Bio101 – Sept 10 lecture notes

Cellular respiration: The process by which organisms break down 'food' molecules* (especially glucose) to make ATP:

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

* FYI: other food molecules include the other carbohydrates, and also fats and proteins that can be broken into the 3-carbon molecule pyruvate…(we will not study this in detail…but you will in Bio103 with Dr. Betancourt)

A couple of quick notes mentioned in lecture:

1) the chemical equation for cellular respiration is the reverse of photosynthesis (which we will cover next week) except that lots of ATP is made!
2) We emphasized the point that plants DO conduct cellular respiration. Although they can construct their own sugars (through photosynthesis), they must run these through cellular respiration in order to generate ATP.

ATP (Adenosine triphosphate): A molecule whose bonds have very high potential energy and which serves as the universal energy currency in cells.

(FYI: The breakdown of ATP to ADP + P produces energy that is used by cells for most processes that require energy: from transmembrane proteins to the twitching of muscle fibers.)

NAD and FAD: H^+ and electron "Shuttle molecules" in cellular respiration.

(NAD and FAD accept hydrogen atoms (and become **NADH / $FADH_2$**) that are split off of glucose during glycolysis, and off of shorter 3-C chains during the Krebs cycle) and they "shuttle" the H atoms (and their electrons!!) from these first two stages of cellular respiration to the electron transport chain. See Figure below!!).

Table 1: Distinguishing energy molecules and their roles.

Molecule	**Biochemical role**	**Banking analog**
Starch / Glycogen / Fats	Medium – long term and stable energy storage	Bank account
Glucose	Transportable energy storage for use in the short term	Traveler's check or personal check
ATP	Immediate energy source for cellular processes	CASH!!!
NAD/NADH and FAD/$FADH_2$	Shuttle H atoms (H^+ ions and electrons) from Glycolysis and Krebs cycle to electron transport chain where most ATP is made	Bank teller that facilitates conversion of check to cash.

So, at its essence, respiration is just the conversion of stored chemical energy in glucose to immediately usable chemical energy of ATP!!

$C_6H_{12}O_6$ + $6O_2$ → $6CO_2$ + $6H_2O$ + (ATP)
(stored chemical energy) (usable chemical energy)

Three stages of cellular respiration:

1) **Glycolysis**
2) **Krebs cycle (aka: citric acid cycle)**
3) **Electron Transport chain (aka: oxidative phosphorylation)**

1) Glycolysis: glucose is split into two 3-carbon molecules of pyruvate. H split off of glucose and added to NAD to form NADH. 2 ATP produced. Occurs in the cytoplasm.

2) Krebs cycle: Pyruvate molecules broken apart, H atoms added to NAD and FAD to form NADH and $FADH_2$. C and O atoms given off as 'waste' product CO_2. 2 ATP produced.

3) Electron transport chain (aka oxidative phosphorylation): 3 important steps in e-transport chain:

i) H atoms (H^+ and e^-) removed from shuttle molecules (NADH, FADH2)
ii) e- passed along a chain of electron receiver molecules, the energy of "falling" e^- harnessed to make ATP
iii) H+ and e^- rejoin, react w/ O2 to form H_20 (O_2 is the final electron acceptor – without it the process stops!!)

Some toxins kill cells (and thus, organisms) by interfering with the electron transport chain – two examples we mentioned in lecture were **rotenone** and **cyanide**.

Why is this process called cellular "respiration" – isn't respiration 'breathing'? Referred to as respiration because the process requires O_2 and generates CO_2 – and this is exactly why we need to breathe – to provide O_2 as the ultimate electron acceptor and get rid of the CO_2 waste product!!

So, what happens when we can't breathe, or can't breathe fast enough to supply the O_2 needed to accept electrons from the transport chain?

If O_2 is not available for cellular respiration, e- cannot be accepted by the transport chain, and therefore H atoms are not removed from NADH / $FADH_2$. As a consequence, NAD in the cell becomes depleted or completely exhausted – and ATP cannot be made and cells die

Mechanisms for generating ATP in absence of O_2

1) Alternative electron acceptors, such as S (sulfur) instead of O. Example: some prokaryotes such as sulfur reducing bacteria in anoxic conditions. The S atoms receive H atoms to form H_2S (in the same way that O accepts H atoms to from H_2O). H_2S (hydrogen sulfide) is the molecule that has the characteristic "rotten egg smell". An example of this is the Andree Clark Bird Refuge adjacent the SB Zoo every spring and summer. Why that time of year? We'll discuss later when we cover algae!

2) Fermentation…

Fermentation – a way of making ATP in the absence of O_2. There are two types of fermentation, both just simply use the breaking down of pyruvate to recycle NADH into the NAD required for glycolysis. Thus, fermentation only yields 2 ATP per molecule of glucose (the ATP is generated during glycolysis), whereas all three stages of respiration yield a combined ~32 total ATP.

Lactic acid fermentation
Waste product: lactic acid
ATP produced per glucose molecule: 2 ATP
Happens in:
A) Eukaryotes deprived of O_2 – such as you when fleeing from your older brother or other authority figure!!

B) Some bacteria and fungi.

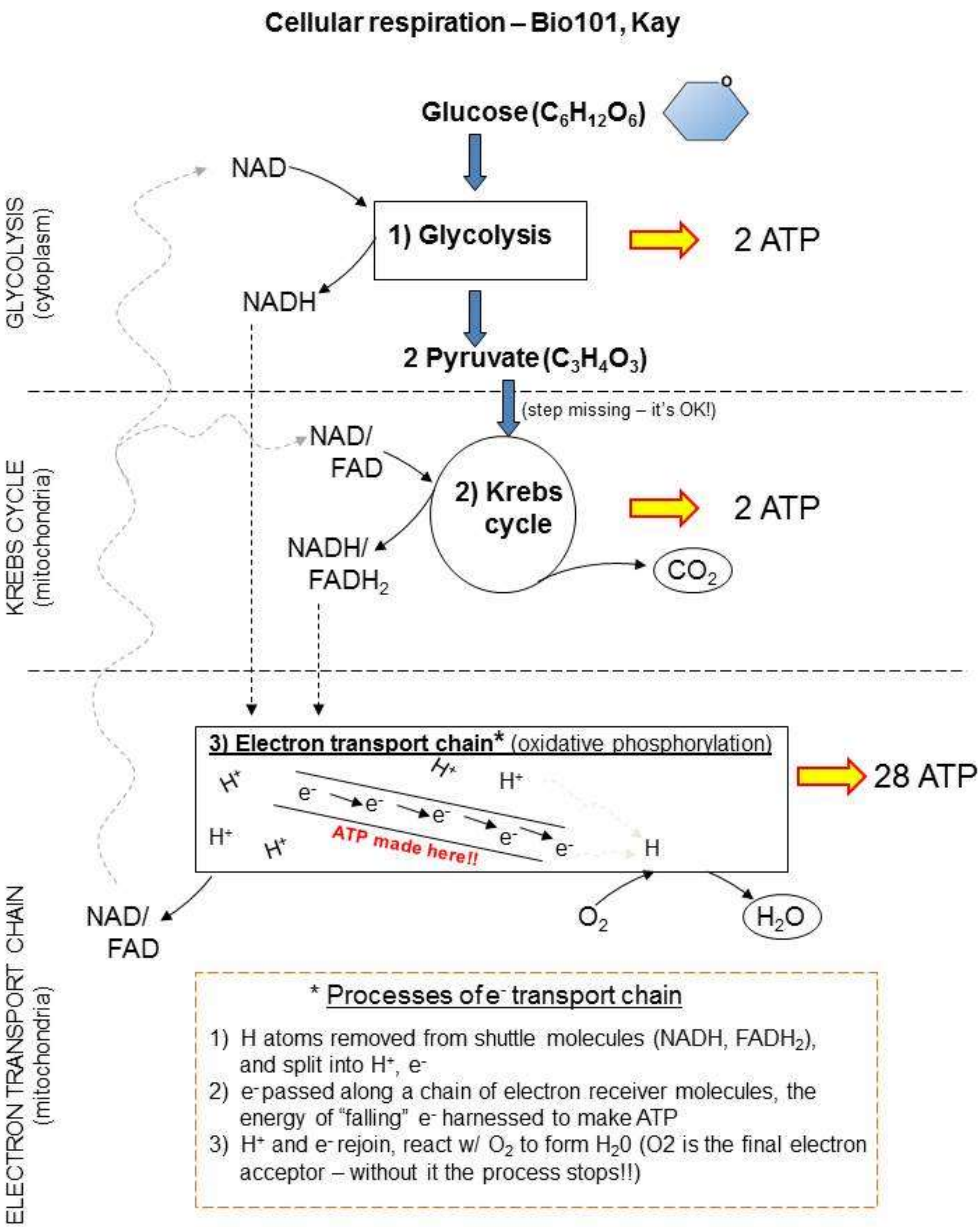
In lab (or perhaps lecture if there was time…) during we discussed/will discuss lactic acid fermentation with regard to production of dairy products such as cheese and yogurt. These contain microbes – why some yogurt says "contains live cultures"). In fact, this is where the term *Lactic* acid fermentation (as in *Lactose*) comes from. The bacteria in cheese and yogurt ferment lactose (milk sugar – contains glucose) into lactic acid, which gives this process its name. Lactic acid also gives yogurt and cheese its tangy flavor.

Regarding cheese making – we discussed the following general overview:
1) Milk is allowed to curdle (form solids, curds). Curdling is due to denaturing of casein proteins in the milk. These proteins are denatured by acids or bacteria, but more typically by the enzyme rennin (which, until very recently, has been obtained from the stomachs of calves at slaughter houses).
2) Cheese curdles are strained, water and the whey (the other major class of protein in milk, which are not denatured and remain liquid) are eliminated.
3) Curdles are pressed in a mold.
4) Cheese is aged with bacteria or fungi (or both!). Lactic acid produced by these organisms helps flavor the cheese.

We then discussed the sequential fermentation of swiss cheese. That seems like great extra credit fodder to me. Were you taking good notes?

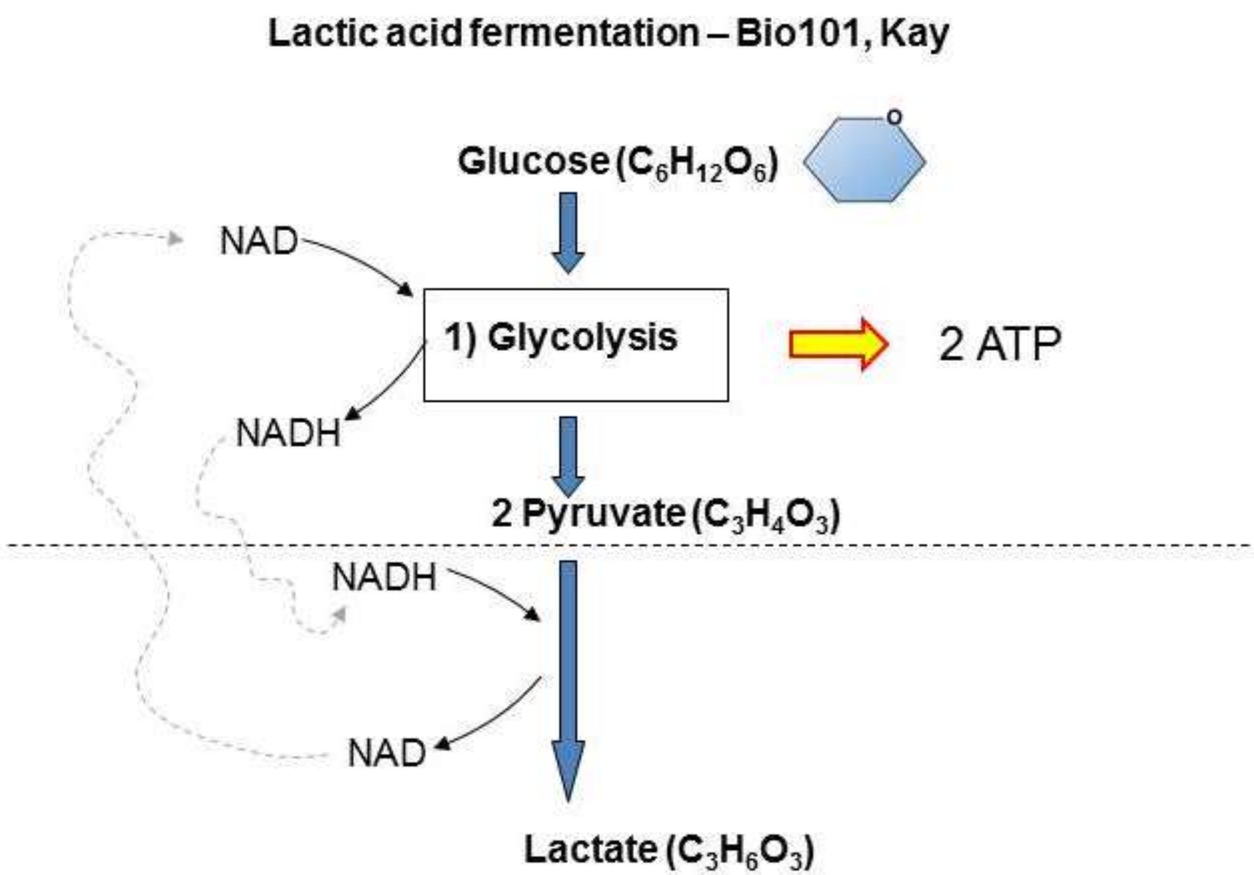
Alcohol fermentation
Waste products: ethanol, and CO_2.
ATP produced per glucose molecule: 2 ATP
Happens in: Yeasts and some bacteria.

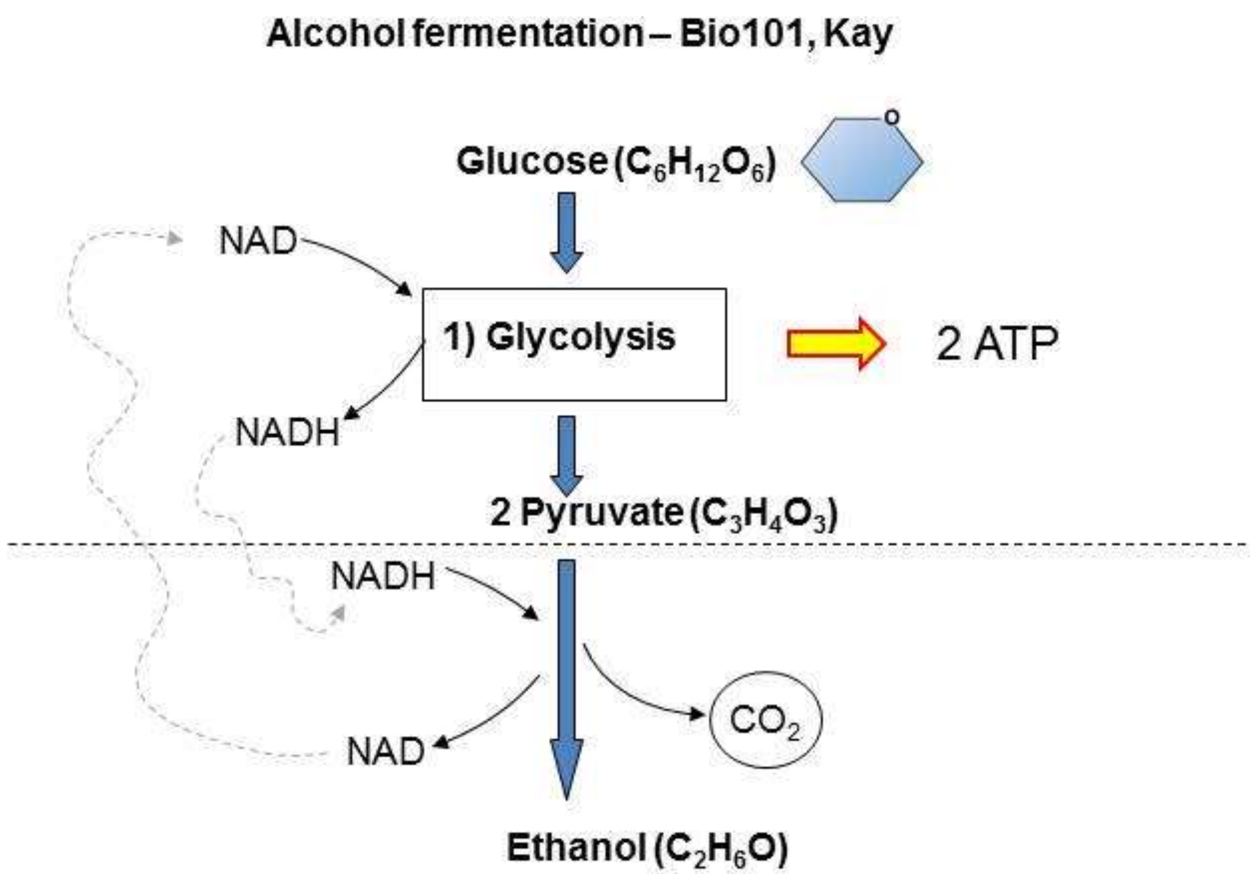
- Yeasts in anaerobic conditions are what generate ethanol and CO_2 in production of alcoholic beverages.
- In wine the CO_2 is allowed to escape, in beer it is contained…hence bubbles…).
- In wine, the sugar source is glucose and fructose in grapes.
- In beer, the story is a bit more complicated becasue the sugar source (mostly) is glucose locked up as starch...we'll discuss later in the semester.
- We will discuss this more in lab.



* Processes of e⁻ transport chain

1) H atoms removed from shuttle molecules (NADH, $FADH_2$), and split into H^+, e^-
2) e^- passed along a chain of electron receiver molecules, the energy of "falling" e^- harnessed to make ATP
3) H^+ and e^- rejoin, react w/ O_2 to form H_20 (O2 is the final electron acceptor – without it the process stops!!)


Lactic acid fermentation – Bio101, Kay
Glucose ($C_6H_{12}O_6$)
NAD
1) Glycolysis
2 ATP
NADH
2 Pyruvate ($C_3H_4O_3$)
NADH
NAD
Lactate ($C_3H_6O_3$)


Alcohol fermentation – Bio101, Kay
Glucose ($C_6H_{12}O_6$)
NAD
1) Glycolysis
2 ATP
NADH
2 Pyruvate ($C_3H_4O_3$)
NADH
CO_2
NAD
Ethanol (C_2H_6O)