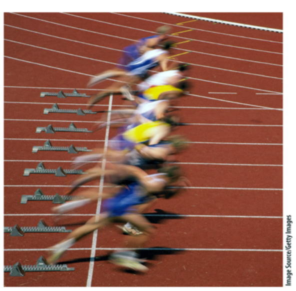
Lecture 23: Agenda

- Announcements
- Topic 9: Energetics and Enzyme Kinetics
  - Case study
  - Michaelis-Menten mdel of enzymes kinetics
- Topic 10: Cellular Respiration

Announcements

- NO SIS until the week after Thanksgiving
- Last discussion after Thanksgiving
- No WQ this week
- No info about the exam results yet.
- Several animations for Ch 7 have been assigned.
- LC Ch7 moved to Monday after Thanksgiving



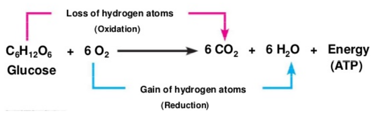
Topic 10: Cellular Respiration

Cellular Respiration
Learning objectives

- Explain how energy if transferred from the chemical bonds of macromolecules like carbohydrates to ATP and electron carriers.
- Describe each of the 4 stages of cellular respiration in terms of reactants molecules, products and amount of energy produced.
- Recognize that most of the energy produced during cellular respiration is through oxidative phosphorylation.
- Describe what molecules are oxidized and what molecules are reduced in the whole process of cellular respiration.
- Compare and contrast Glycolysis and Fermentation.
- Predict how the cellular response would change depending on its energy level.

Oxidation-Reduction (Redox) Reactions imply transfer of energy

- An atom or molecule that loses an electron is said to be "oxidized"; an atom or molecule that gains an electron is said to be "reduced"
- These reactions are always linked – the energetic electrons are transferred when bonds are made or broken



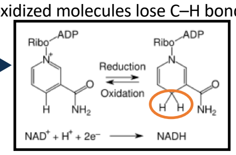
+H = reduced

− H = Oxidized

Oxidation-Reduction (Redox) Reactions imply transfer of energy

- Energetic electrons carry potential energy so the molecule gaining electrons gains potential energy
- Redox reactions involving organic molecules such as NAD+ or FAD, **the gain (or loss) of electrons often implies the gain (or loss) of protons (H+)**. Reduced molecules increase C–H bonds, and the corresponding oxidized molecules lose C–H bonds.

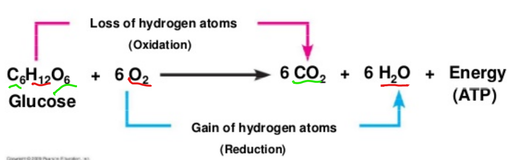
NAD^+ to NADH →



$NaD^+ \xrightarrow{\text{reduced}} NaDH$

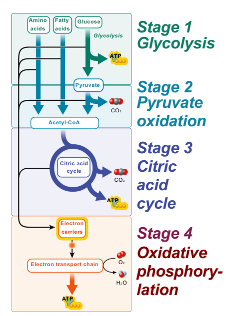
$FAD \xleftarrow{\text{oxidation}} FADH_2$

Rearrangement of hydrogen atoms (with their electrons) in the redox reactions of cellular respiration



A cellular respiration equation

Cellular Respiration



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Stages 1 & 2: Fuel molecules are partially broken down, producing ATP and electron carriers.

Stage 3: Fuel molecules are fully broken down, producing ATP and electron carriers.

Stage 4: Electron carriers donate electrons to the electron transport chain, leading to the synthesis of ATP.

Cellular Respiration Stages

1. Glycolysis (cytoplasm)
2. Pyruvate oxidation (mitochondria)
3. Citric acid cycle (mitochondria)
4. Oxidative phosphorylation (mitochondria)

catabolic

Carbohydrate Catabolism

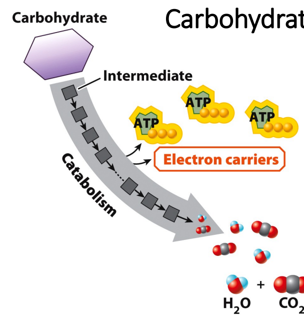

Figure 7.3a
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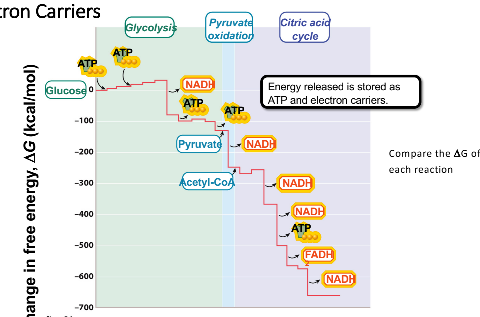
carb energy ends up in electron carrier

Electron Carriers



Compare the ΔG of each reaction

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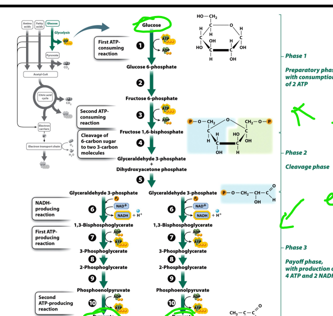
exogonic

Stage 1: Glycolysis



-2ATP

endergonic

exogenic

+2ATP

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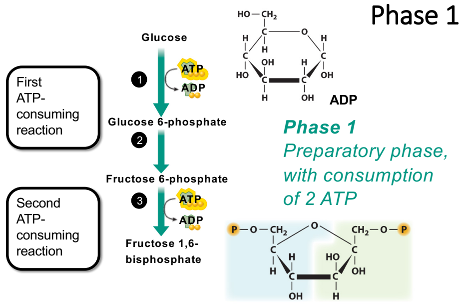
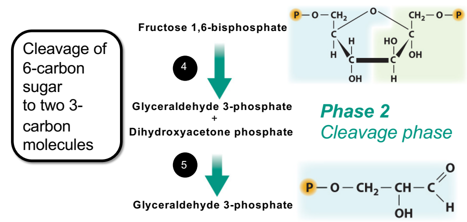
-2ATP + glucose => 2 Pyruvate + 2ATP

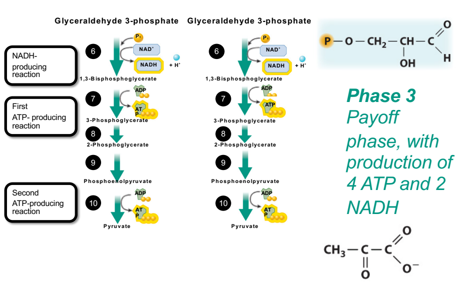
Phase 1



Phase 2



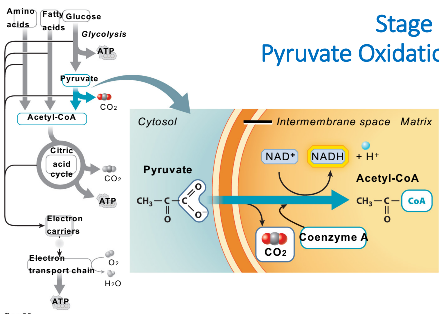
Phase 3



At the End of Glycolysis

- 4 ATP – 2 ATP used during phase 1 = 2 ATP (net gain)
- 2 NADH
- 2 molecules of Pyruvate
- Pyruvate is the substrate for the Pyruvate Oxidation

Stage 2: Pyruvate Oxidation



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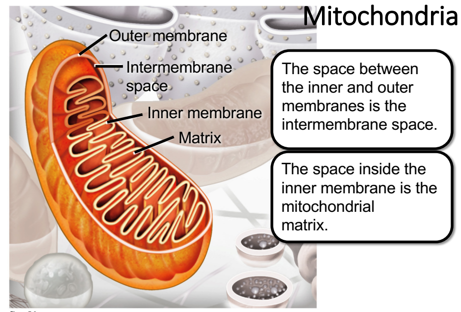
Mitochondria



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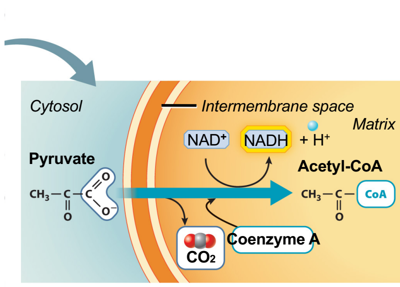
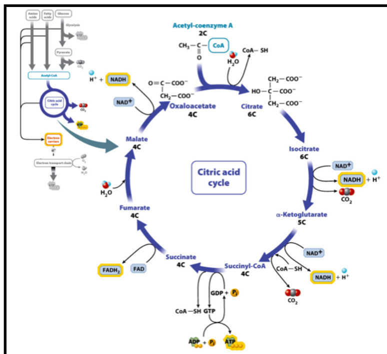
Pyruvate Oxidation



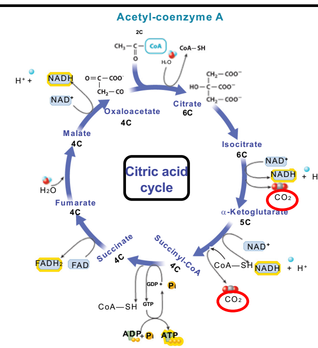
At the End of Pyruvate Oxidation:

- Remember we started with 2 pyruvate molecules
- 2 NADH, $2CO_2$, and 2 Acetyl-CoA.
- Acetyl-CoA is the substrate of the citric acid cycle



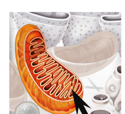
Stage 3: Citric Acid Cycle

Acetyl-CoA is completely oxidized



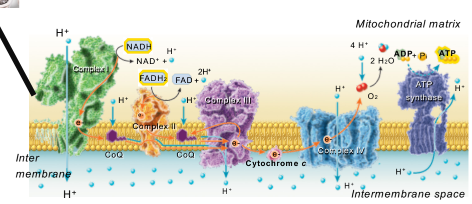
At the End of citric acid cycle:

- Remember we started with 2 acetyl-CoA molecules
- 6 NADH, 2 $FADH_2$, $2CO_2$, and 2 ATP.
- The electron carriers NADH and $FADH_2$ will donate electrons in the electron transport chain to make ATP by oxidative phosphorylation



Stage 4: Electron Transport Chain

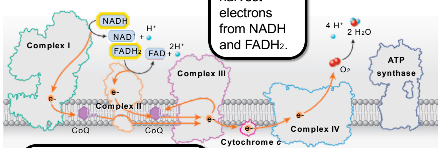
The electron transport chain in cellular respiration



Electron Transport Chain

Electron transport

Complexes I and II harvest electrons from NADH and $FADH_2$.



Coenzyme Q is reduced to $CoQH_2$ and transfers electrons from complexes I and II to complex III.

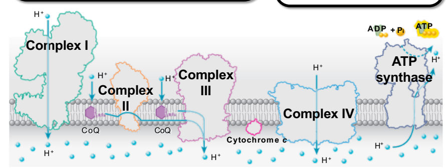
Cytochrome *c* moves to complex IV where oxygen is reduced to form water.

Electron Transport Chain

Proton transport and ATP synthesis

The transport of electrons in complexes I, III, and IV is coupled with the transport of protons across the inner membrane, from the mitochondrial matrix to the intermembrane space.

ATP synthase uses the electrochemical proton gradient to drive the synthesis of ATP.

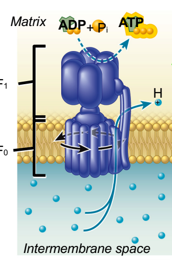


– 2 units
allows protons to move back
rotates

ATP Synthase

2 The F_1 subunit then uses this rotational energy to catalyze the synthesis of ATP.

1 The F_0 subunit forms a channel that rotates as protons pass through it.



– make ATP
– rotates
+ allows H+ to escape
= fuels SU

ATP synthase is a molecular machine that is composed of two subunits, F_0 and F_1.

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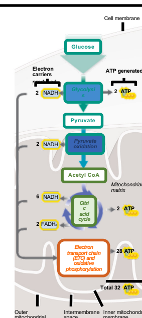


32 ATP

The Flow of Energy in Cellular Respiration

11/20/19

Substrate-level phosphorylation = 4 ATP

Oxidative phosphorylation = 28 ATP

TABLE 7.1 Approximate Total ATP Yield in Cellular Respiration.

PATHWAY	SUBSTRATE-LEVEL PHOSPHORYLATION	OXIDATIVE PHOSPHORYLATION	TOTAL ATP
Glycolysis (glucose → 2 pyruvate)	2 ATP	2 NADH = 5 ATP	7
Pyruvate oxidation (2 pyruvate → 2 acetyl-CoA)	0 ATP	2 NADH = 5 ATP	5
Citric acid cycle (2 turns, 1 for each acetyl-CoA)	2 ATP	6 NADH = 15 ATP 2 $FADH_2$ = 3 ATP	20
Total	4 ATP	28 ATP	32

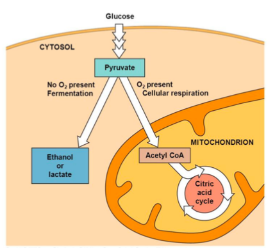
Remember

- Matter doesn't become energy.
- During aerobic respiration, glucose becomes progressively oxidized up to CO_2
- Energy released as molecules are broken down is coupled to the synthesis of ATP via substrate phosphorylation or stored in electron carriers (NADH and $FADH_2$) as those get reduced.
- Most of the ATP is produced by oxidative phosphorylation

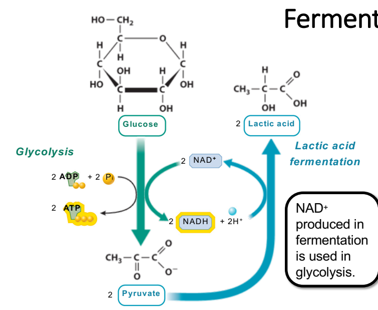
$$C_6H_{12}O_6 + 6O_2 \rightarrow 6\ CO_2 + 6\ H_2O + ATP$$

In the absence of oxygen, glucose is broken down via fermentation

- Likely, a primitive form of metabolism, from before the atmosphere had oxygen
- Faster but less efficient: produces less energy because glucose is only partially oxidized
  - Lactic acid fermentation (animals & bacteria)
  - Ethanol fermentation (fungi & plants)



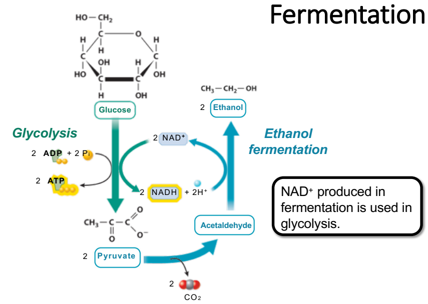
Fermentation



Glucose + 2 ADP + 2 P_i → 2 lactic acid + 2 ATP + 2 H_2O

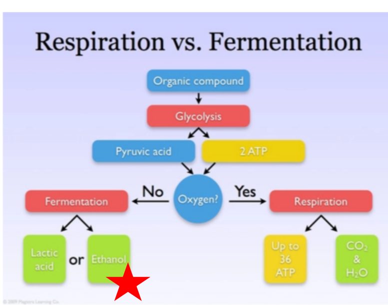
During intense exercise, there may be not enough oxygen (do you have a heart rate monitor?).

Fermentation



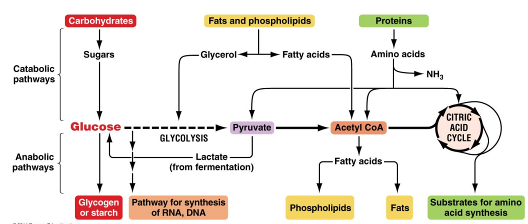
Glucose + 2 ADP + 2 P_i → 2 ethanol + 2 ATP + 2 H_2O + 2CO_2

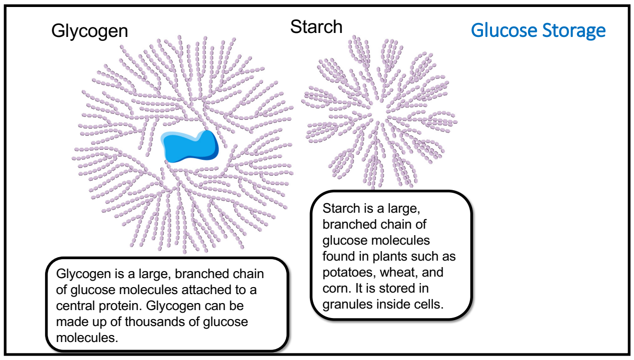
latic acid is by-product of fermentation

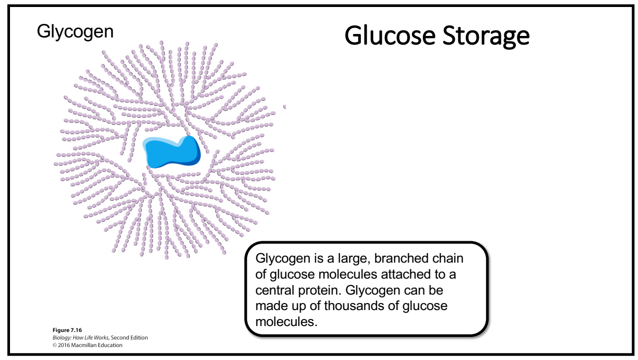


Note that both forms of fermentation only produce 2 ATPs (from glycolysis)

Not all macromolecules get broken down. If they are in excess, they get stored




Glycogen
Starch
Glucose Storage
Starch is a large, branched chain of glucose molecules found in plants such as potatoes, wheat, and corn. It is stored in granules inside cells.
Glycogen is a large, branched chain of glucose molecules attached to a central protein. Glycogen can be made up of thousands of glucose molecules.


Glycogen
Glucose Storage
Glycogen is a large, branched chain of glucose molecules attached to a central protein. Glycogen can be made up of thousands of glucose molecules.
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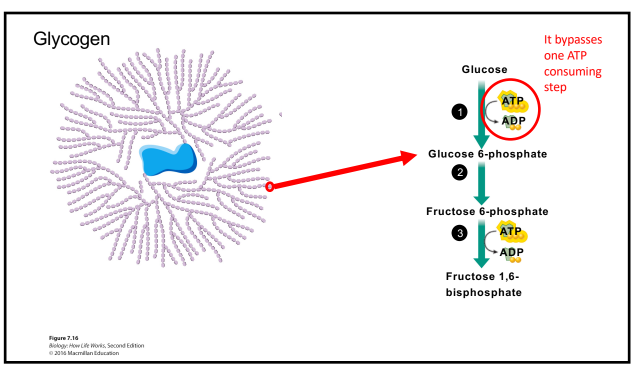
Glycogen
It bypasses one ATP consuming step
Glucose
1
ATP
ADP
Glucose 6-phosphate
2
Fructose 6-phosphate
3
ATP
ADP
Fructose 1,6-bisphosphate
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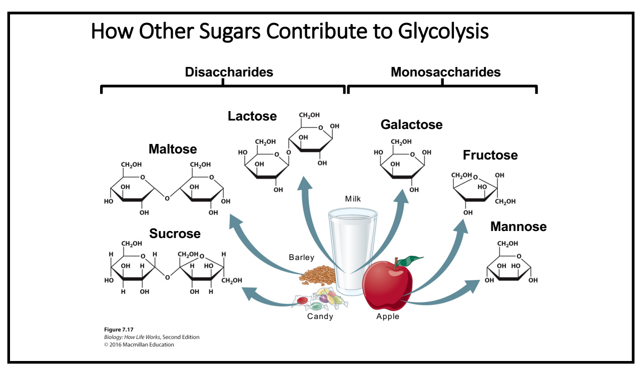
How Other Sugars Contribute to Glycolysis
Disaccharides
Monosaccharides
Lactose
Galactose
Maltose
Fructose
Sucrose
Mannose
Milk
Barley
Candy
Apple
Figure 7.17
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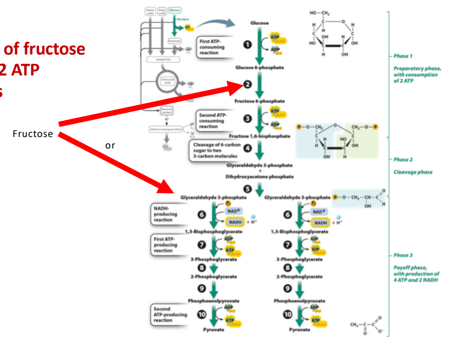
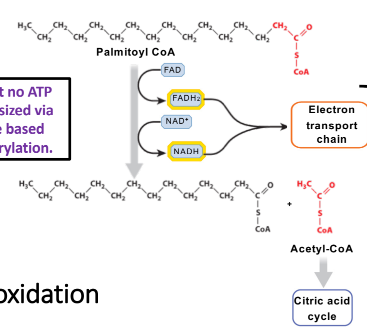
The metabolism of fructose can bypass 1 or 2 ATP consuming steps



Fatty acids are good source of energy



Note that no ATP is synthesized via substrate based phosphorylation.

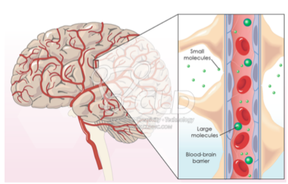
A lot of ATP

But red blood cells and brain don't like this energy

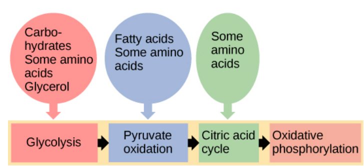
β-oxidation

A note about why brain and RBC cannot use ATP from fats

- RBC don't have mitochondria, actually get their energy by fermentation. β-oxidation takes place in the mitochondria…
- The brain is protected by a blood-brain barrier. This barrier prevents the access of lipids. So, even though CNS cells do have mitochondria, lipids are not accessible.



For more information, go to:
https://www.nature.com/scitable/topicpage/dynamic-adaptation-of-nutrient-utilization-in-humans-14232807



1 gr sugar = 4 cal
1 gr fat = 9 cal
1 gr protein = 4 cal