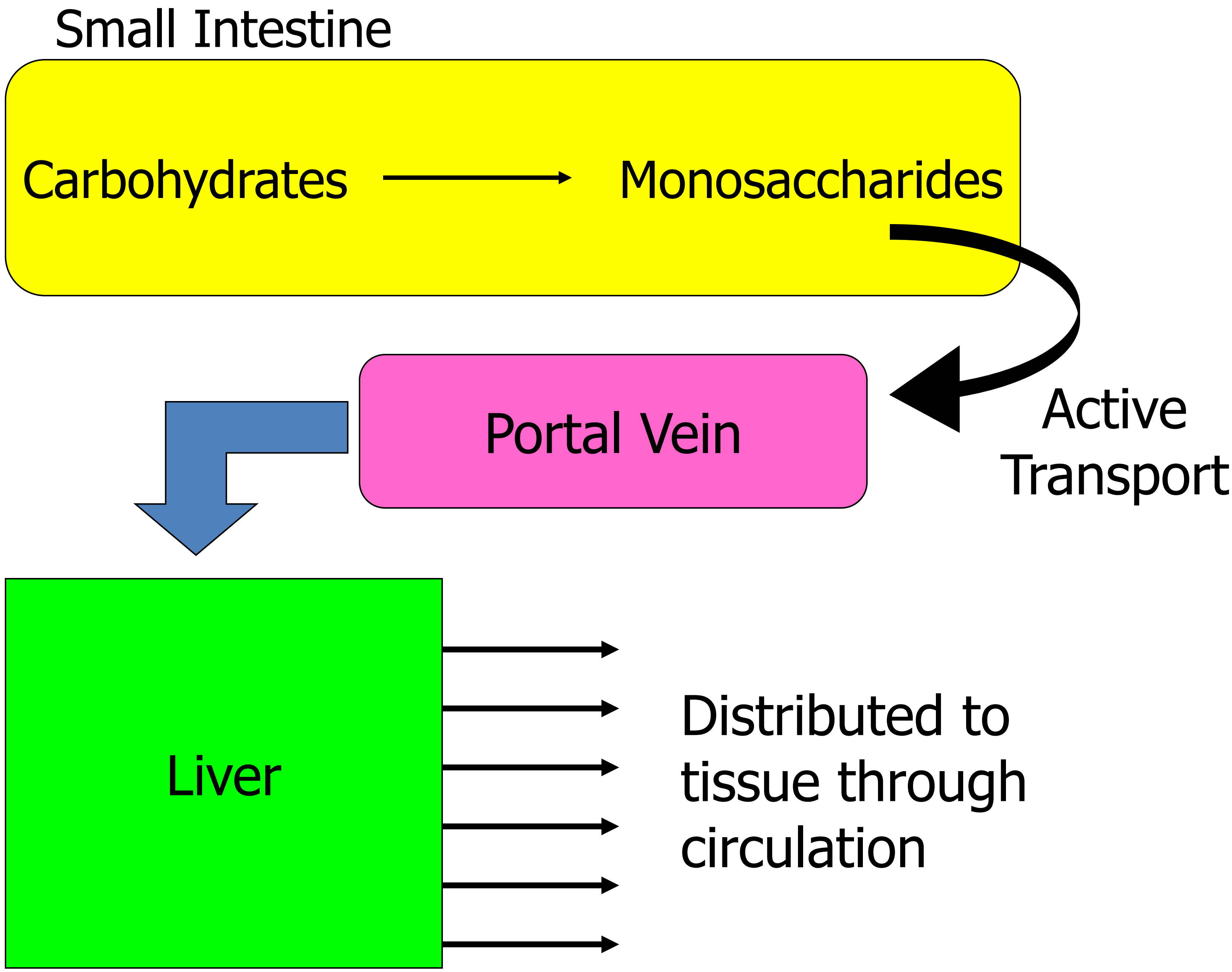
In the **monogastric** diet, starch is the primary **carbohydrate**

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

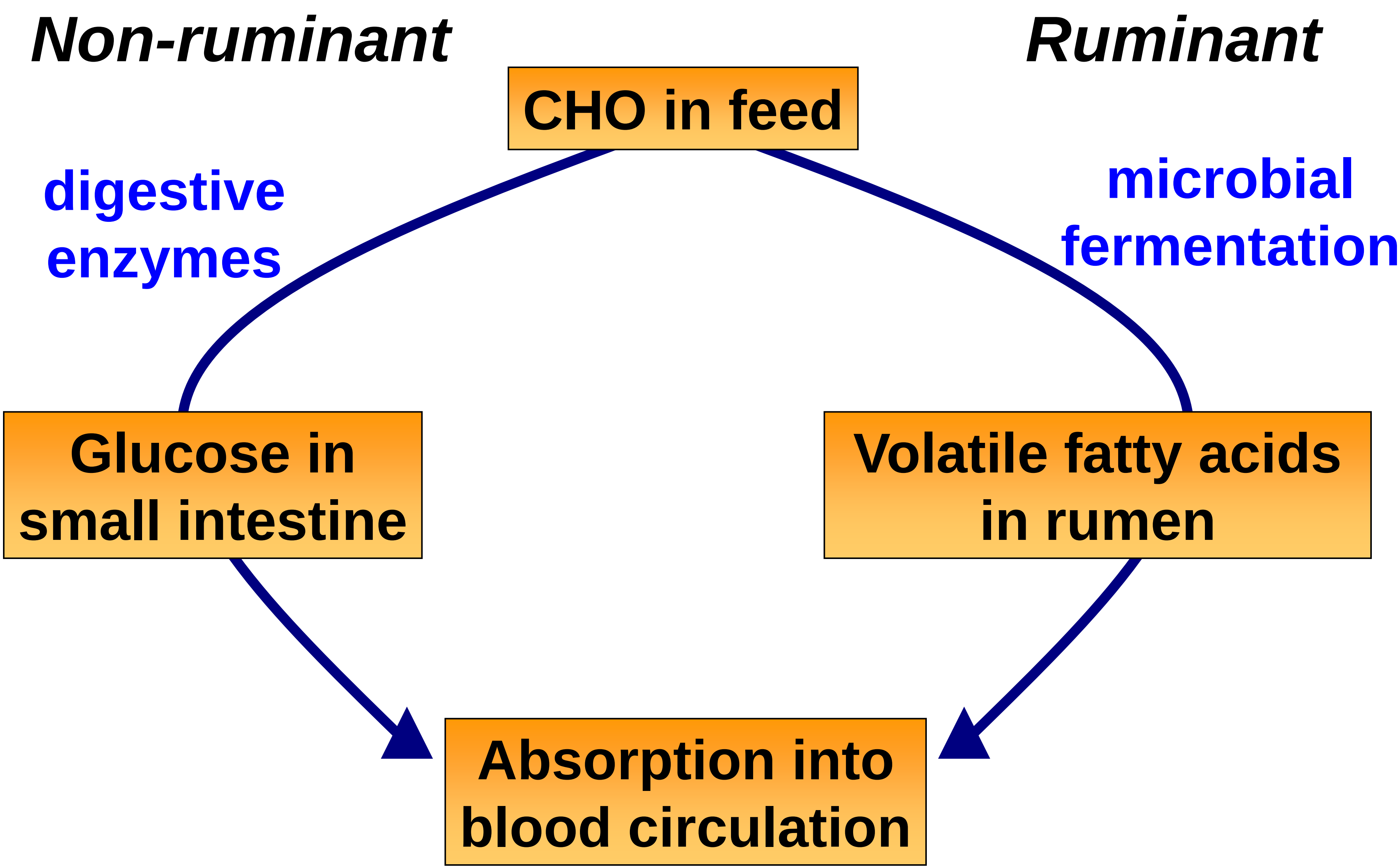

starch molecule
glucose molecules
cells of an intestinal wall
blood vessel
Elizabeth Morales


SMALL INTESTINE
LARGE INTESTINE
Muscularis Mucosae
Intestinal Crypts
Intestinal Villi
NO Villi!
Intestinal Crypts
Muscularis Mucosae
Glands in the Submucosa
Tunica Submucosa
Tunica Submucosa
Tunica Muscularis Externa
Lymphatic Nodules in the Submucosa
Tunica Muscularis Externa
Myenteric Nerve Plexus
Myenteric Nerve Plxus
Tunica Serosa (Peritoneum)


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



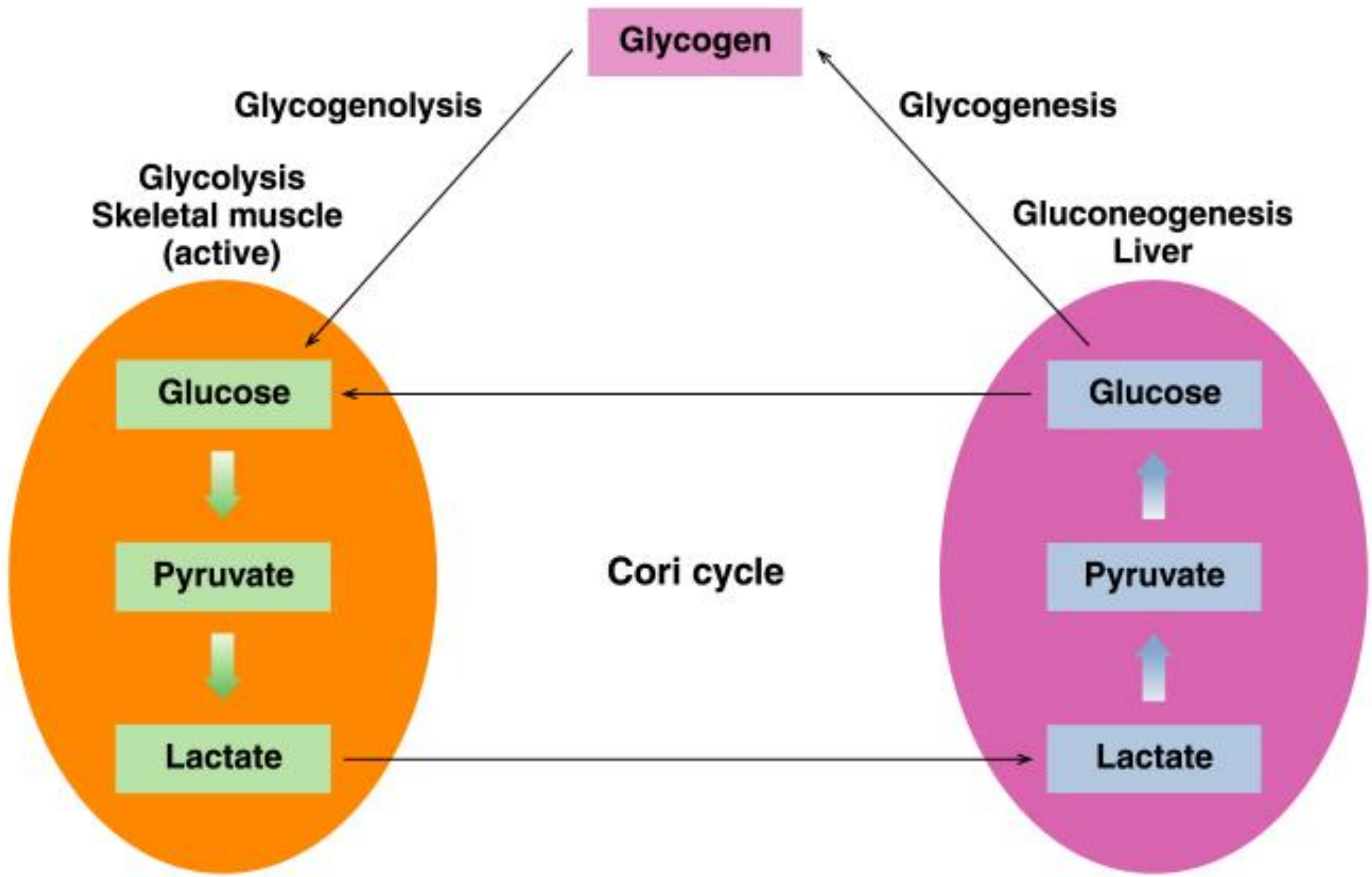
Microbial Populations

- 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

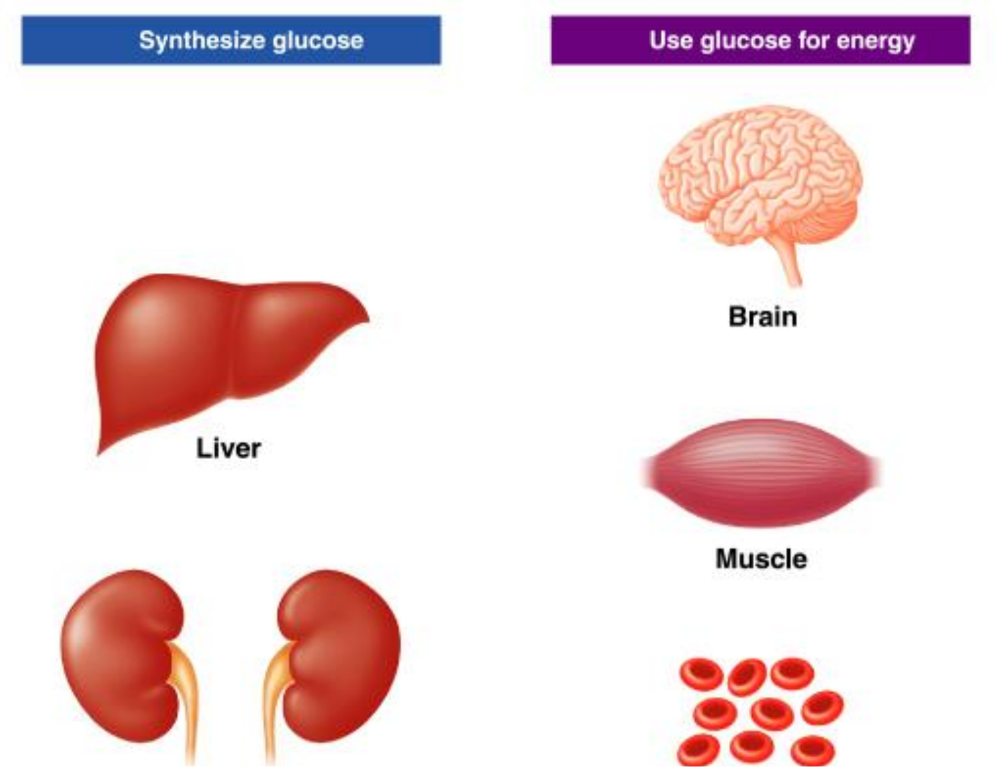
Regulation occurs as

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

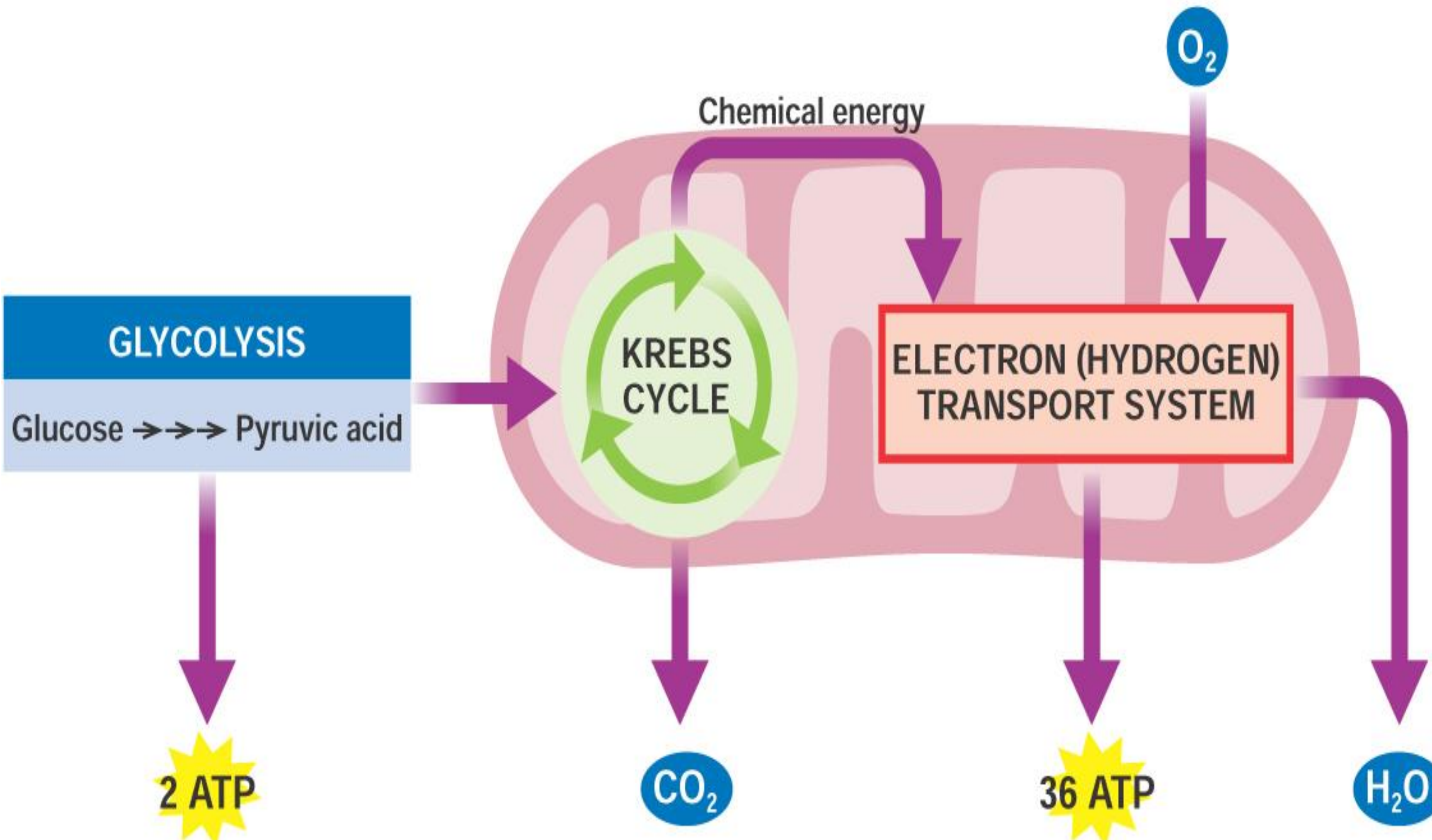
Utilization of Glucose

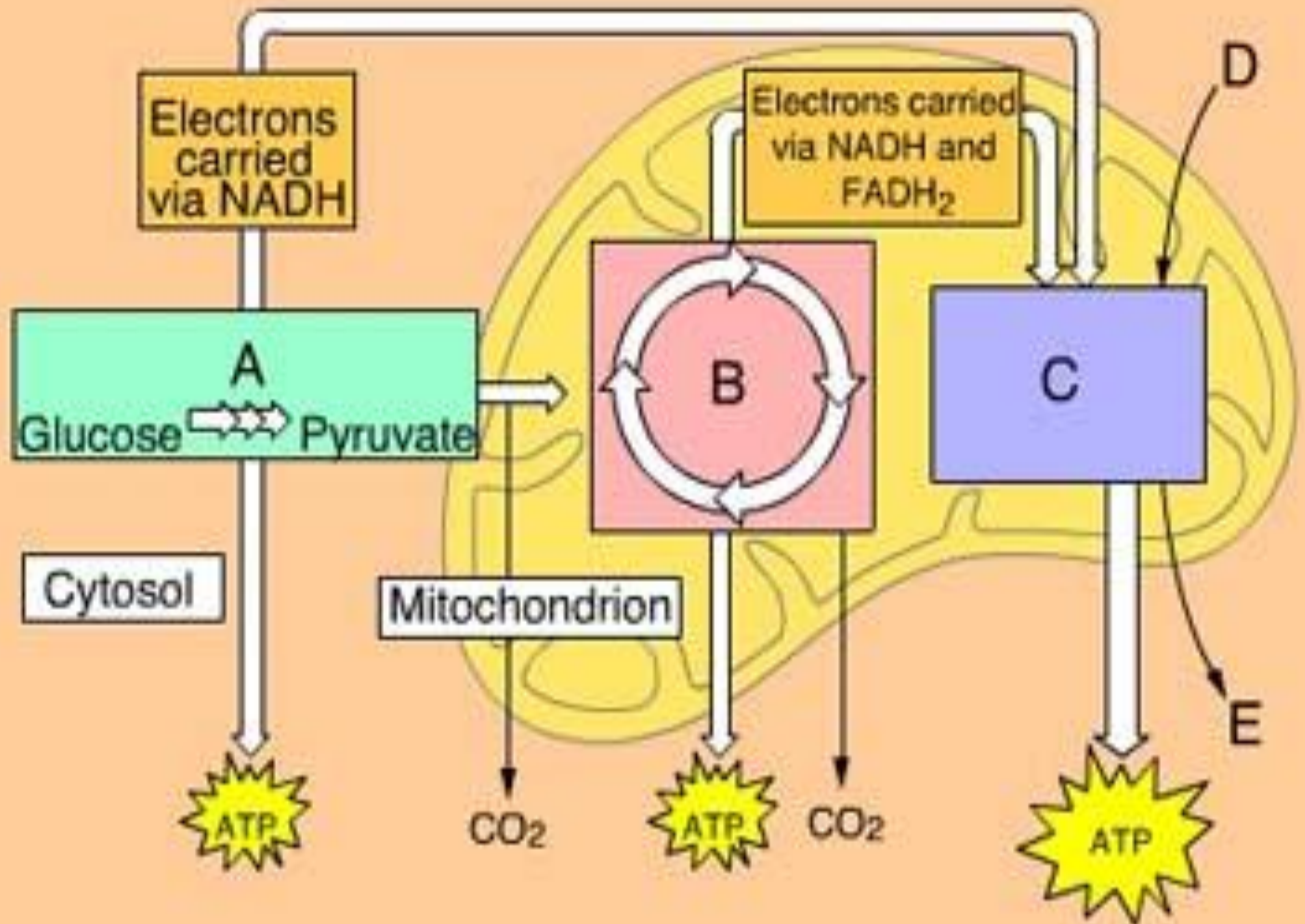
Glucose

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



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

End products of glycolysis

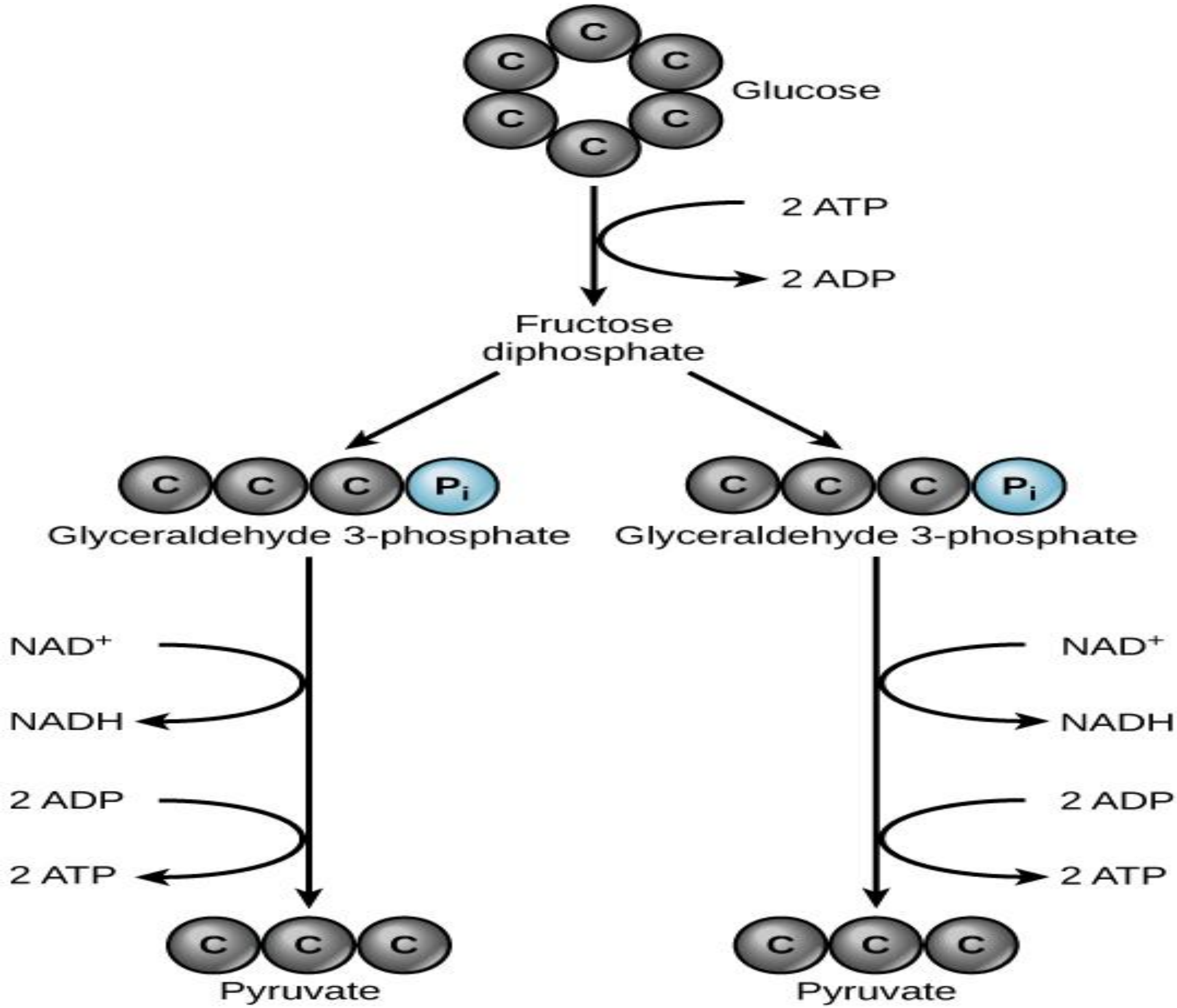
1- In cells with mitochondria & an adequate supply of oxygen
(***Aerobic glycolysis***)

- ***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

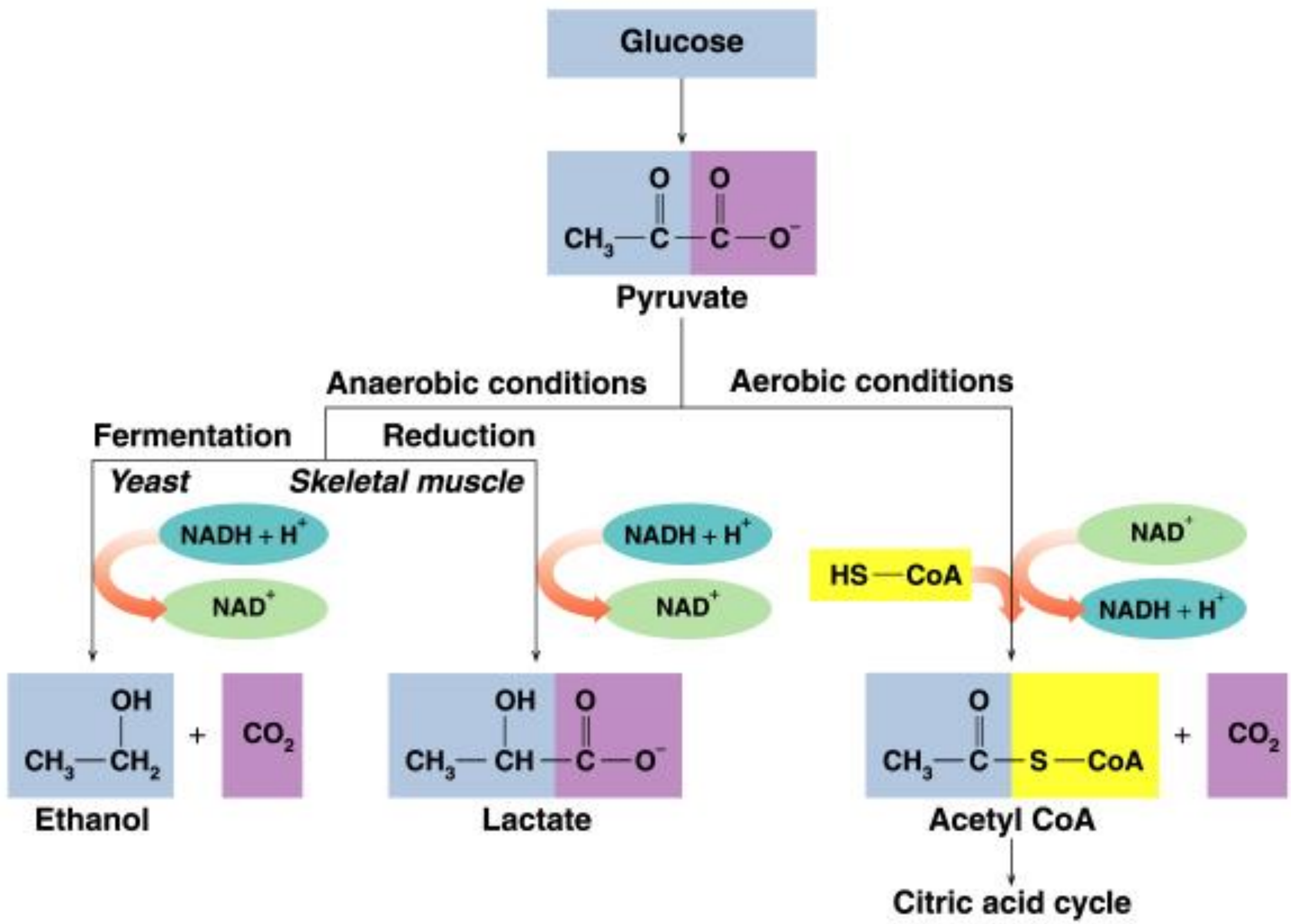
- ***NADH****:* utilizes mitochondria & oxygen to yield energy

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

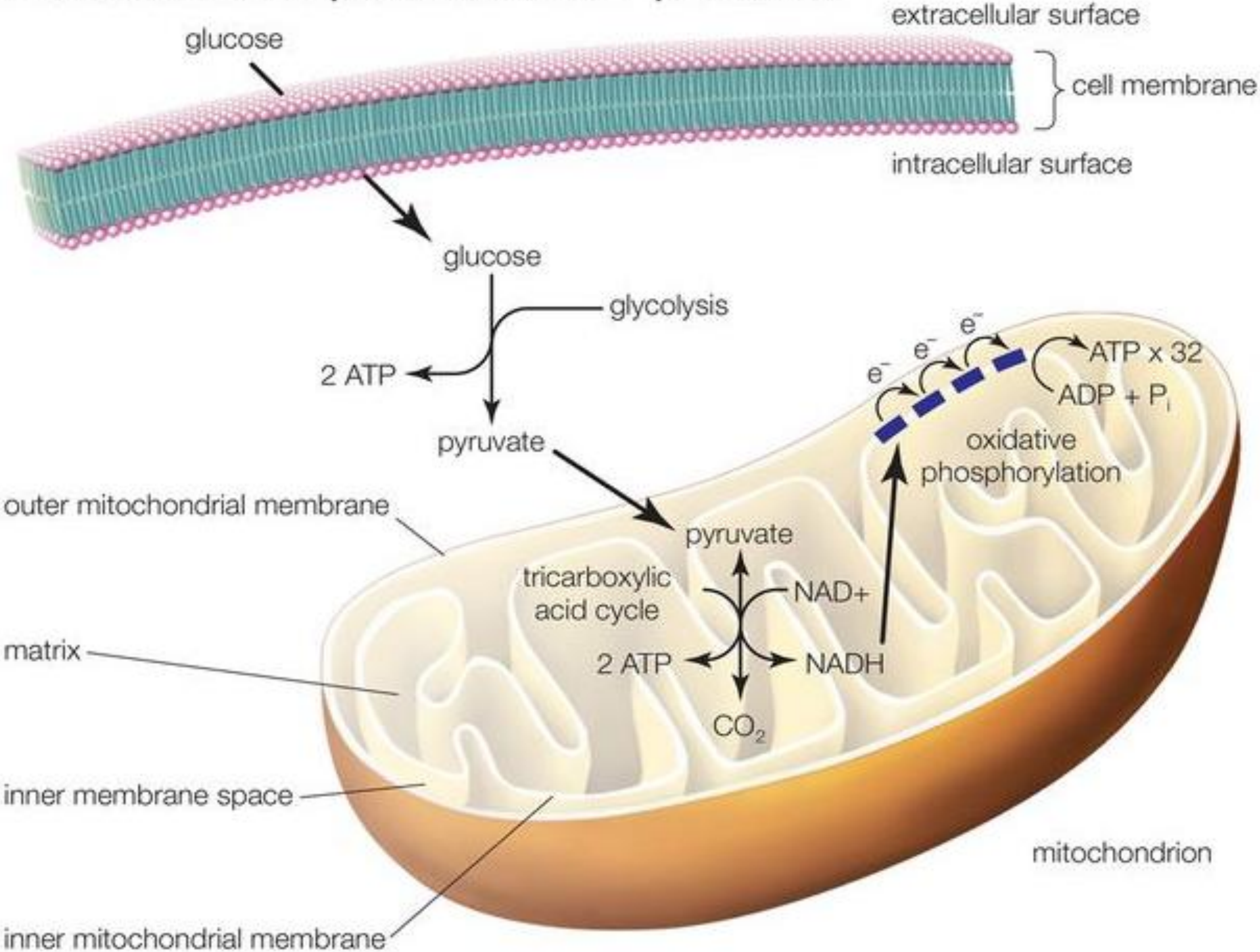
Lactate: formed from pyruvate (by utilizing NADH)


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

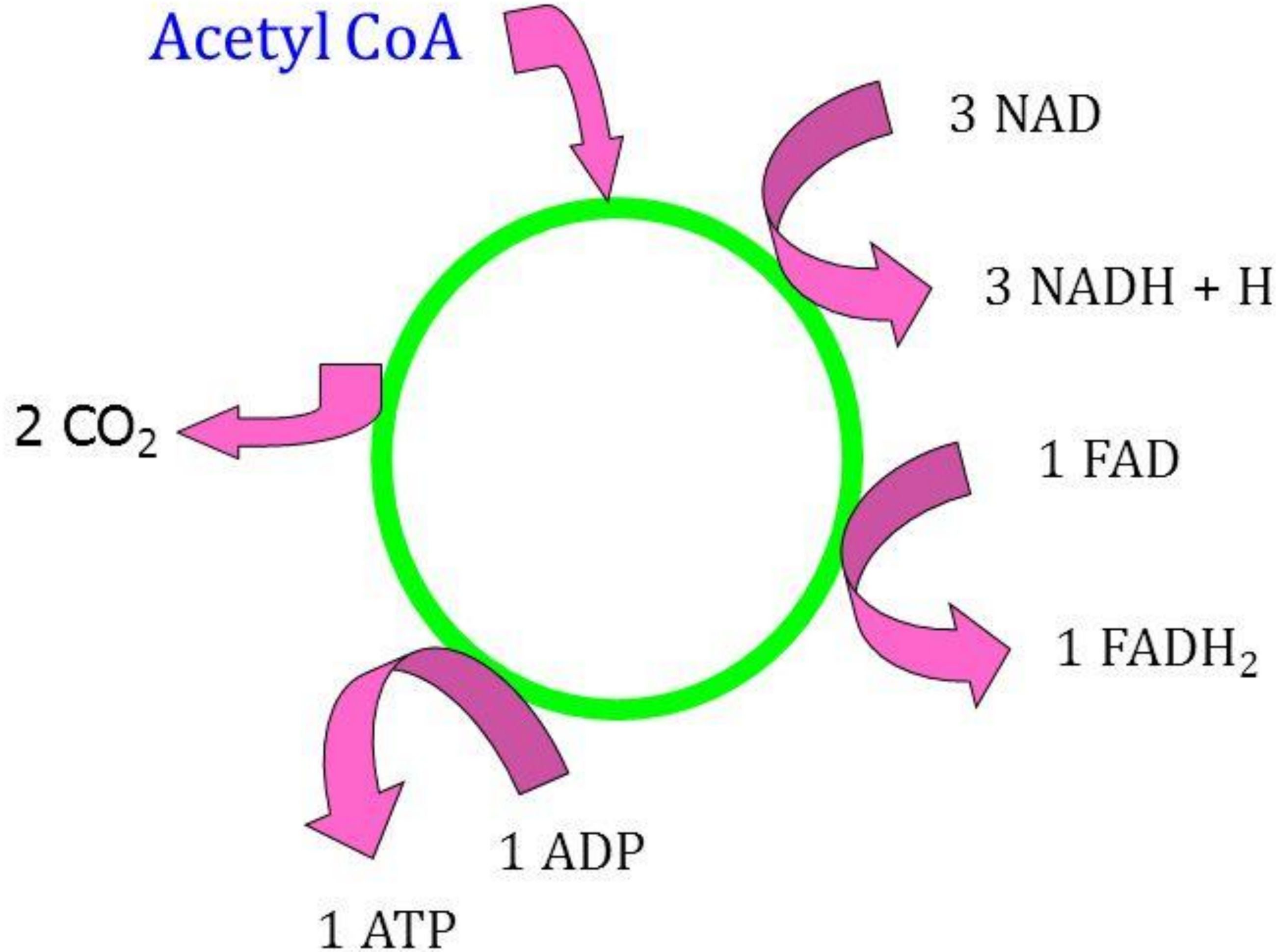
Pathways for Pyruvate

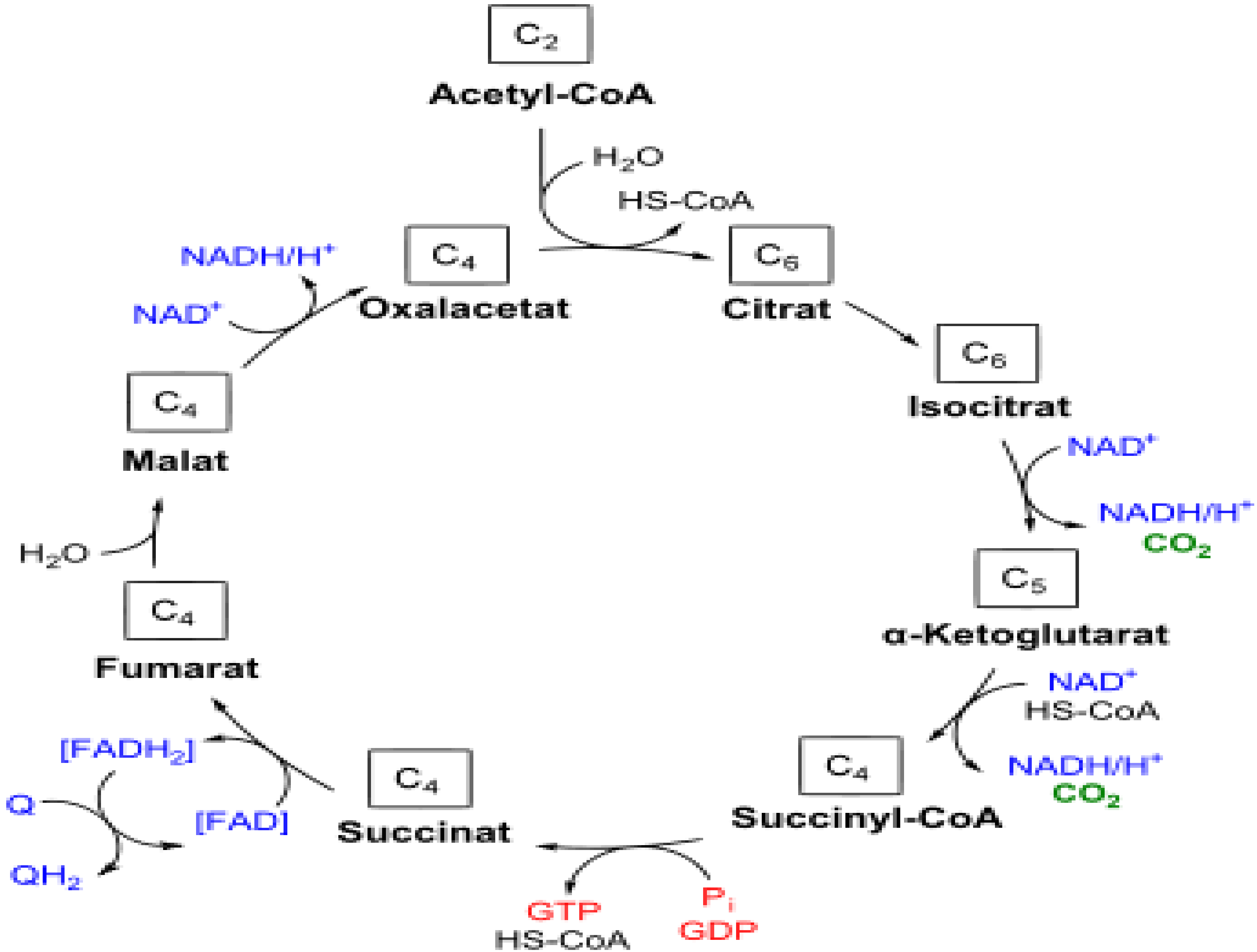


Basic overview of processes of ATP production



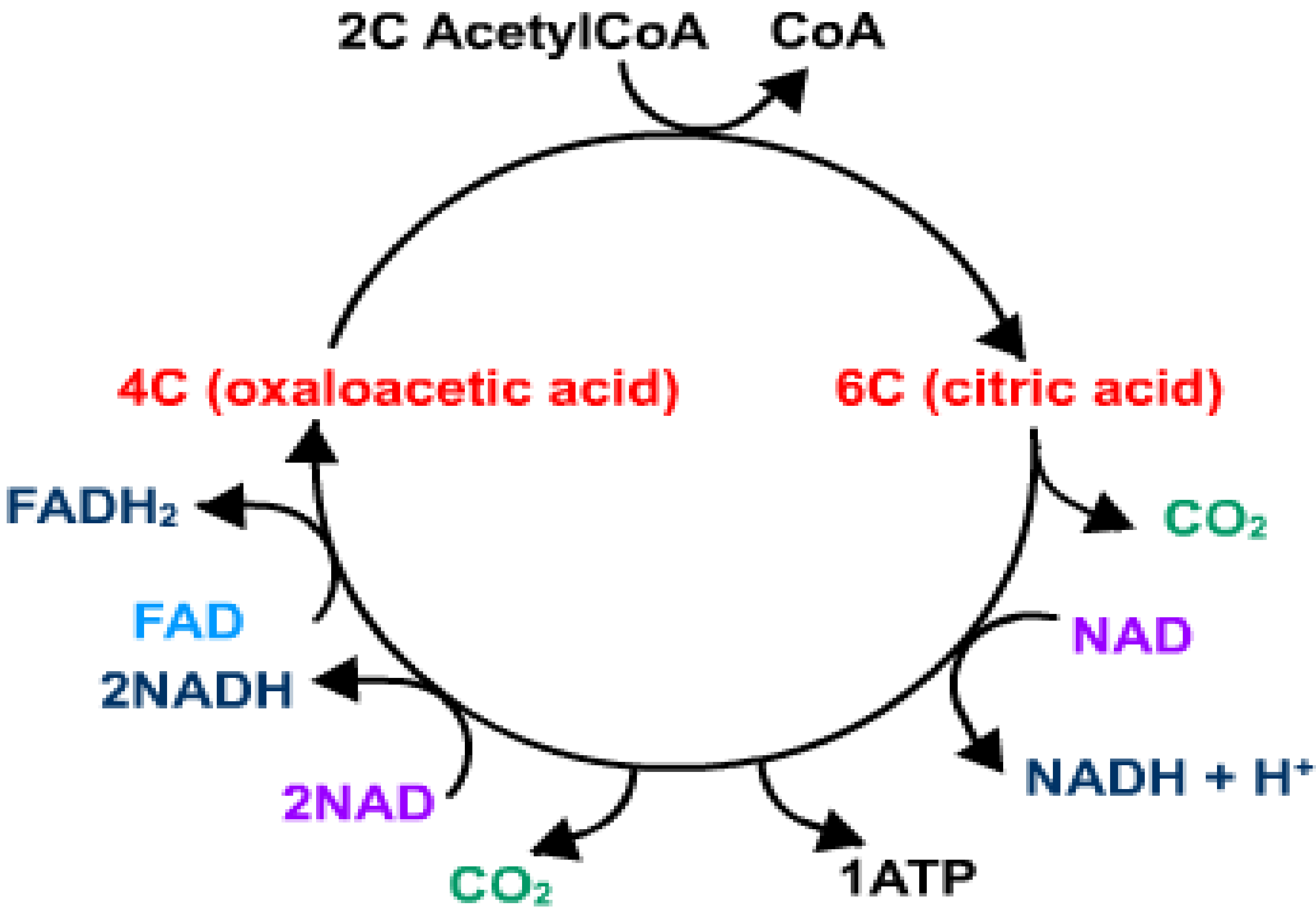
Citric Acid Cycle CYCLE - SUMMARY



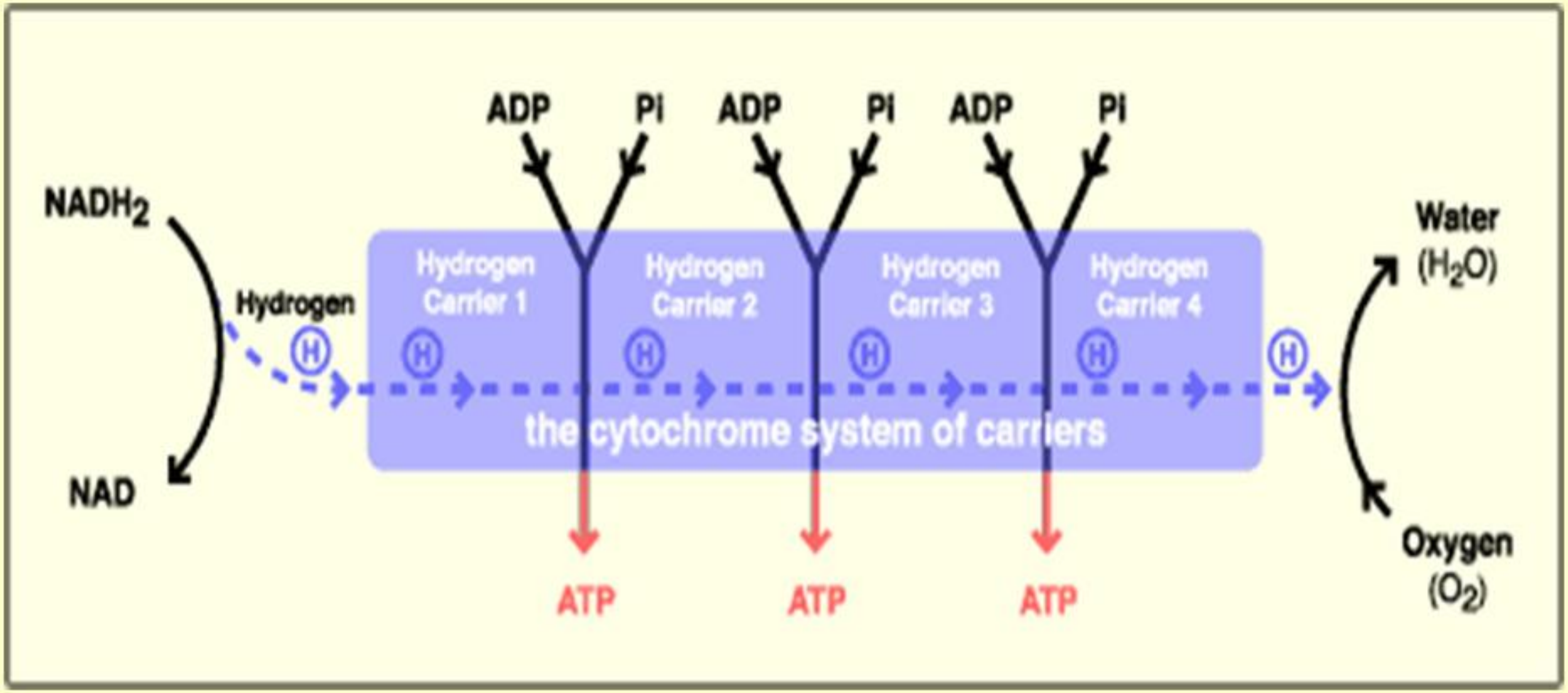


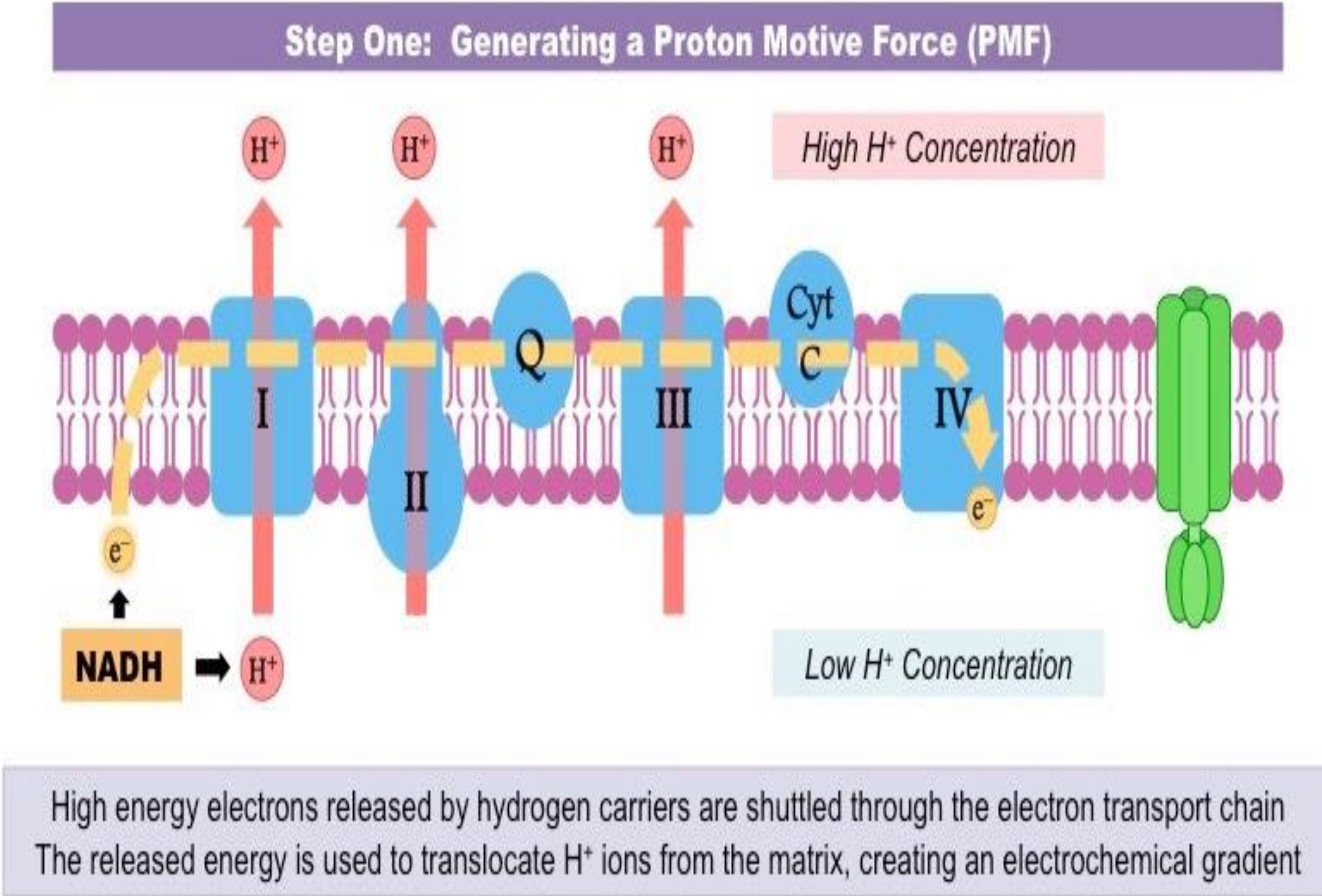
C_2
Acetyl-CoA
H_2O
HS-CoA
C_4
Oxalacetat
C_6
Citrat
$NADH/H^+$
NAD^+
C_6
Isocitrat
C_4
Malat
NAD^+
$NADH/H^+$
CO_2
H_2O
C_5
α-Ketoglutarat
C_4
Fumarat
NAD^+
HS-CoA
$[FADH_2]$
C_4
Succinat
C_4
Succinyl-CoA
$NADH/H^+$
CO_2
Q
[FAD]
QH_2
GTP
HS-CoA
P_i
GDP

Krebs cycle

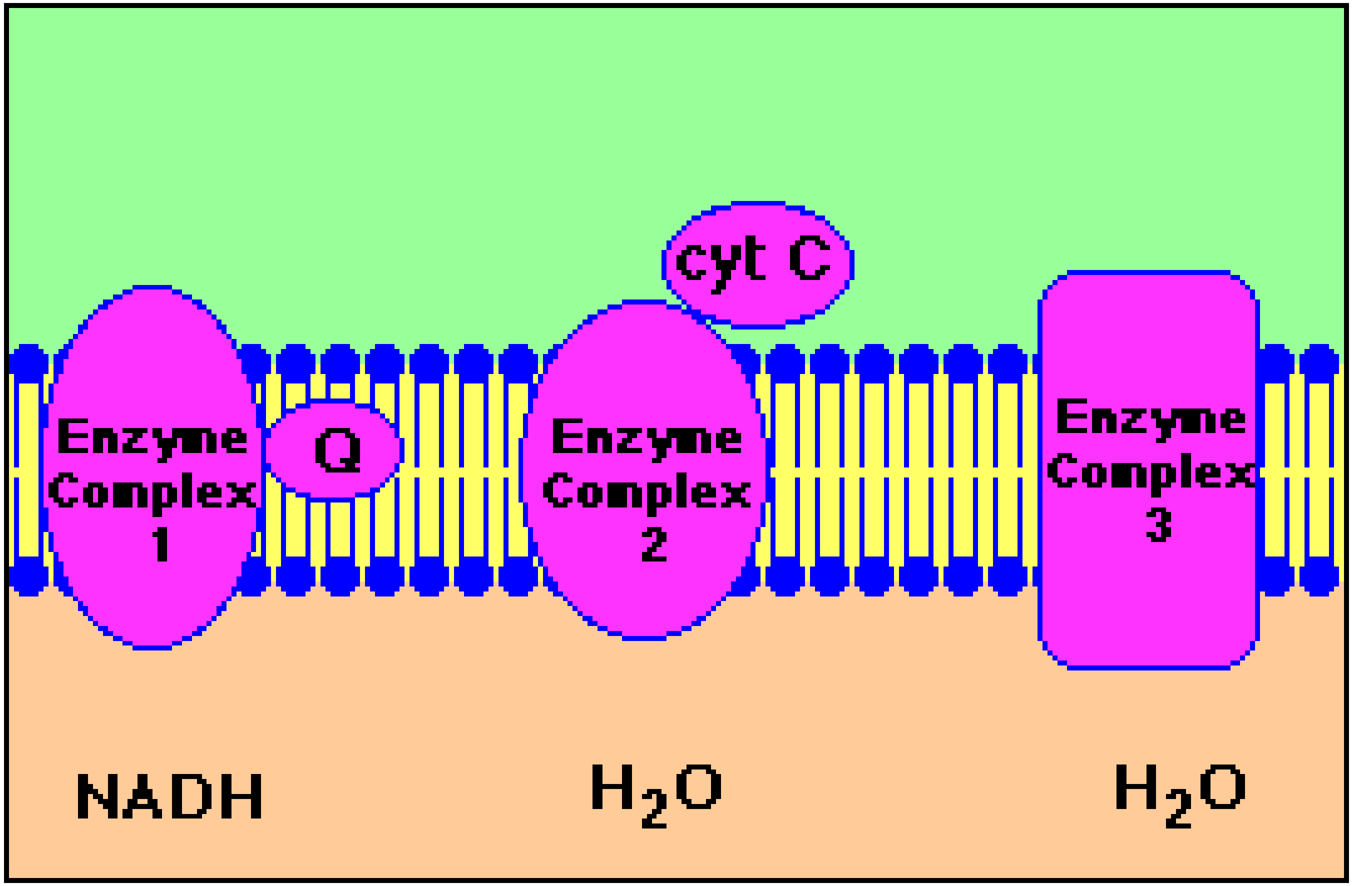


2C AcetylCoA
CoA
4C (oxaloacetic acid)
6C (citric acid)
FADH2
CO2
FAD
NAD
2NADH
NADH + H+
2NAD
CO2
1ATP

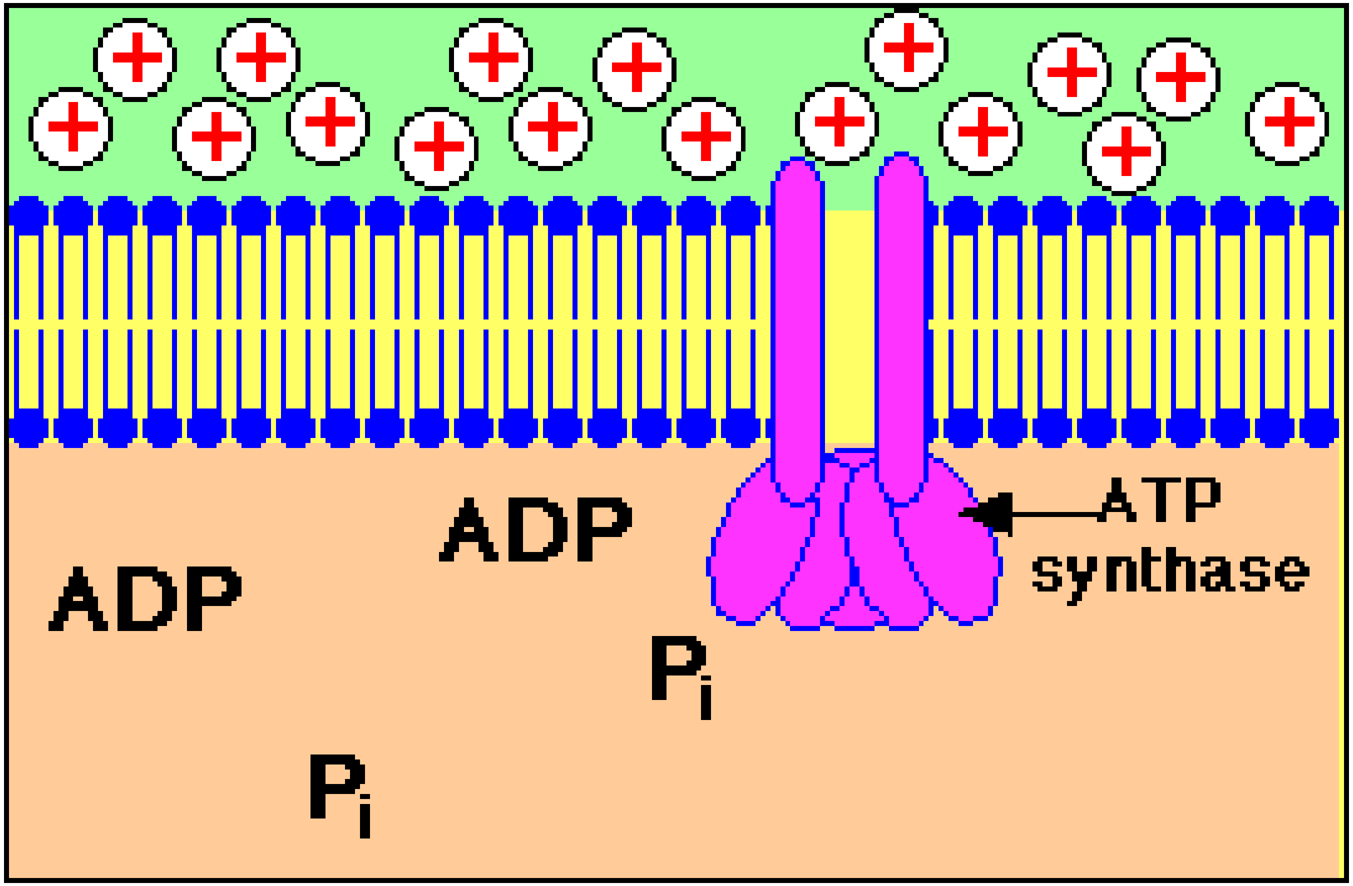

ADP
Pi
ADP
Pi
ADP
Pi
NADH2
Hydrogen
Hydrogen Carrier 1
Hydrogen Carrier 2
Hydrogen Carrier 3
Hydrogen Carrier 4
H
the cytochrome system of carriers
NAD
ATP
ATP
ATP
Water (H_2O)
Oxygen (O_2)



Q : cytochrome c – oxidoreductase



1. Protons are moved across the membrane, from the cytosol to the intermembrane space.
2. Electrons are transported along the membrane, through a series of protein carriers depicted as “Q” and “cyt C” in the diagram.
3. **Oxygen is the final electron acceptor**, combining with electrons and H+ ions to produce water.



ADP
ADP
P_i
P_i
ATP synthase

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