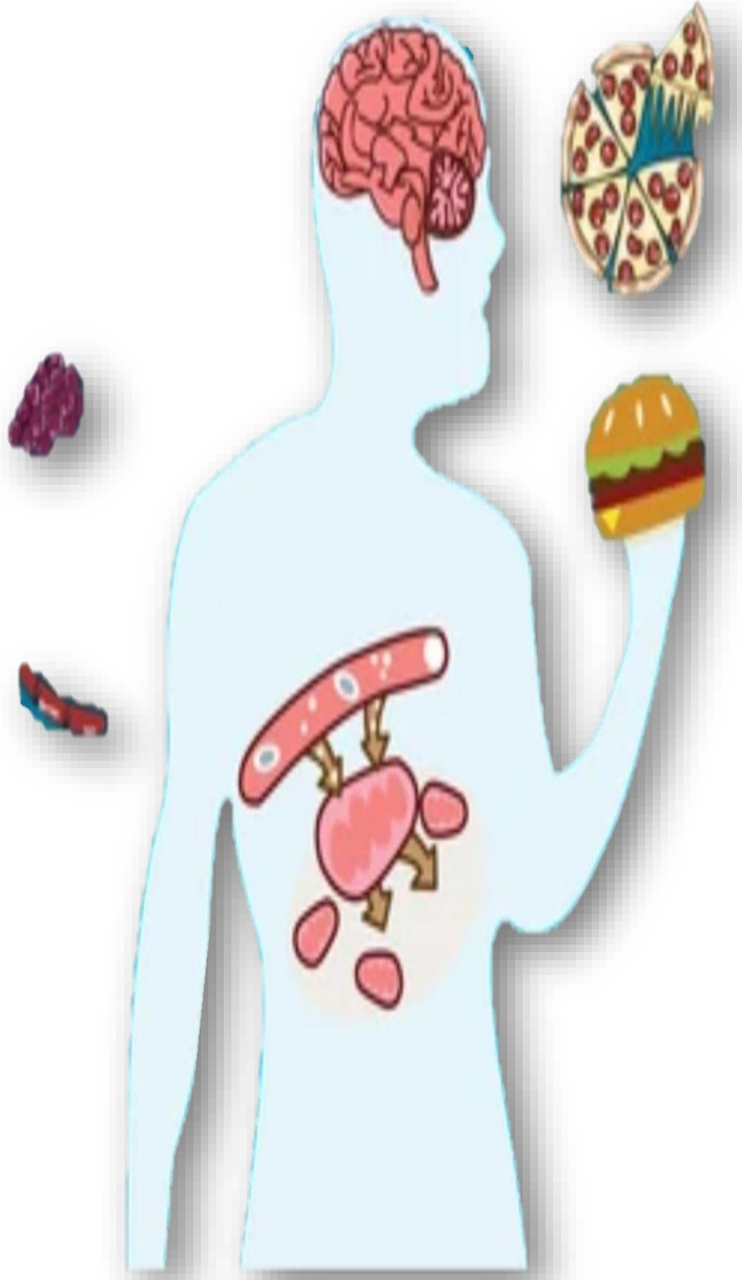
Lecture two Theory

Carbohydrate Metabolism



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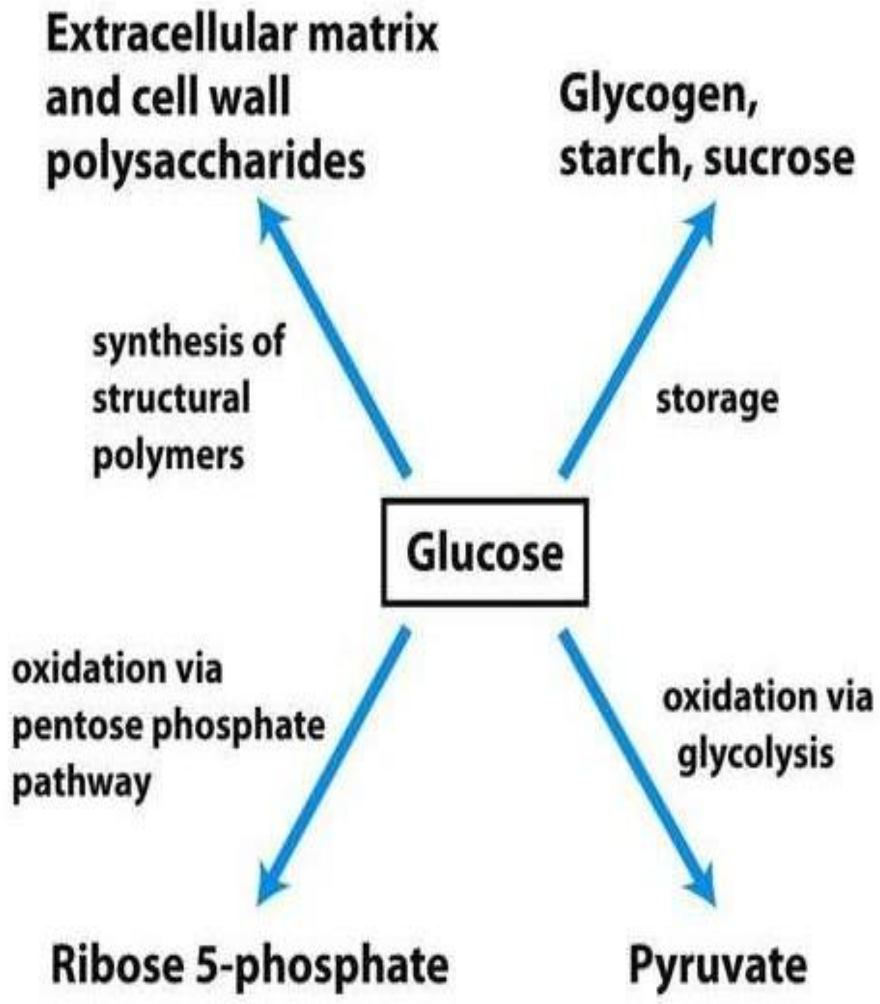
GLUCOSE IN CARBOHYDRATE METABOLISM



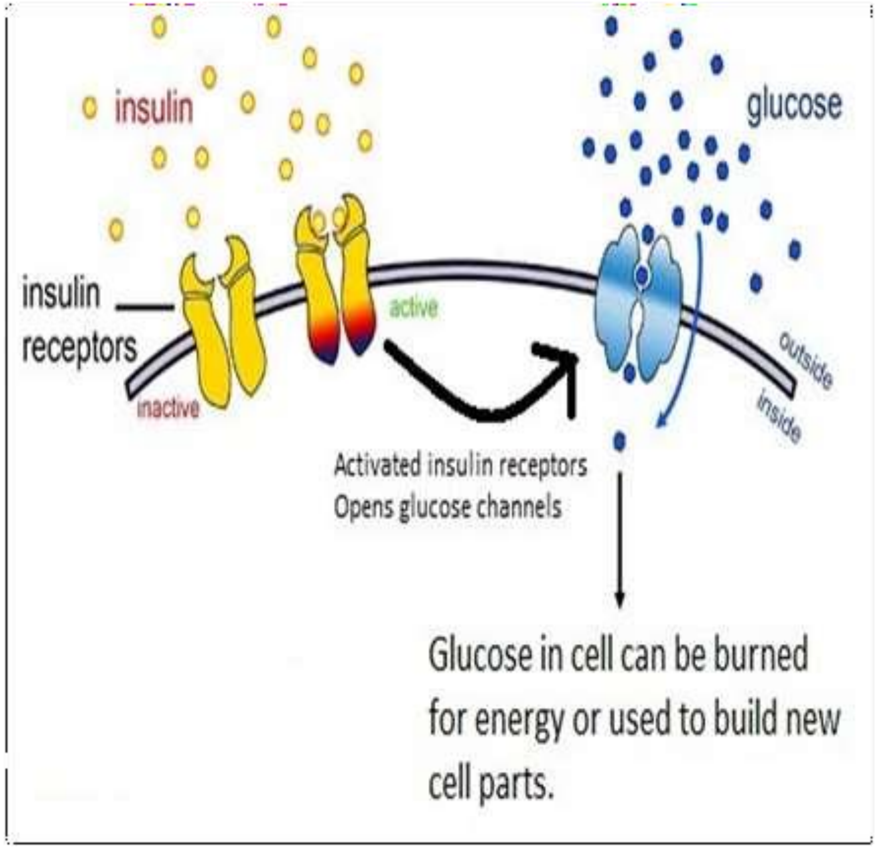
- The final products of carbohydrate digestion in the alimentary tract are almost entirely **glucose**, **fructose, and galactose**—with glucose representing, on average, about 80 percent of these products.
- After absorption from the intestinal tract, much of the fructose and almost all the galactose are rapidly **converted into glucose** in the liver.
- Glucose then becomes the final common pathway for the transport of almost all carbohydrates to the tissue cells.

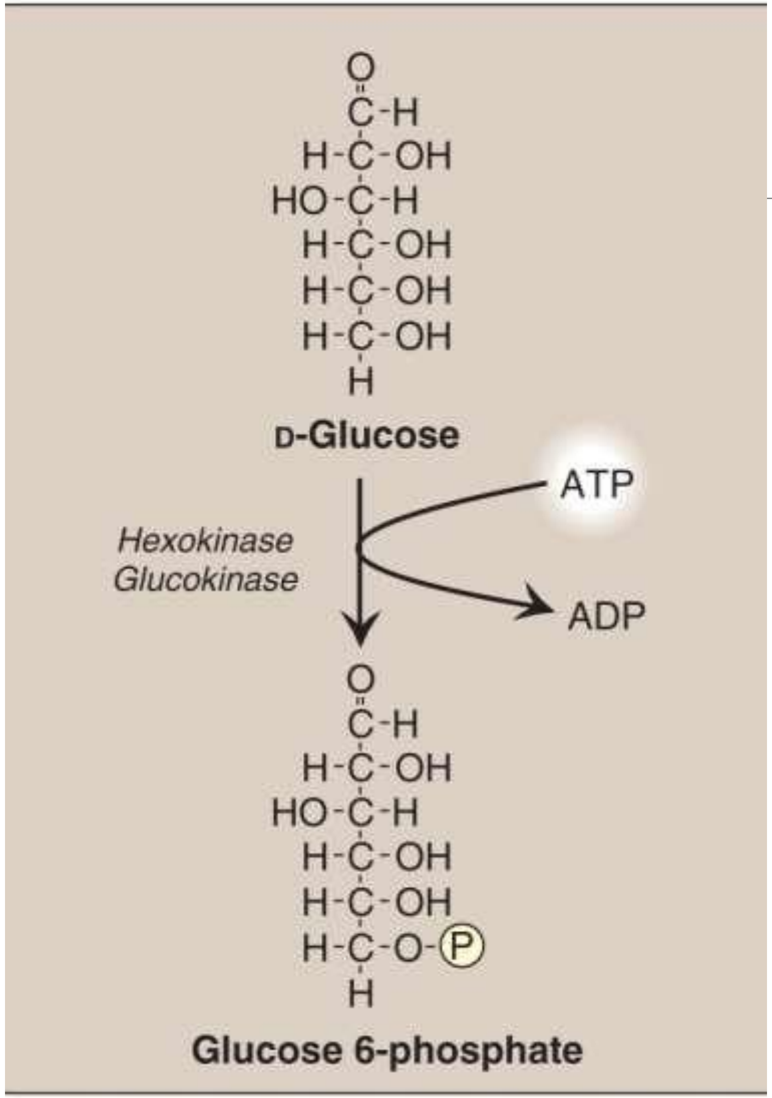
INSULIN INCREASES FACILITATED DIFFUSION OF GLUCOSE

- The rate of glucose transport, as well as transport of some other monosaccharides, is greatly **increased** by insulin.

- When large amounts of insulin are secreted by the pancreas, the rate of glucose transport into most cells increases to 10 or more times the rate of transport when no insulin is secreted.

- Conversely, the amounts of glucose that can diffuse to the insides of most cells of the body in the absence of insulin, with the exception of liver and brain cells, are far too little to supply the amount of glucose normally required for energy metabolism.





PHOSPHORYLATION OF GLUCOSE

Immediately upon entry into the cells, glucose combines with a phosphate radical

This phosphorylation is promoted mainly by:

- Glucokinase enzyme in the liver
- Hexokinase enzyme in most other cells

PHOSPHORYLATION OF GLUCOSE

- The phosphorylation of glucose is almost completely irreversible

except,

- in liver cells, renal tubular and intestinal epithelial cells

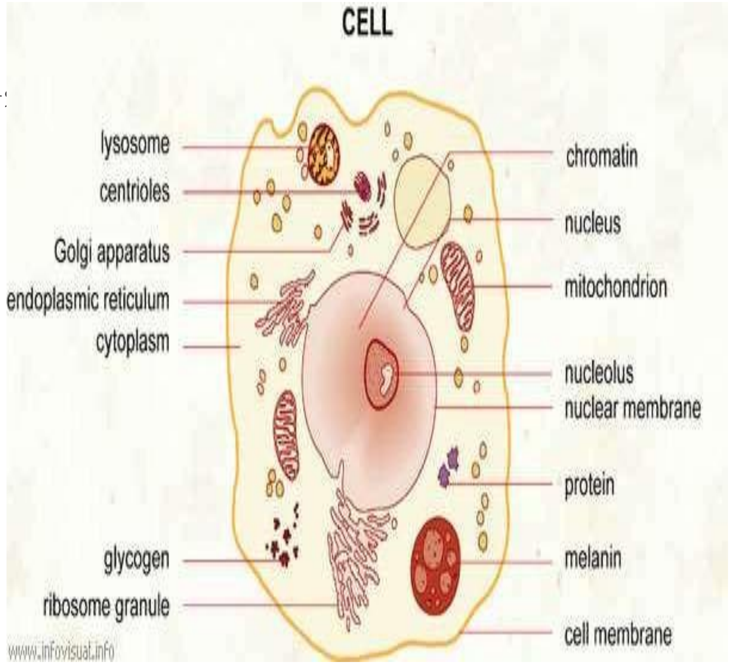
- In these cells, another enzyme, called glucose phosphatase, is available, and when activated, it can reverse the reaction.

Purpose of glucose phosphorylation

In most tissues of the body, phosphorylation serves to capture the glucose in the cell, because glucose almost immediately bind with phosphate, it will not diffuse back out, except from those special cells.

GLYCOGEN IS STORED IN THE LIVER AND MUSCLE

- After absorption into a cell, glucose can be used immediately for release of energy to the cell, or it can be stored in the form of glycogen, which is a large polymer of glucose.
- All cells of the body are capable of storing at least some glycogen, but certain cells can store large amounts, especially liver and muscle cells.
- The glycogen molecules can be polymerized to almost any molecular weight; most of the glycogen are accumulated in the form of solid granules.



ACTIVATION OF PHOSPHORYLASE BY EPINEPHRINE OR BY GLUCAGON.

- Two hormones, epinephrine and glucagon, can activate phosphorylase and thereby cause rapid glycogenolysis.

- Epinephrine is released by the adrenal medullae when the sympathetic nervous system is stimulated.

- Glucagon is secreted by the alpha cells of the pancreas when the blood glucose concentration falls too low.

RELEASE OF ENERGY FROM GLUCOSE

<u>**Three major steps:**</u>

1 Glycolysis

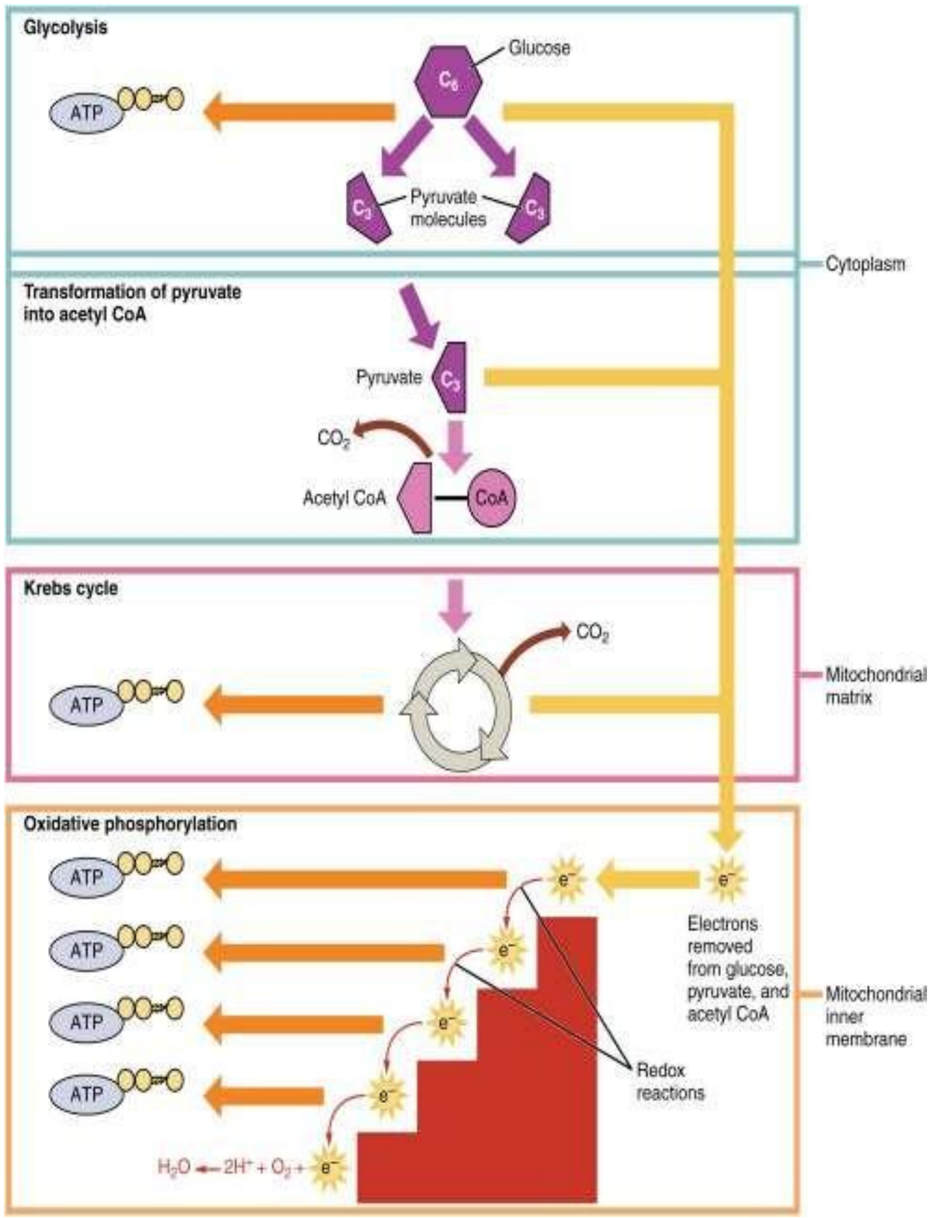
2 Cretic Acid cycle (kerbs)

3 Oxidative phosphorylation

- Cells of the body contain special enzymes that cause the glucose molecule to split a little at a time in many successive steps,

So, that its energy is released in small packets to form one molecule of ATP at a time,

Thus, forming a total of 38 moles of ATP for each mole of glucose metabolized by the cells.

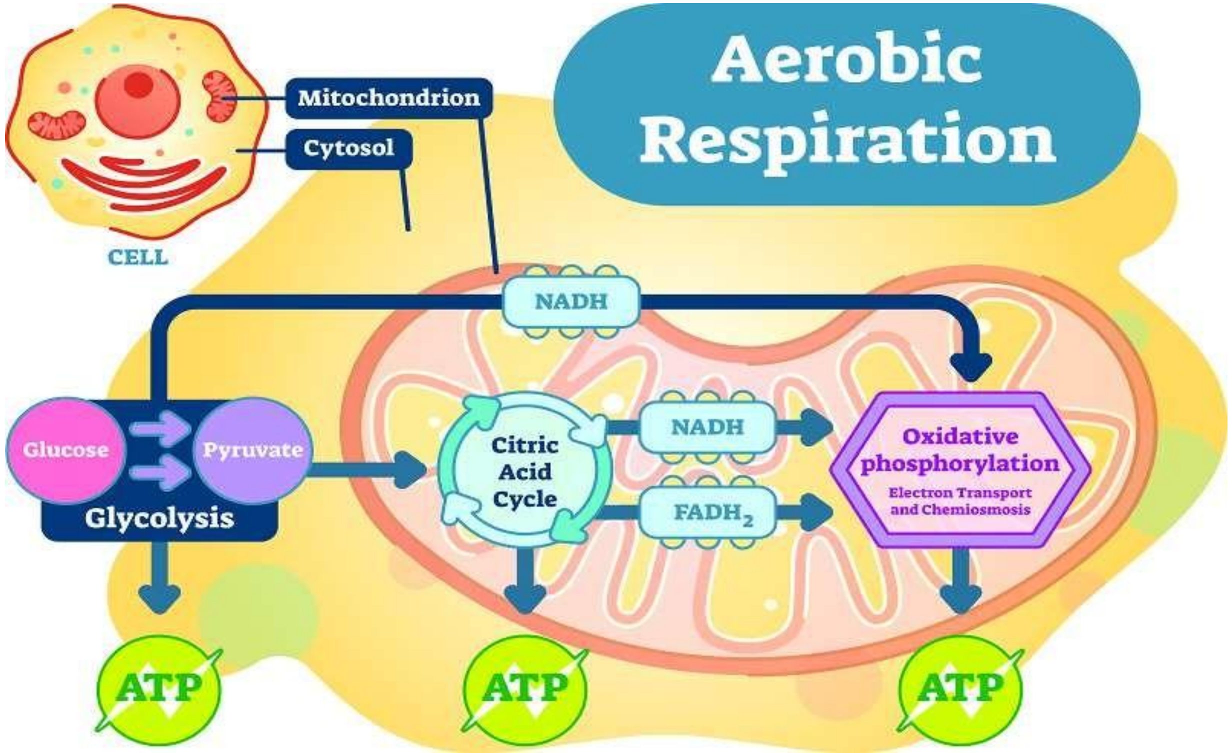


1- GLYCOLYSIS

Releasing energy from the glucose molecule is initiated by glycolysis.

The purpose of glycolysis:

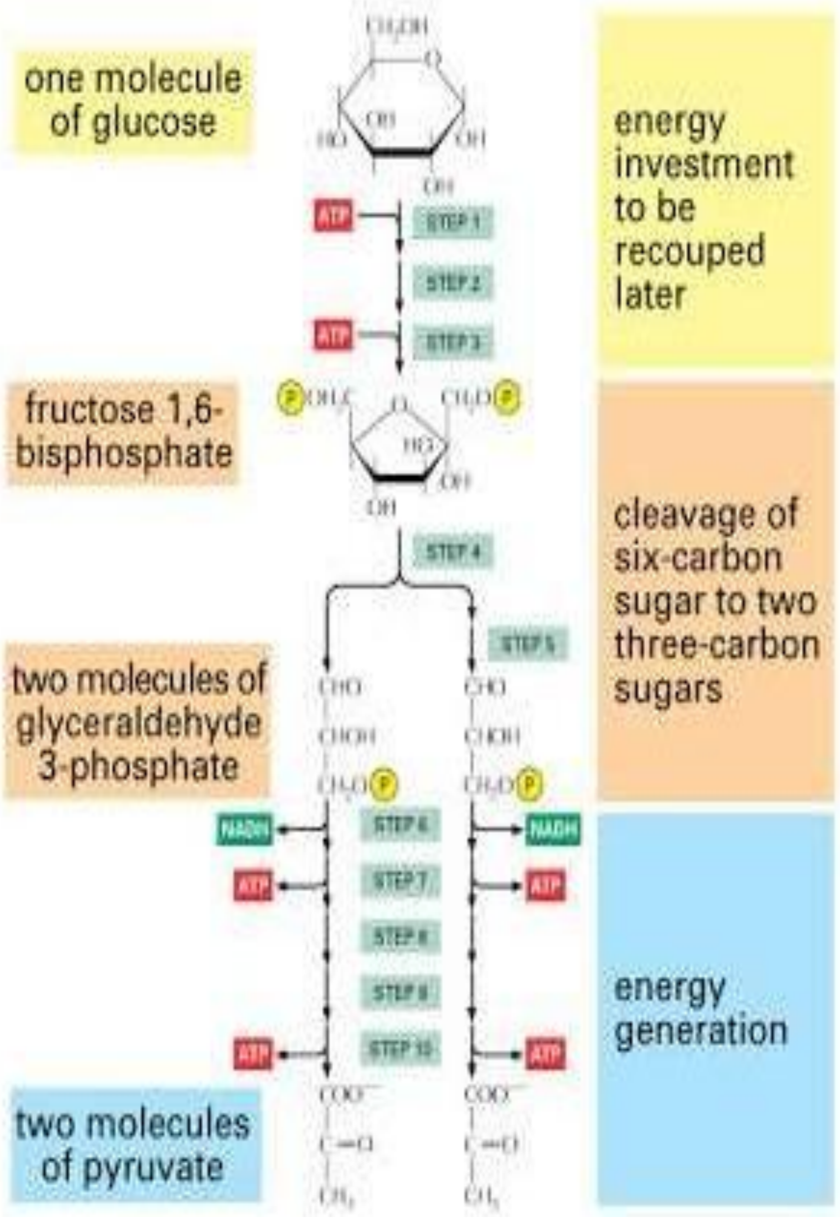
- Splitting Glucose to Form two molecules Pyruvic Acid.
- It happens in the cytoplasm.
- Glycolysis occurs by 10 sequent chemical reactions.
- Each step is catalyzed by at least one specific protein enzyme.



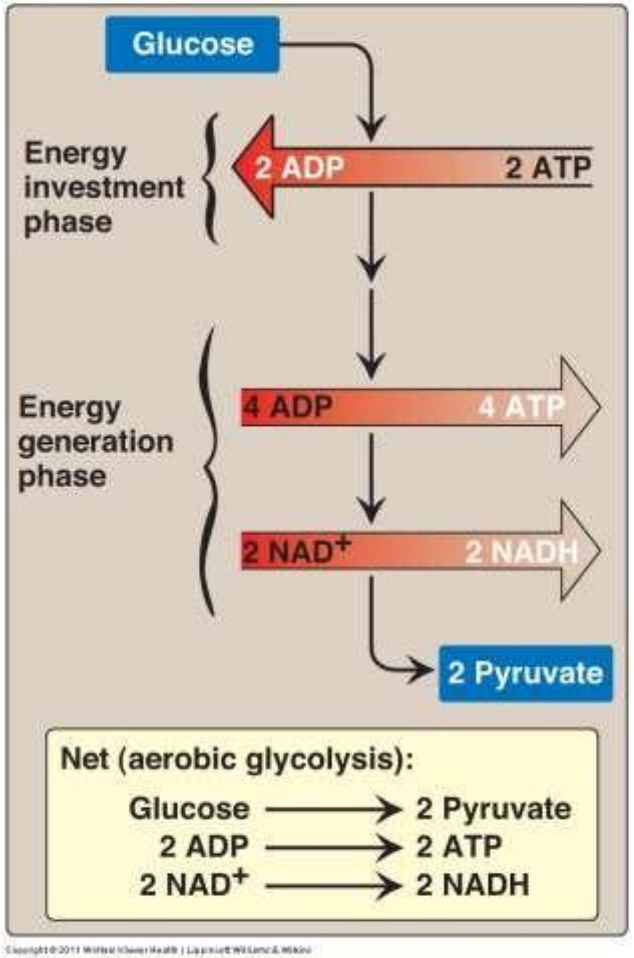
1- GLYCOLYSIS

The steps of glycolysis:

1. Glucose is first converted into fructose-1,6 diphosphate.
2. Fructose-1,6-diphosphate split into two glyceraldehyde-3- phosphate.
3. Each of which is then converted through five additional steps into pyruvic acid.



FORMATION OF ATP DURING GLYCOLYSIS



Despite the many chemical reactions in the glycolytic series, only a small portion of the free energy in the glucose molecule is released at most steps.

A total of 4 moles of ATP are formed in glycolysis

But, 2 moles of ATP are used in the first half of glycolysis.

So, the final net gain in ATP molecules by the entire glycolytic process is only 2 moles for each mole of glucose utilized.

Glycolysis produces:

Net energy :2 ATP

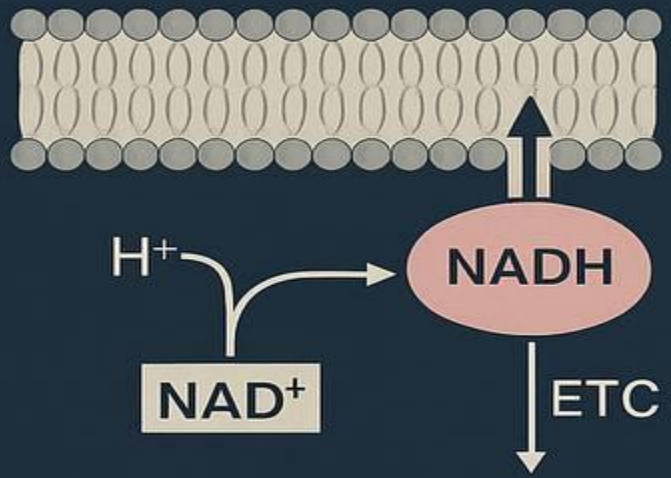
Net electron transfer: 2 NADH

Net reaction**:** 2 pyruvate molecules

pyruvate enters the **citric acid cycle** to produce more energy.

Chemiosmostic Mechanism – Stage 1: Electron Transport Begins

- Hydrogen atoms are removed from food molecules
- Each hydrogen → 1 proton (H^+) + 1 electron (e^-)
- Electrons go to NAD^+ → NADH
- NADH carries electrons to the Electron Transport Chain (ETC)

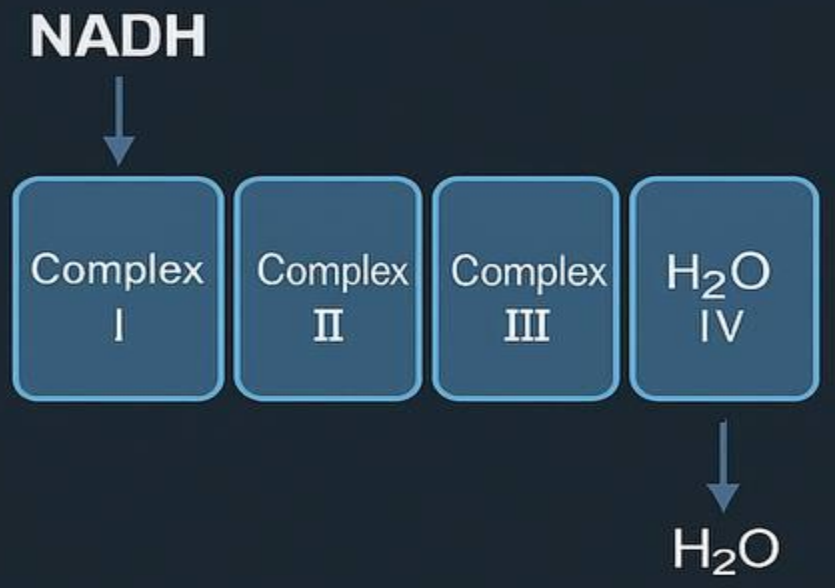


Step 1: Hydrogen Ionization & NADH Formation

Result: NADH becomes the main carrier of high-energy electrons used to make ATP

CHEMIOSMOTIC MECHANISM – STAGE 2: ELECTRON TRANSPORT AND WATER FORMATION

- Electrons from NADH and $FADH_2$ enter the Electron Transport Chain (ETC) inside the inner mitochondrial membrane.
- Each electron passes through a series of carriers (Complex I → IV), releassing ener-gy at every step
- The released energy is used to pump H* ions across the membrane, building an electrochemical gradient
- Finally, oxygen acts as finafinal electron acceptor, combining with H" to form water

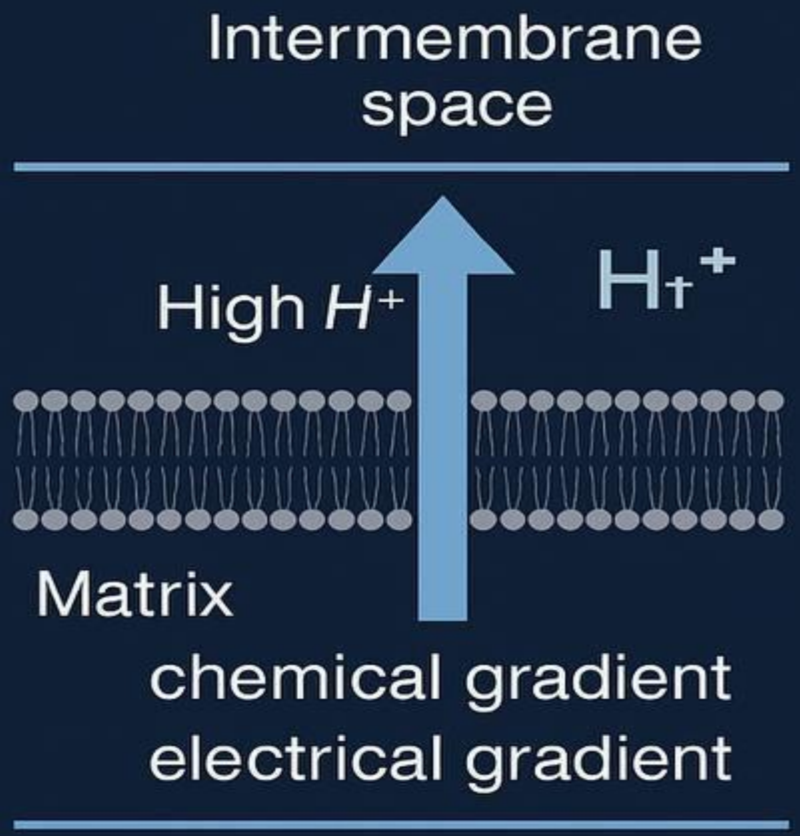


Step 2: Electron Flow and Water Formation

Result: Electrons flow through the ETC → energy is released → oxygen converts to water → hydrogen

CHEMIOSMOTIC MECHANISM – STAGE 3: PROTON PUMPING AND ENERGY GRADIENT

- The *Electron Transport* Chain (ETC) releases energy as electrons move between complexes.
- This energy is used to pump H^+ ions from the mitochondrial matrix to the intermembrane space.
- As a result, a high H^+ concentration builds up outside the inner membrane.
- This creates both:
  - a chemical gradient (difference in H^-)
  - and an electrical gradient (inside negative, outside positive)

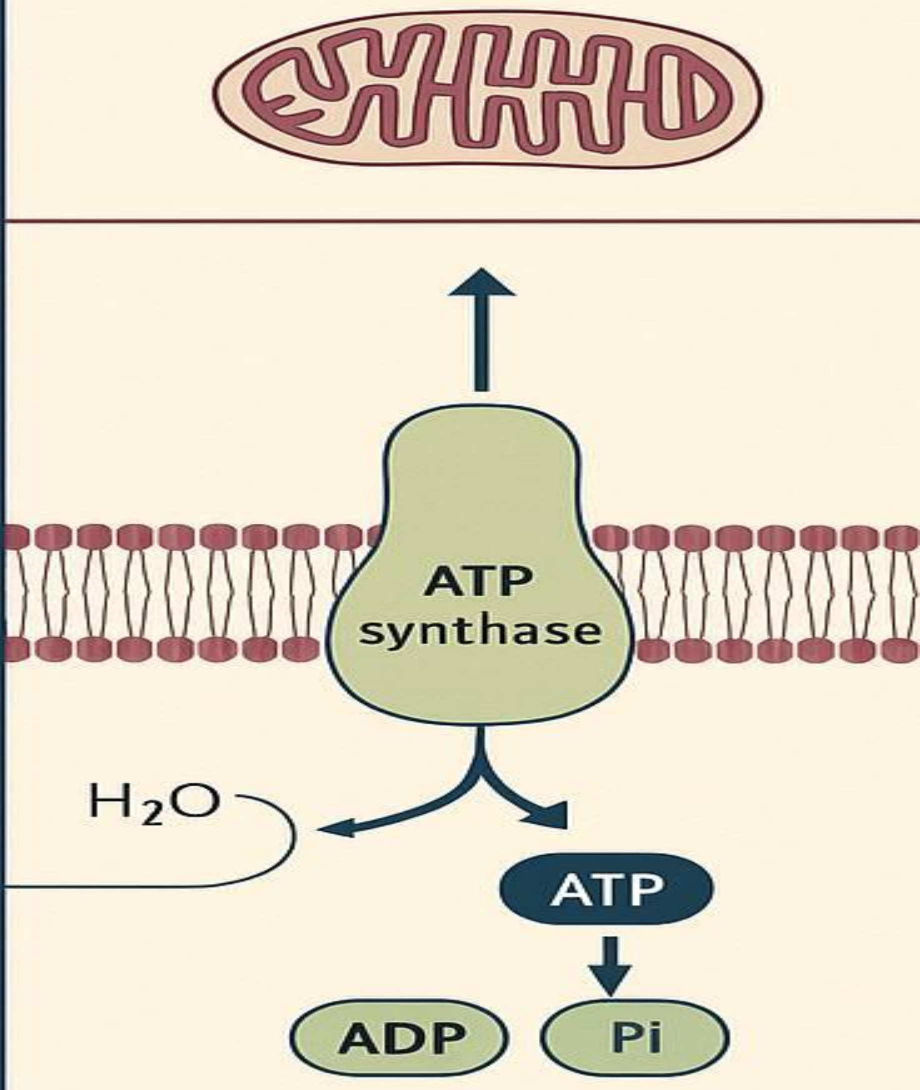


Step 3: Building the Proton Gradient for ATP Production

CHEMIOSMOTIC MECHANISM OF THE MITOCHONDRIA TO FORM ATP

Stage 3: Formation of ATP

- The high concentration of positively charged hydrogen ions in the outer chamber and the large electrical potential difference across the inner membrane cause the hydrogen ions to flow into the inner mito-chondrial matrix through the substan-ce of the ATPase molecule.
- In doing so, energy derived from this hydrogen ion flow is used by ATPase to convert ADP into ATP by comb-ining ADP with a free ionic phosphate radical (Pi), thus adding another high-energy phosphate bond to the molecule.



SUMMARY OF ATP FORMATION DURING THE BREAKDOWN OF GLUCOSE

Pathways	Sit	Main goal	ATP net	Other products
Glycolysis	Cytoplasm	Produce 2 pyruvate molecules	2	2 NADH 2 Pyruvate
Connected stage	Mitochondrial matrix	Conversion of Pyruvic Acid to Acetyl Coenzyme A(Acetyl-CoA)	0	2 CO_2 2 NADH 2 Acetyl-CoA
Citric Acid Cycle	Mitochondrial matrix	Produce high-energy electrons	2	8 NADH 2 $FADH_2$
Oxidative Phosphorylation	Mitochondria matrix and inner membrane	Produce high amount of ATP	34	6 O_2 12 H_2O 2 FAD 10NAD^+

EFFECT OF ATP AND ADP CELL CONCENTRATIONS IN CONTROLLING GLYCOLYSIS AND GLUCOSE OXIDATION

- Continual release of energy from glucose when the cells do not need energy would be an extremely wasteful process.

- Instead, glycolysis and the subsequent oxidation of hydrogen atoms are continually controlled **based on** the need of the cells for ATP.

- This control is *accomplished by* the effects of cell concentrations of both ADP and ATP.

EFFECT OF ATP AND ADP CELL CONCENTRATIONS IN CONTROLLING GLYCOLYSIS AND GLUCOSE OXIDATION

ATP role in control energy metabolism(glycolysis and glucose oxidation) :

1. **Inhibit** the enzyme **phosphofructokinase** (promotes the formation of fructose-1,6-diphosphate, one of the initial steps in the glycolysis).
2. Slow or stop glycolysis by the net effect of **excess** cellular **ATP**, which in turn stops most carbohydrate metabolism.

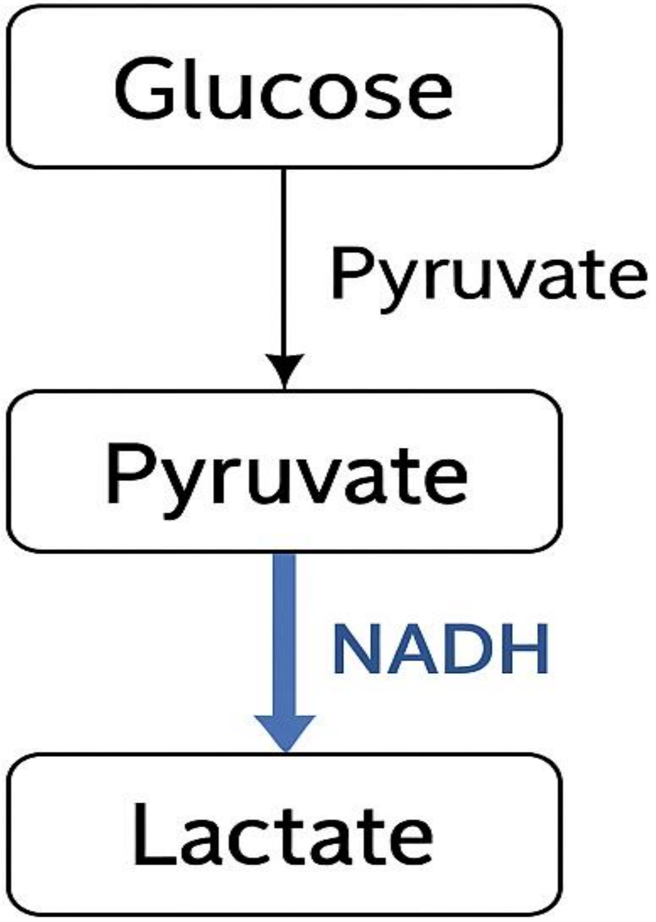
ADP (and AMP as well) role in control energy metabolism(glycolysis and glucose oxidation) :

1 **Increasing** enzyme **phosphofructokinase** activity.

2 **Increase** glycolysis by the net effect of **excess** cellular **ADP**.

Lactic Acid Fermentation (Anaerobic Glycolysis)

- Occurs when oxygen is limited (anaerobic conditions).
- Pyruvate is reduced to Lactate by the enzyme Lactate Dıhydrogenase (LDH).
- Reaction: Pyruvate + NADH ← Lactate + NAD^+
- Regenerates NAD^+ allowing glycolysis to continue ATP production.
- Net yield: 2 ATP per glucose molecule
- Lactate diffuses to the bloodstream and can be reconverted to glucose in the liver (Cori cycle)



Lactic acid fermentation regeenerates NAD^+ under anaeroblc onditions

Summary & Key Points

- Glycolysis: Glucose →2 Pyruvate + 2 ATP + 2 NADH
- Lactic Fermentation: Pyruvate → Lactate (regenerates NAD^+)
- TCA cycle in murbankm edation
  Produces 6 NADH, 2 $FADH_2$, 2 GTP
- Oxidative phosphorylation
  ~26–28 ATP generated
- Total yield ≈ 30–32 ATP per glucose molecule
- Regulation: High ATP inhibits PFK-1; High ADP activates glycoly

ATP production steps	
Step	**ATP yield**
Glycolysis	2
TCA cycle	2
Oxidative phosphorylation	26 – 28

Integrated overview of ATP production from carbohydrate metabolism


thank
you