Cellular Respiration

Definitions

A. Cellular respiration=the controlled release of energy in the form of ATP

-Can be aerobic of anaerobic

B. ATP=adenosine triphosphate

-a chemical that can diffuse to any part of the cell and release energy

-made from organic compounds in the cells through cellular respiration

Overall process

A. Organic compounds + oxygen →
carbon dioxide + water + energy

B. Food is the fuel for cellular respiration
-food=organic compounds (carbs/fats/proteins)

C. Cellular respiration is a catabolic pathway (it releases energy by breaking down complex molecules)

D. We will study the breakdown of glucose

ATP is recycled by the cells

- $ATP + H_2O \rightarrow ADP + P_i$ + energy
- ATP is hydrolyzed to form ADP, inorganic phosphate and energy

  -An exergonic reaction

C. The inorganic phosphate will attach to another ATP molecule

D. The new ATP molecule is phosphorylated

$ADP + P_i \rightarrow ATP + H_2O$

-This an endergonic reaction

Redox reactions

A. Cellular respiration involves movement of electrons (gain or loss)
B. Redox reactions indicate movement of electrons
C. Oxidation=
    -gain oxygen -lose electrons
D. Reduction=
    -lose oxygen -gain electrons

Redox reactions

E. Two ways to remember

1. OIL RIG (refers to electron movement)
   - oxidation is loss
   - reduction is gain
2. LEO the lion goes GER
   LEO (lose electrons oxidation)
   GER (gain electrons reduction)

Redox reactions

F. The most common carrier is NAD^+

G. H atoms have one proton and one electron

H. When two H atoms are removed from a substrate NAD^+ accepts the electrons from both atoms and a proton from one of them

I. $NAD^+ + 2H \rightarrow NADH + H^+$

#4. Redox reactions

I. $NAD^+ + 2H \rightarrow NADH + H^+$

Has no charge because it took the electron from the free H to neutralize the original NAD+

Has a (+) charge because its electron is attached to the NADH

- $NAD^+ + 2H \rightarrow NADH + H^+$

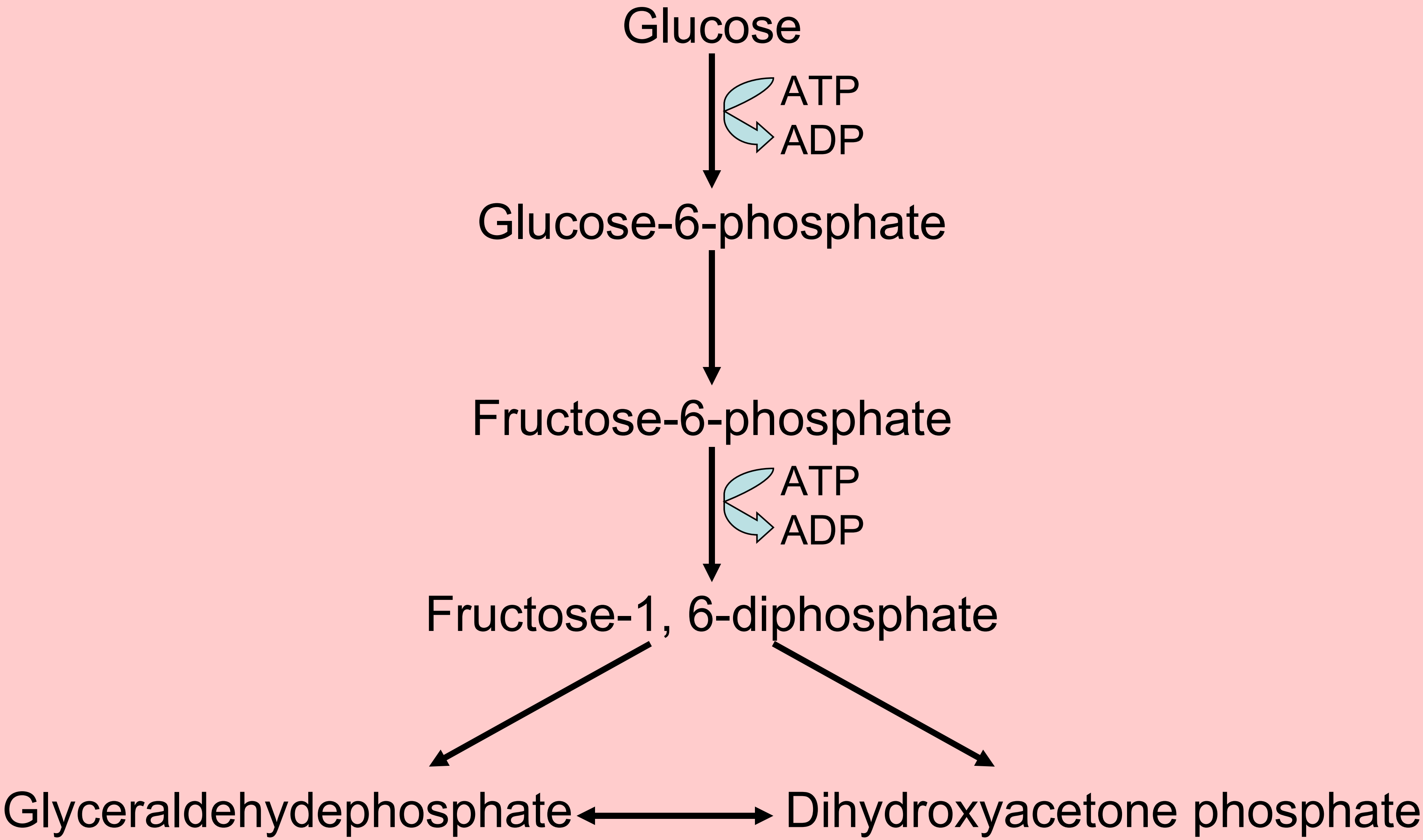
*Determine which molecules were oxidized and which were reduced

Oxidation	**Reduction**
Gain oxygen	Lose oxygen
Lose hydrogen	Gain hydrogen
Lose electrons	Gain electrons

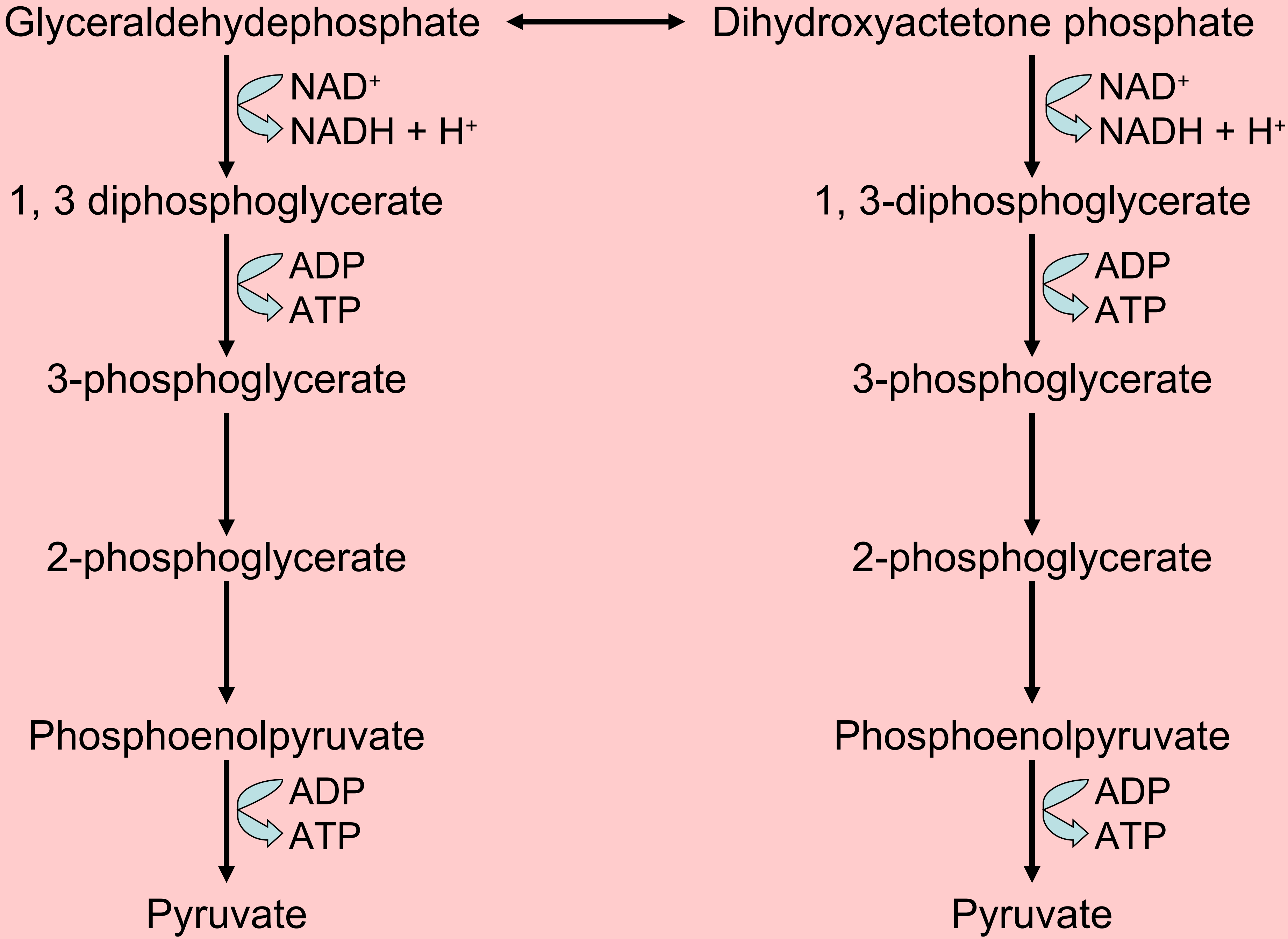
Glycolysis

- Glycolysis-'splitting of sugar' (1^{st} step of cellular respiration)
- Break down of glucose into 2 pyruvate molecules
- One 6-carbon sugar is broken down into two 3-carbon sugars
- Takes place in the cytoplasm (a.k.a. cytosol)
- Oxygen is not required for glycolysis

Glycolysis



these two are isomers of each other


Glyceraldehydephosphate
Dihydroxyactetone phosphate
NAD+
NADH + H+
1, 3 diphosphoglycerate
ADP
ATP
3-phosphoglycerate
2-phosphoglycerate
Phosphoenolpyruvate
ADP
ATP
Pyruvate
NAD+
NADH + H+
1, 3-diphosphoglycerate
ADP
ATP
3-phosphoglycerate
2-phosphoglycerate
Phosphoenolpyruvate
ADP
ATP
Pyruvate

Glycolysis

Review

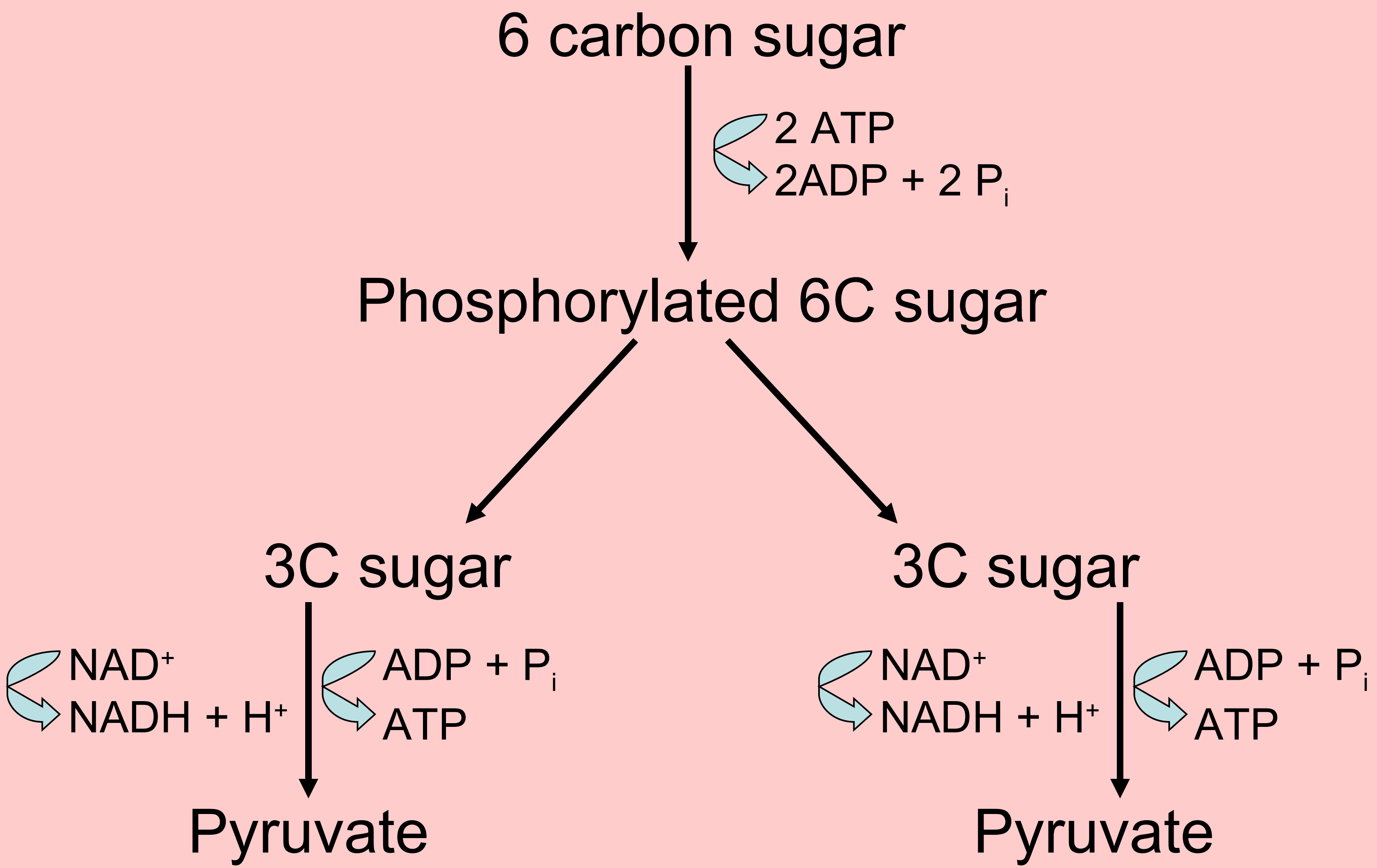
- Explain what is happening during each step of the reaction. See the red book to help you with your explaination.
- How many ATP molecules are gained?
- How many NADH + H^+ are gained?
- When energy is released, what is formed?

Glycolysis (an overview)

$$\text{Glucose} + 2\text{ADP} + 2\text{P}_i + 2\text{NAD}^+ \longrightarrow$$

$$2\text{Pyruvate} + 2\text{ATP} + 2\text{NADH} + 2\text{H}^+ + 2\text{H}_2\text{O}$$

Glycolysis (another overview)



Glycolysis (the products)

A. Overall products
  -2 Pyruvate
  -2 ATP
  -2 NADH
  -2 H^+
  -2 H_2O

B. NAD+ is reduced to NADH

C. 6 carbon sugar is broken down into two 3-carbon sugars

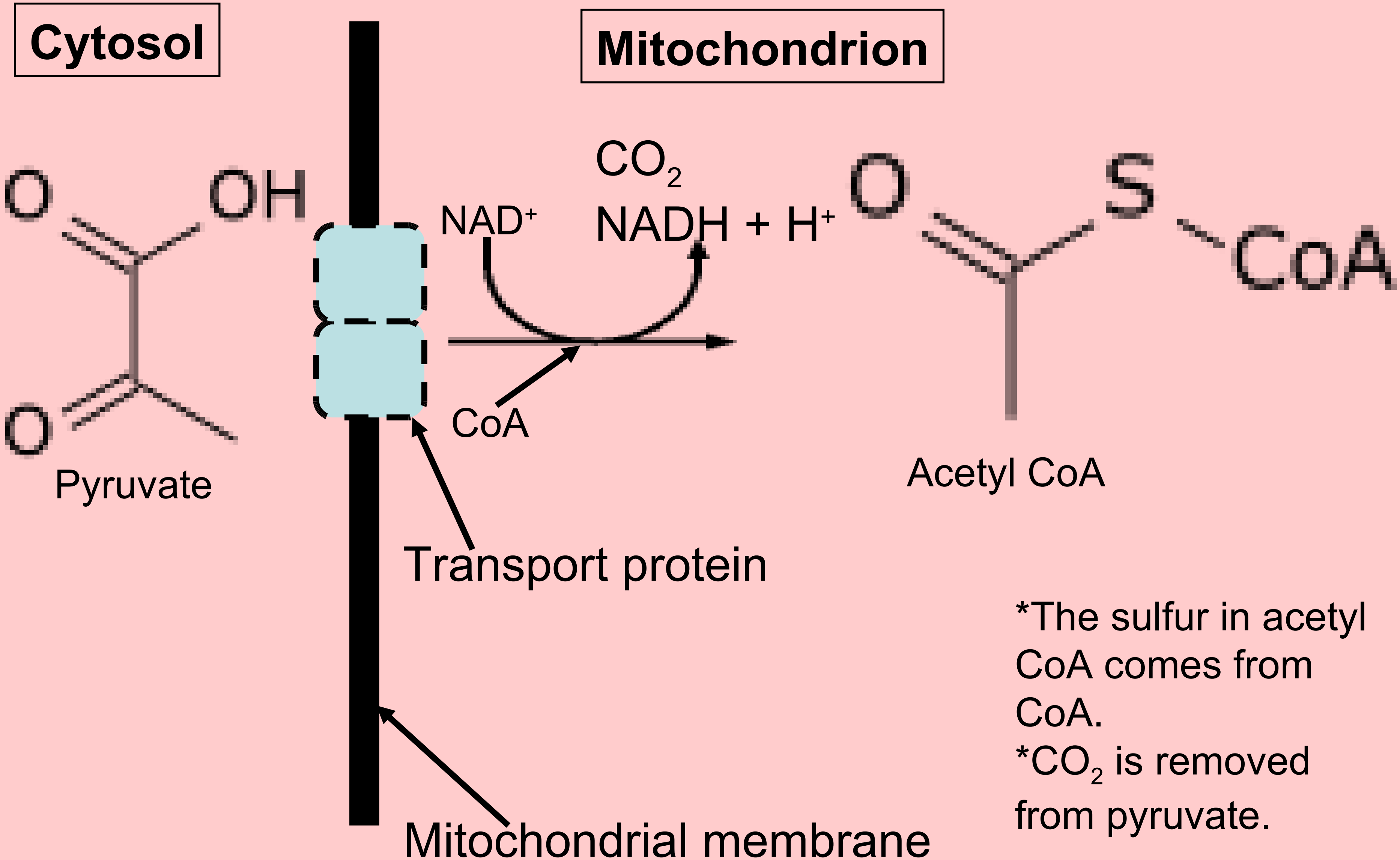
D. The 3-carbon are oxidized to pyruvate

Oxidative decarboxylation (the link reaction)

A. Pyruvate gets converted into acetyl coenzyme A (acetyl CoA)
B. This step is between glycolysis and the Kreb's cycle
C. Occurs in the mitochondria
D. Pyruvate + CoA + $NAD^+ \rightarrow$

Acetyl CoA + CO_2 + NADH + H^+

Oxidative decarboxylation



*The sulfur in acetyl CoA comes from CoA.
*CO_2 is removed from pyruvate.

The Krebs Cycle
(a.k.a the citric acid cycle)

- After glycolysis, **if oxygen is present**, the pyruvate molecules move from the cytoplasm to the mitochondria. Then they go through **oxidative decarboxylation (the link reaction)**.
- Next step=Krebs cycle

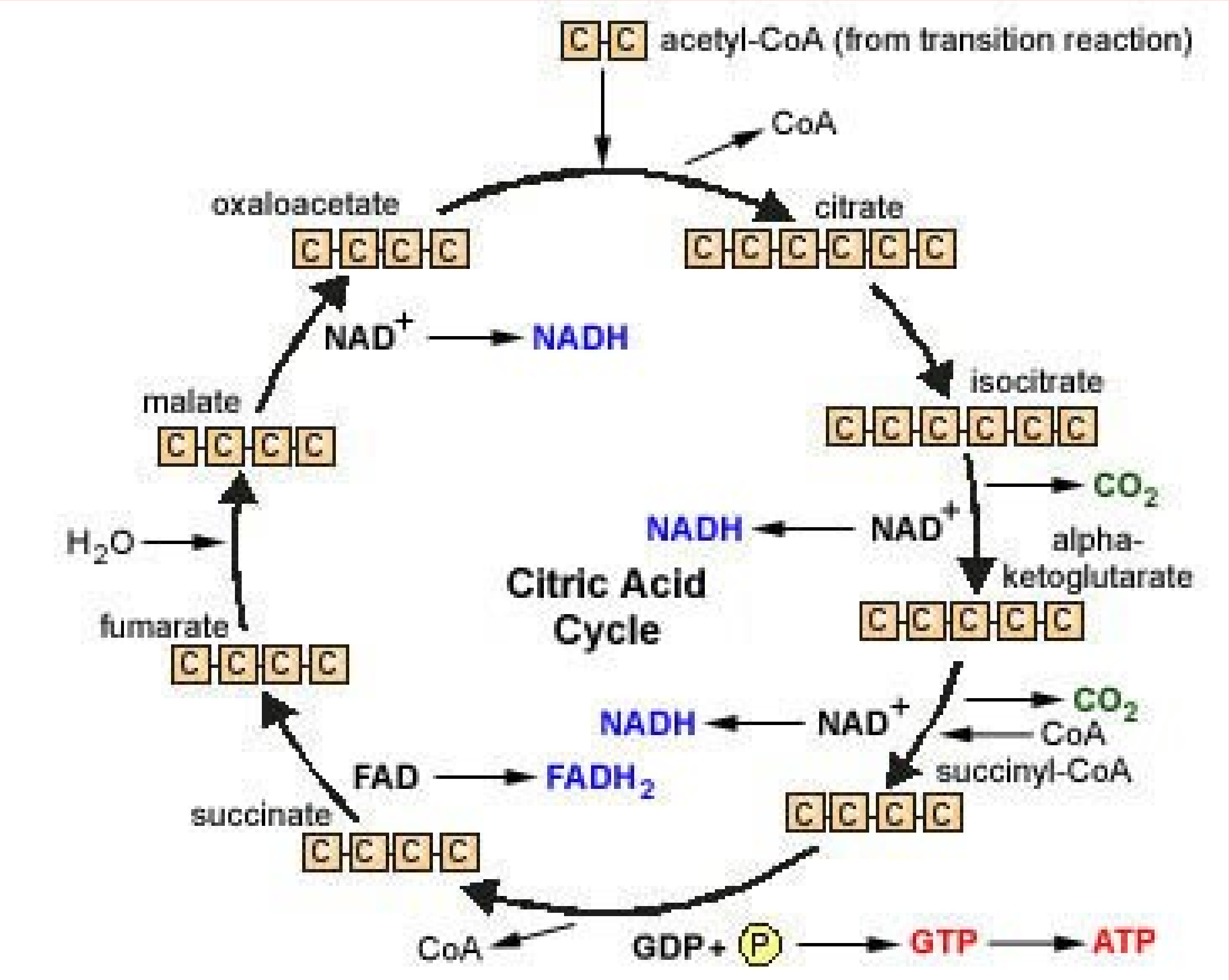
The Kreb's cycle

C. Kreb's cycle=a metabolic process that completes the breakdown of glucose

-occurs in the mitochondria and starts with pyruvate molecules that were produced in glycolysis

-requires oxygen, thus it is part of aerobic respiration

The Kreb's cycle



The Kreb's cycle

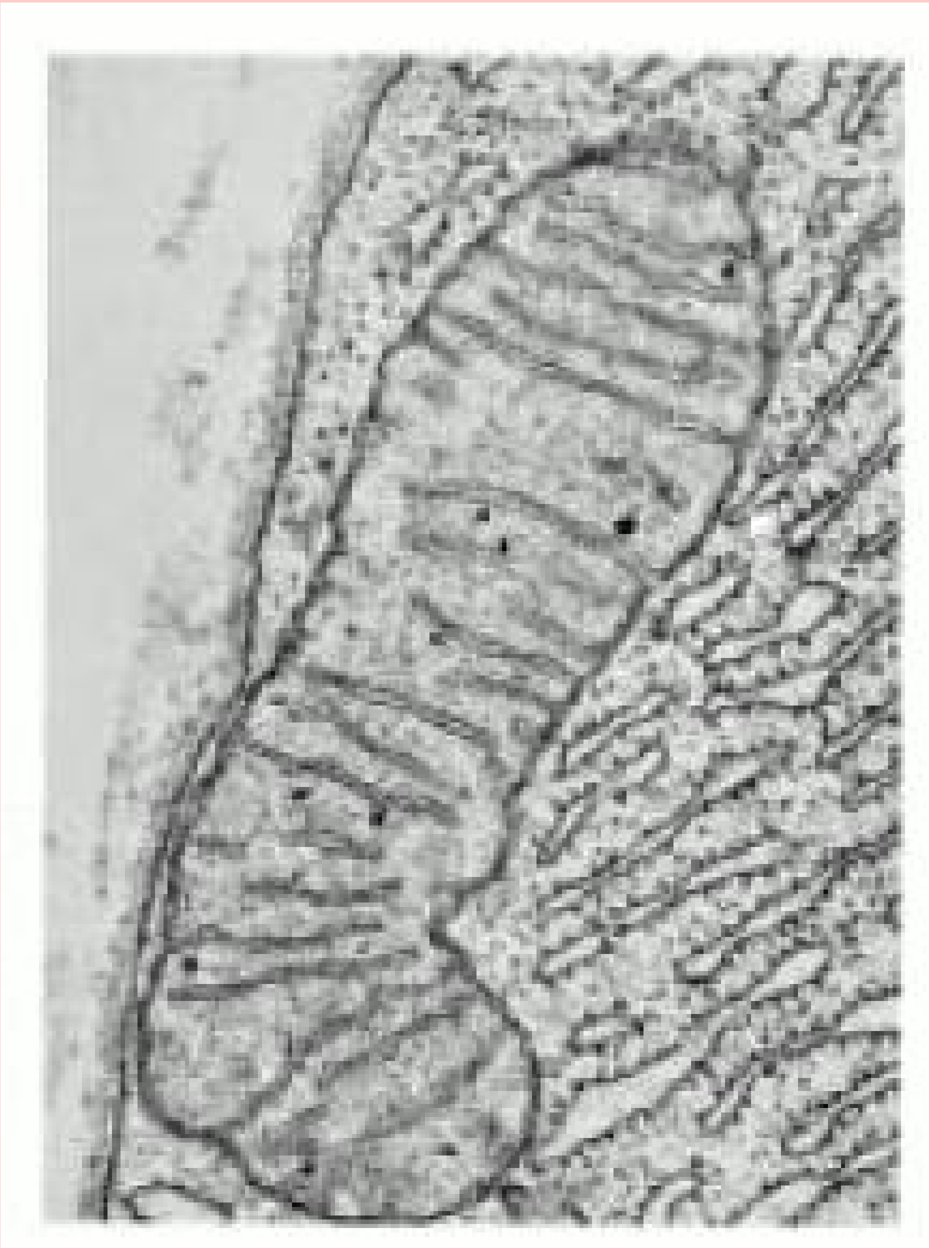
D. Krebs cycle animation1

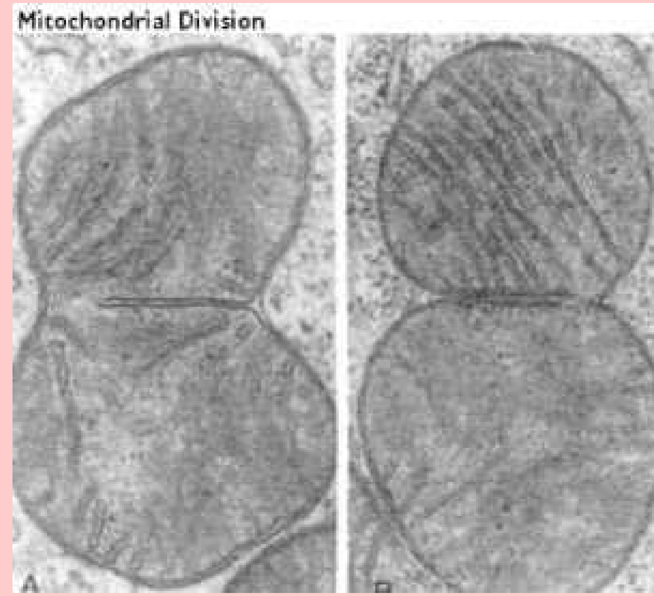
E. Products of Krebs cycle

- $2CO_2$
- 1ATP
- $1FADH_2$
- $3NADH + H^+$

} Per turn of the Krebs cycle

Electron micrographs of mitochondria





Assignment

Draw and annotate a diagram of a mitochondrion as seen in an electron micrograph.

Include the following:

- -intermembrane space
- -cristae
- -circular DNA
- -inner membrane
- -matrix
- -outer membrane

Oxidative Phosphorylation and the Electron Transport Chain

A. General electron pathway

food→NADH→ETC→oxygen

B. ETC is a series of electron carriers located in the inner membrane of the mitochondria

Oxidative Phosphorylation and the Electron Transport Chain

C. NADH supplies two electrons to the ETC

$NAD^+ + 2H \rightarrow NADH + H^+$

D. In the ETC electrons move through the chain reducing and oxidizing the molecules as they pass

E. The ETC is made mostly of proteins

F. The NADH molecules transport the electrons to the ETC

-$FADH_2$ is added at a lower energy level

Oxidative Phosphorylation and the Electron Transport Chain

G. The electrons move down the mitochondrial membrane through the electron carriers

H. A concentration gradient is generated

-positive in the intermembrane space

Oxidative Phosphorylation and the Electron Transport Chain

I. At the end of the ETC oxygen accepts hydrogen and one electron to form water

J. The H^+ ions that passed through the proteins into the cytoplasm flow through ATP synthase into the mitochondrial matrix

K. The energy generated by the proton movement creates ATP by joining ADP and P_i

Oxidative Phosphorylation and the Electron Transport Chain

M. If no oxygen is available the ETC stops

- -NADH is not converted back to NAD+, and $FADH_2$ is not converted back to FAD
- -If no NAD+ is available for oxidative decarboxylation (the link reaction) the Krebs cycle cannot occur
- -Glycolysis continues because oxygen is not required

Oxidative Phosphorylation and the Electron Transport Chain

J. NADH produces 3 ATP per molecule

K. $FADH_2$ produces 2 ATP per molecule

Oxidative Phosphorylation and the Electron Transport Chain

A quick review

2. NADH and FADH2 pass electrons to the ETC
3. As electrons move along the chain H+ ions are removed from the matrix and put in the intermembrane
4. This creates a proton gradient
5. The ionized H atoms have potential energy because they are charged

Oxidative Phosphorylation and the Electron Transport Chain

5. H+ flows through ATP synthase (an enzyme) into the mitochondrial matrix
6. ATP is then produced
7. About 34 ATP come from oxidative phosphorylation

ATP Production During Aerobic Respiration

A. Glycolysis

- -2 ATP — -2H_20
- -2 NADH +H^+ — -2Pyruvate

B. Oxidative decarboxylation (per glucose)

- -2 acetyl CoA — -2CO_2
- -2 NADH +H^+

C. Krebs cycle (per glucose not per turn)

- -2ATP — -2CO_2
- -6 NADH +H^+ — -2$FADH_2$

D. Oxidative phosphorylation

- -34 ATP (you must account for NADH and $FADH_2$)

E. Total ATP production = 38 ATP per glucose

Chemiosmotic Theory

A. Proposed by Peter Mitchell
B. Chemiosmosis=diffusion of ions across a membrane
   -relates to ATP synthesis and H+ ions across the mitochondrial membrane
C. H+ ions diffuse from an area of high concentration to an area of low concentration
D. Movement of H+ ions creates an electrochemical gradient of protons
E. The energy from the H+ ions is used to make ATP
F. ATP synthase makes ATP via chemiosmosis
G. The energy from the H+ ions is captured in ATP

The Mitochondrion Structure

A. Outer membrane-separates mitochondria from the cytoplasm
B. Inter membrane space- has higher amounts of H+ ions because of the ETC
C. Inner membrane-folded into cristae to increase surface area

   -impermeable to H+ ions

   -contains electron carriers and ATP synthase

- Matrix-contains enzymes for the Krebs cycle
- H+ ions get pumped from the matrix to the inter membrane through the proteins in the inner membrane

Anaerobic respiration

- Without oxygen
- Pyruvate remains in the cytoplasm (no link reaction, no Krebs cycle)
- Pyruvate is converted into waste and removed from the cells
- No ATP is produced (except from glycolysis)
- In humans the waste=lactate (lactic acid)
- In yeast the waste=ethanol and CO_2

Anaerobic respiration

G. Once the pyruvate is converted into waste, the cells can go through glycolysis again

H. If pyruvate was not converted into waste the cells would not go through glycolysis

(Glycolysis produces pyruvate. If it is already present there is no reason to make more.)

Anaerobic respiration in animals

A. Example: During exercise our bodies require a lot of energy

-The body can only supply a limited amount of oxygen for cellular respiration

-Energy is not produced at the rate required

-Cells will use anaerobic respiration to release extra energy

-This produces lactic acid (a waste product)

Anaerobic respiration in yeast

A. We use yeast to make bread
B. CO_2 produced causes bread to rise by creating air pockets
C. The ethanol (alcohol) produced evaporated during baking

Anaerobic respiration is also known as . . .

A. Lactic acid fermentation-breaks down pyruvate into lactic acid

   -in muscles of animals

B. Ethanol fermentation

   -performed by yeast and some bacteria

   -breaks down pyruvate into ethanol and CO_2

Fat and Protein Breakdown

A. Fats

-have more energy per gram than carbohydrates or proteins (~2x as much)

-fatty acid chains are oxidized and broken into smaller 2 carbon chains

-the 2 carbon chains are converted into acetyl CoA to enter the Kreb's cycle

Fat and Protein Breakdown

B. Proteins

-must be converted into individual amino acids

-excess a.a. are converted by enzymes into intermediated of glycolysis and Krebs cycle

-a.a. go through deamination (amino groups are removed)

-nitrogenous wastes from the amino groups are released as wastes

-new compounds enter glycolysis or Krebs