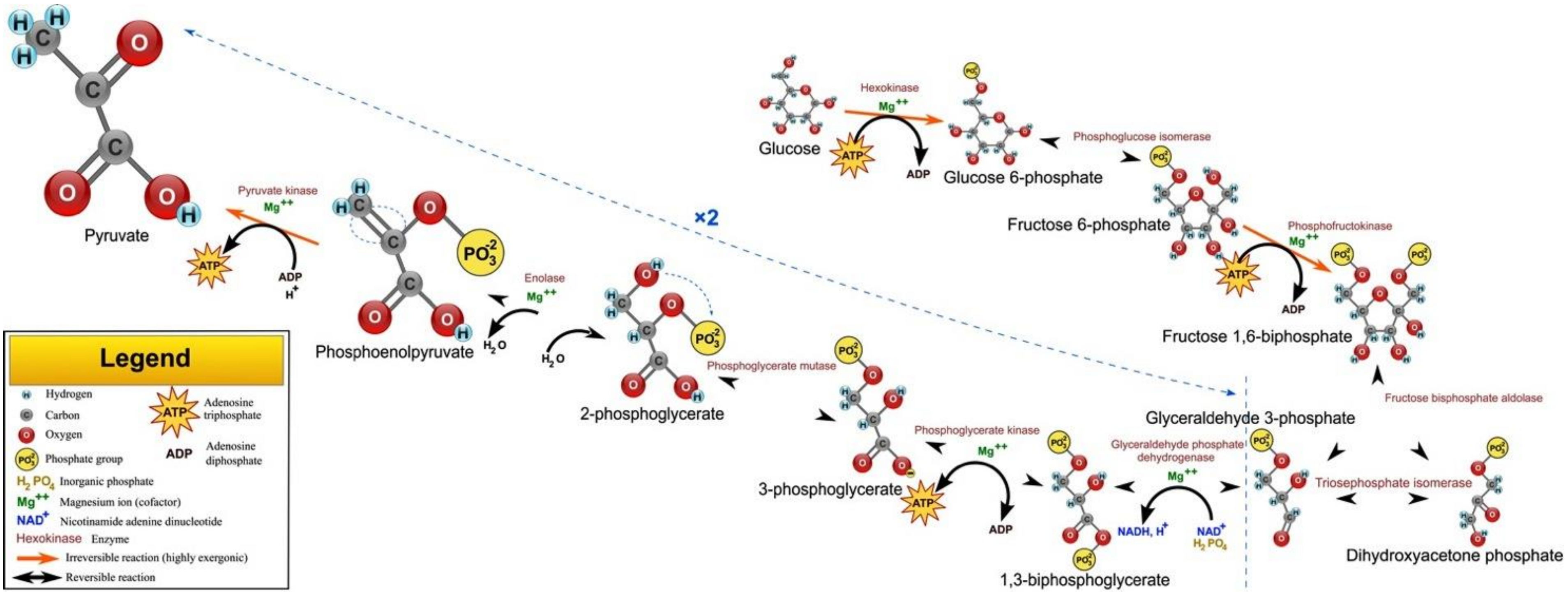
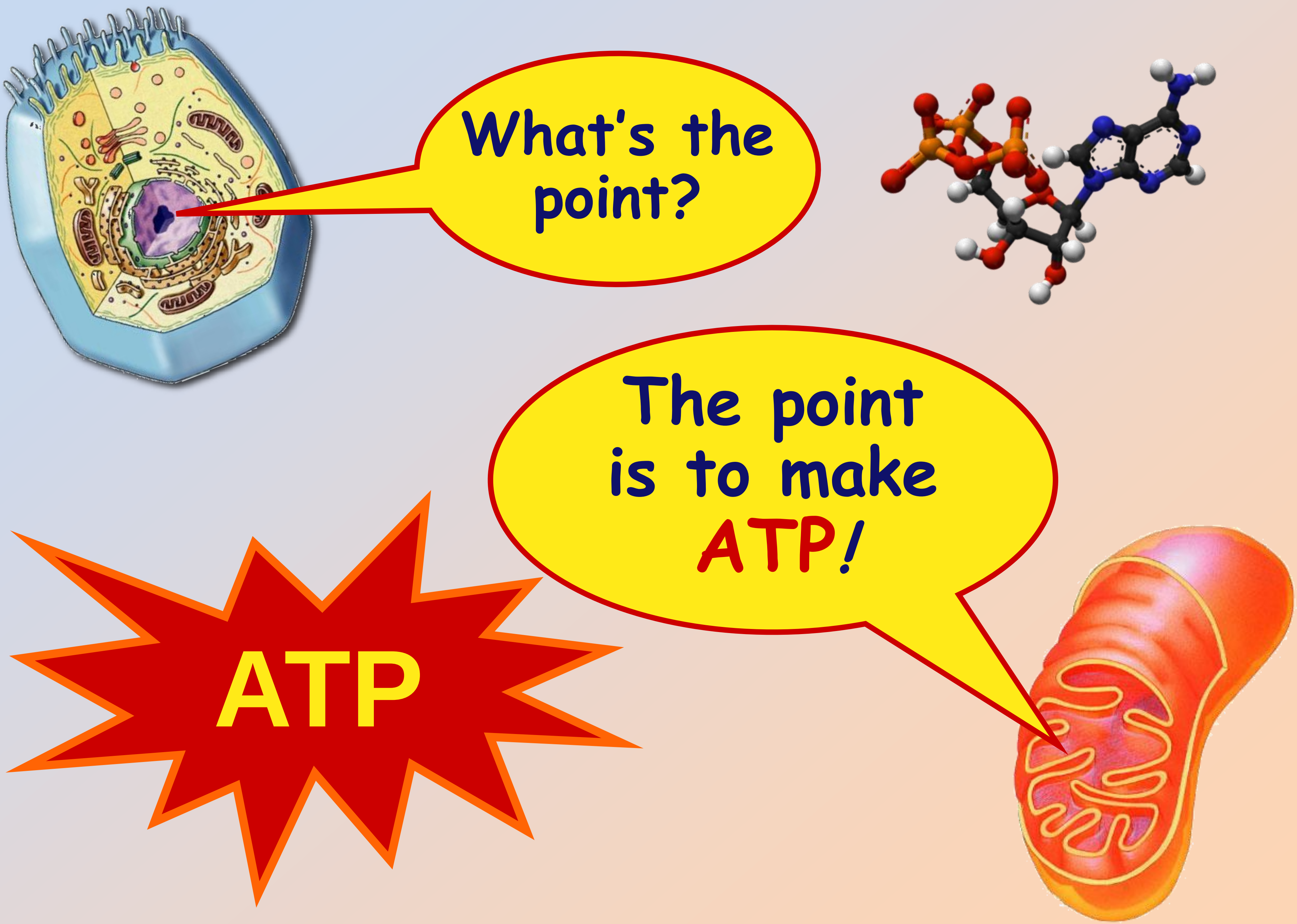


Cellular Respiration

Stage 1:

Glycolysis (Ch. 6)


What's the point?
The point is to make ATP!
ATP

Harvesting stored energy

- Energy is stored in organic molecules
  - carbohydrates, fats, proteins
- Heterotrophs eat these organic molecules → food
  - digest organic molecules to get…
    - raw materials for synthesis
    - fuels for energy



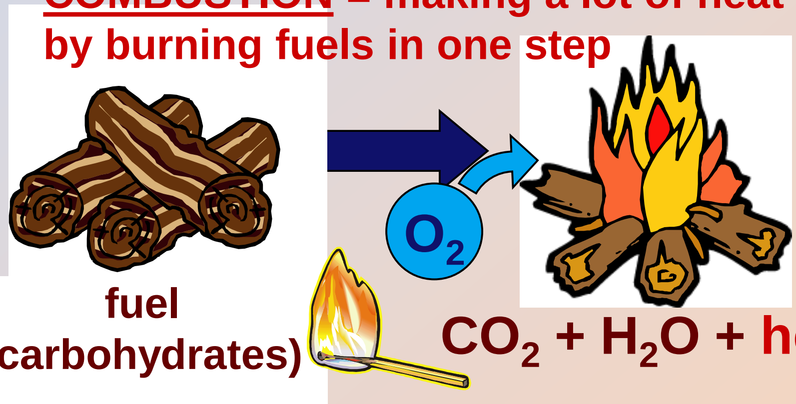
Harvesting stored energy

- Glucose is the model
  - catabolism of glucose to produce ATP

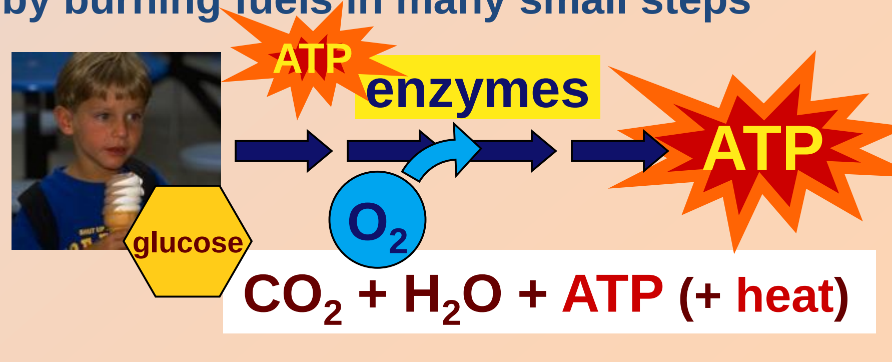
respiration

glucose	**+ oxygen**	**→**	**energy**	**+ water**	**+ carbon dioxide**		
$C_6H_{12}O_6$	$+\ 6O_2$	$\rightarrow$	**ATP**	$+\ 6H_2O$	$+\ 6CO_2$	**+ heat**	

COMBUSTION = making a lot of heat energy by burning fuels in one step

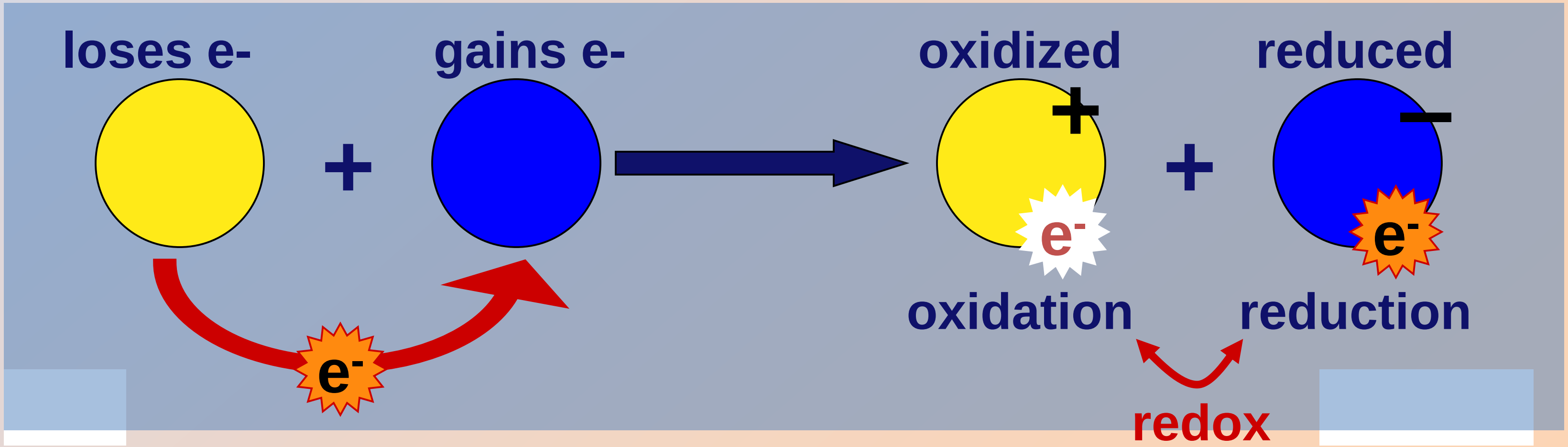


RESPIRATION = making ATP (& some heat) by burning fuels in many small steps



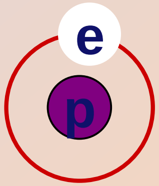
How do we harvest energy from fuels?

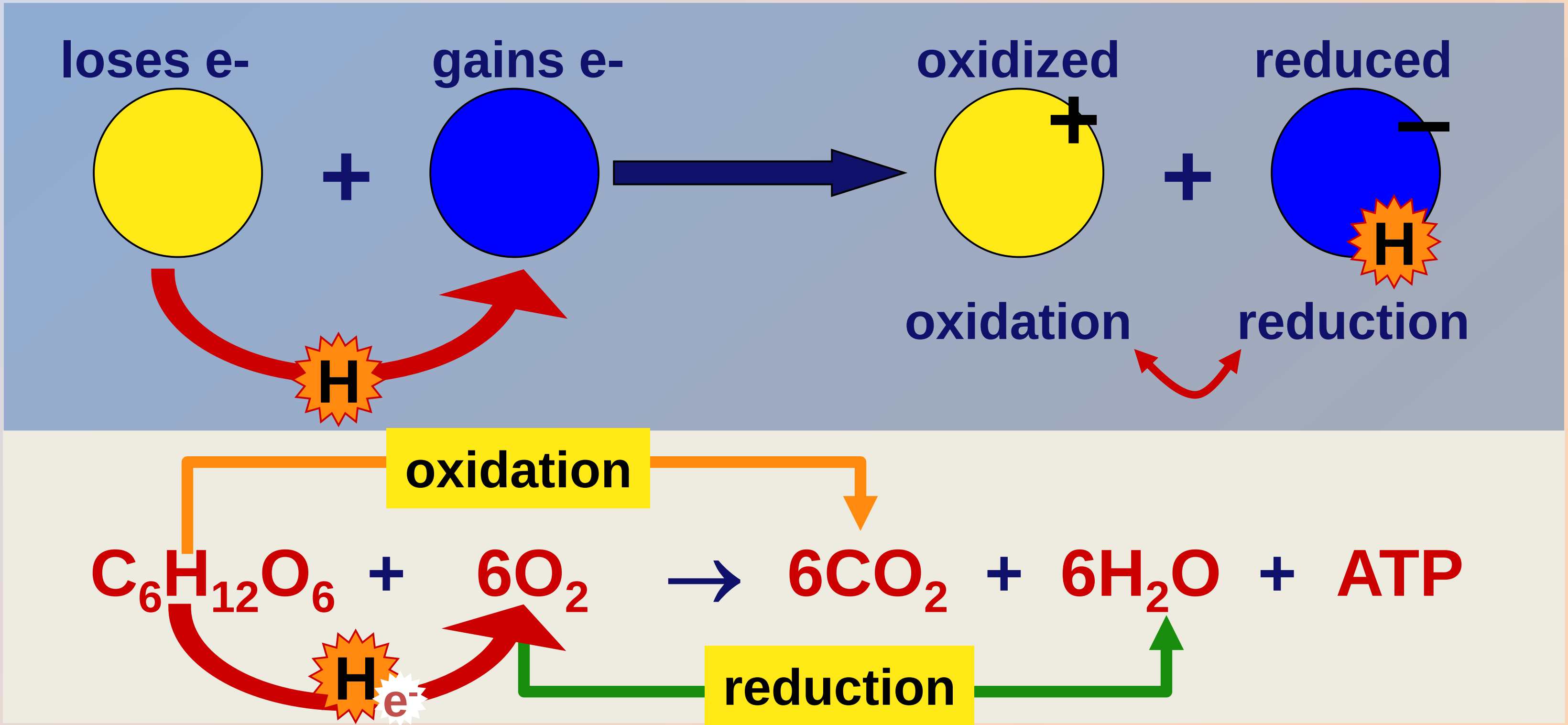
- Digest large molecules into smaller ones
  - break bonds & move electrons from one molecule to another
    - as electrons move they "carry energy" with them
    - that energy is stored in another bond, released as heat or harvested to make ATP



How do we move electrons in biology?

- Moving electrons in living systems
  - electrons cannot move alone in cells
    - electrons move as part of H atom
    - move H = move electrons

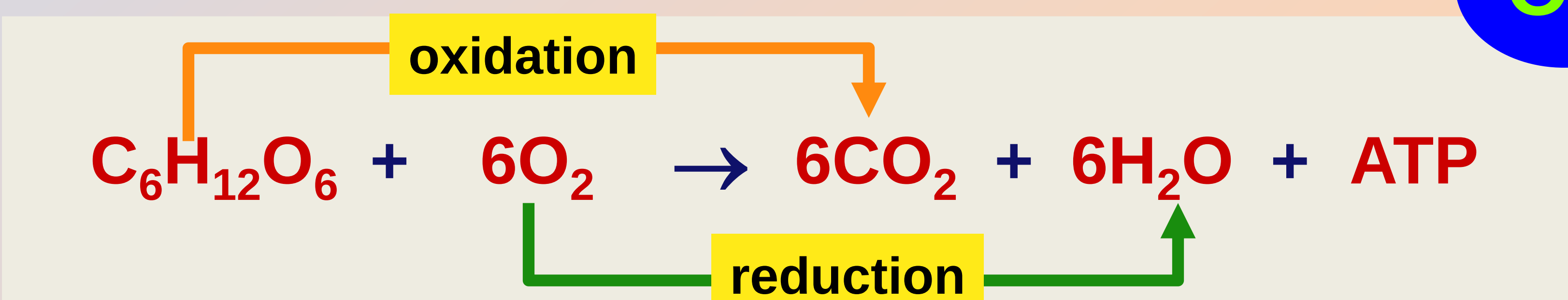




Coupling oxidation & reduction

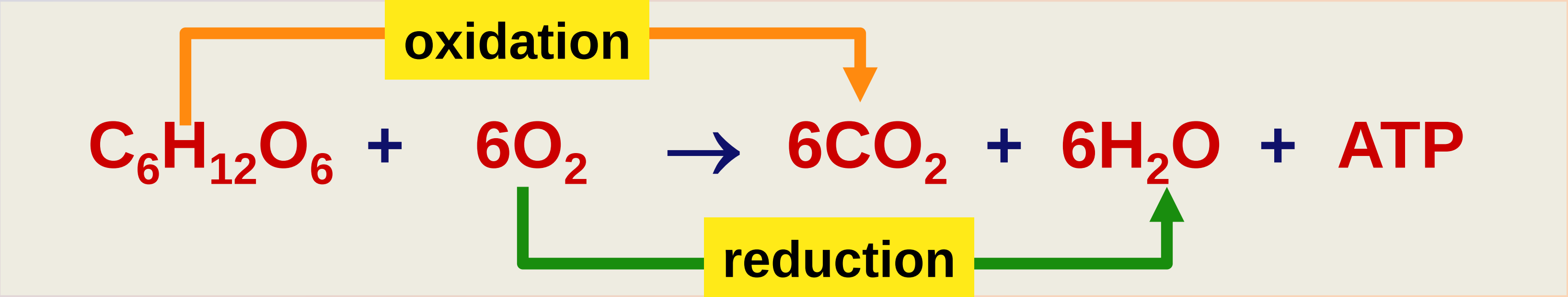
- REDOX reactions in respiration
  - release energy (break C-C bonds in organics)
    - Strip electrons from C-H bonds: remove H atoms
    - electrons attracted to more electronegative atoms
      - in biology, the most electronegative atom?
      - $O_2 \rightarrow H_2O$ = oxygen has been <u>reduced</u>
  - <u>couple REDOX reactions & use the released energy to synthesize ATP</u>

O_2



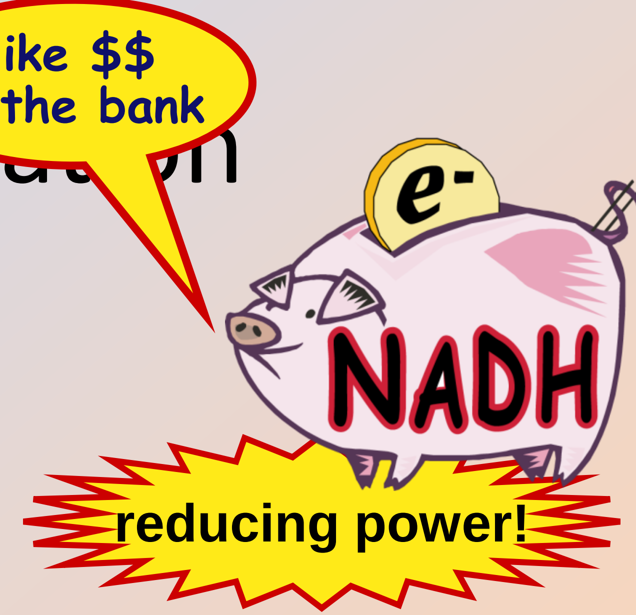
Oxidation & reduction

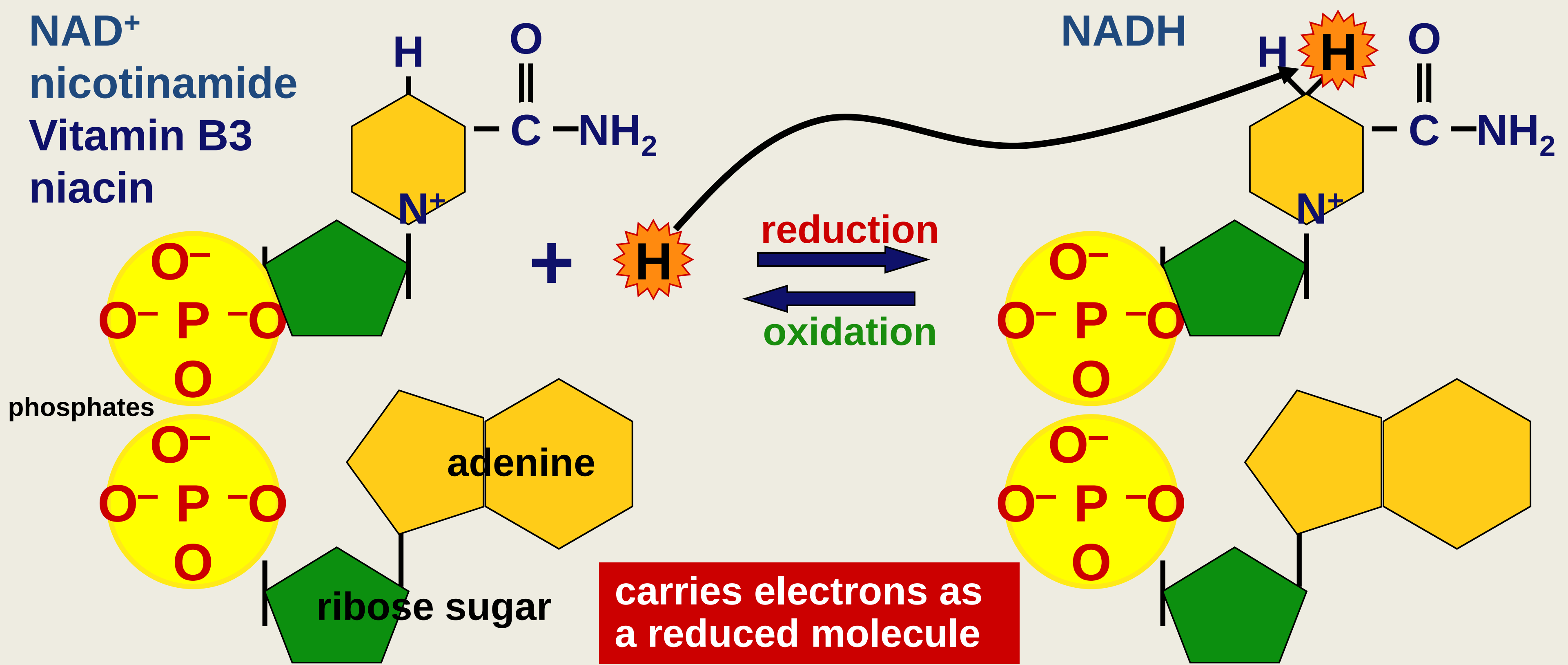
- Oxidation
  - adding O
  - removing H
  - loss of electrons
  - releases energy
  - exergonic
- Reduction
  - removing O
  - adding H
  - gain of electrons
  - stores energy
  - endergonic



Moving electrons in respiration

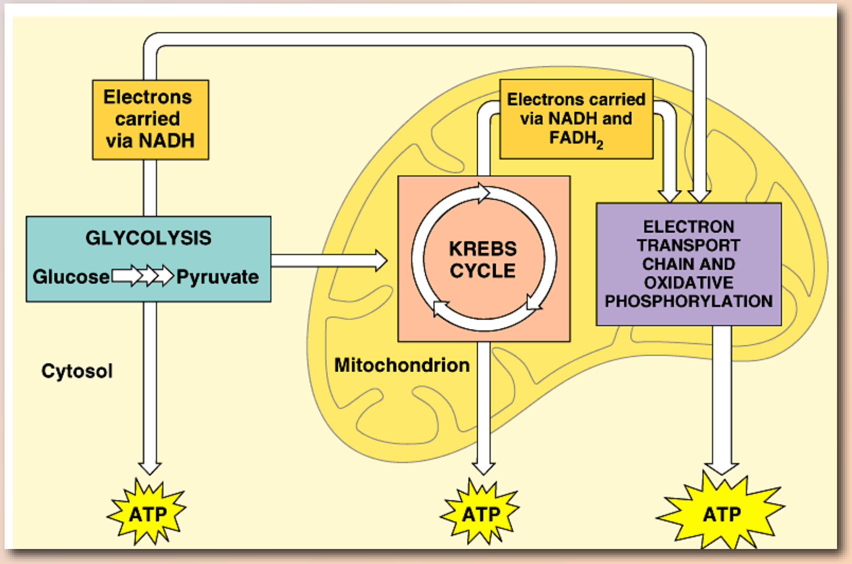
- <u>Electron carriers</u> move electrons by shuttling H atoms around
  - $NAD^+ \rightarrow$ NADH (reduced)
  - $FAD^{+2} \rightarrow FADH_2$ (reduced)





Overview of cellular respiration

- 4 metabolic stages
  - Anaerobic respiration
    1. Glycolysis
       - respiration without O_2
       - in cytosol
  - Aerobic respiration
       - respiration using O_2
       - in mitochondria
    2. Pyruvate oxidation
    3. Krebs cycle
    4. Electron transport chain



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

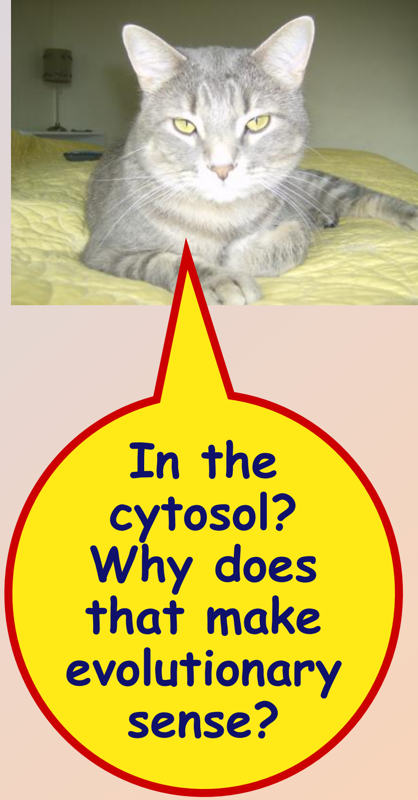
Glycolysis

- Breaking down glucose
  - "glyco – lysis" (splitting sugar)

glucose → → → → → pyruvate

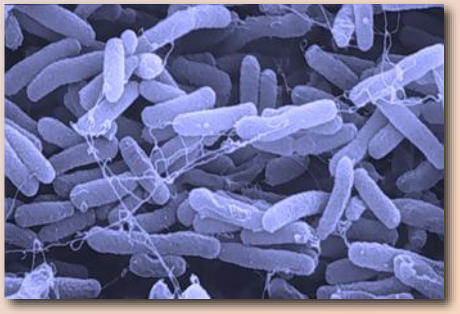
6C → 2x 3C

  - ancient pathway which harvests energy
    - where energy transfer first evolved
    - still is starting point for ALL cellular respiration
  - but it's inefficient
    - generate only 2 ATP for every 1 glucose
  - occurs in cytosol



Evolutionary perspective

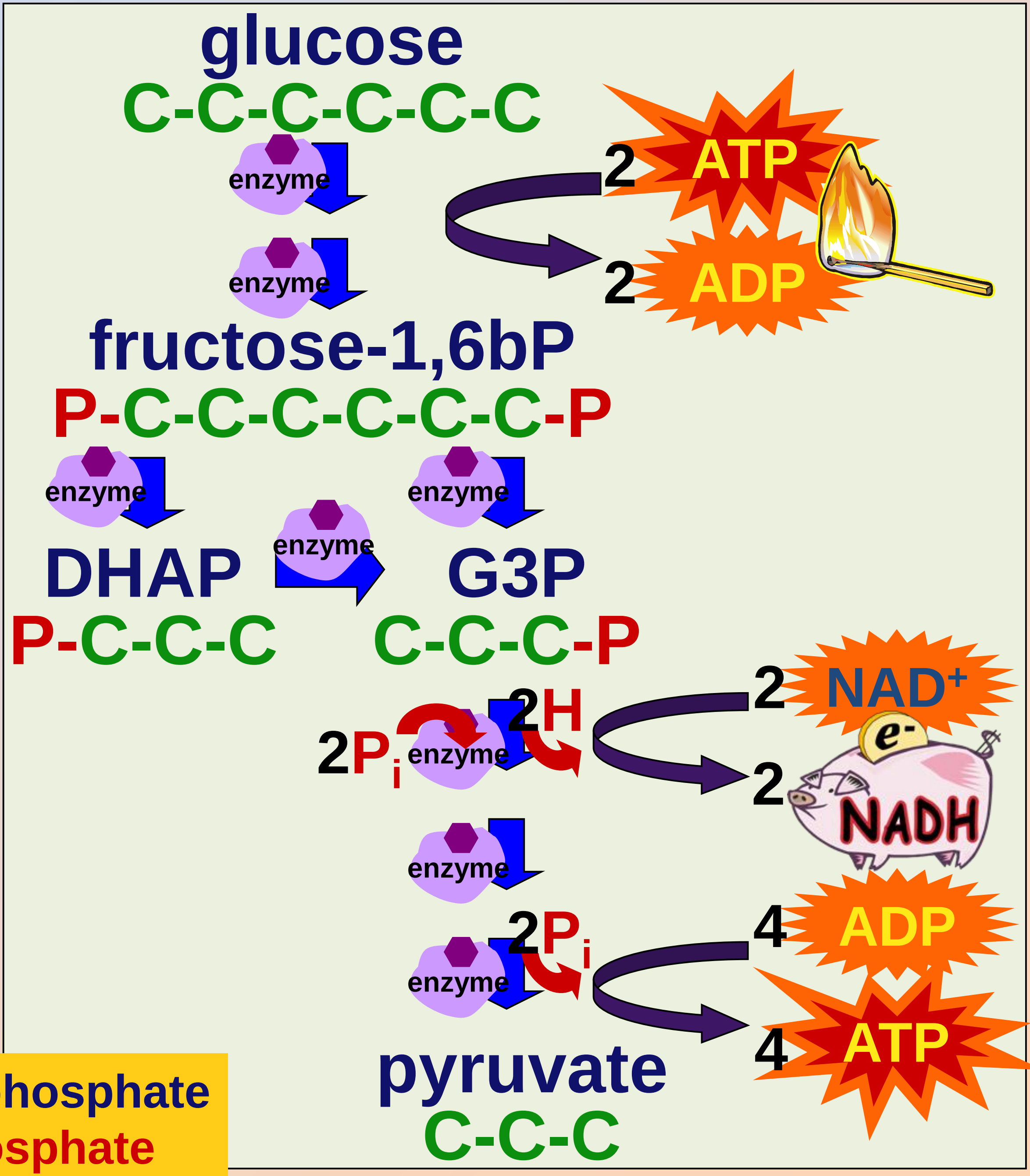
- Prokaryotes
  - first cells had no organelles
- Anaerobic atmosphere
  - life on Earth first evolved without free oxygen (O_2) in atmosphere
  - energy had to be captured from organic molecules in absence of O_2
- Prokaryotes that evolved glycolysis are ancestors of all modern life
  - ALL cells still utilize glycolysis



Overview

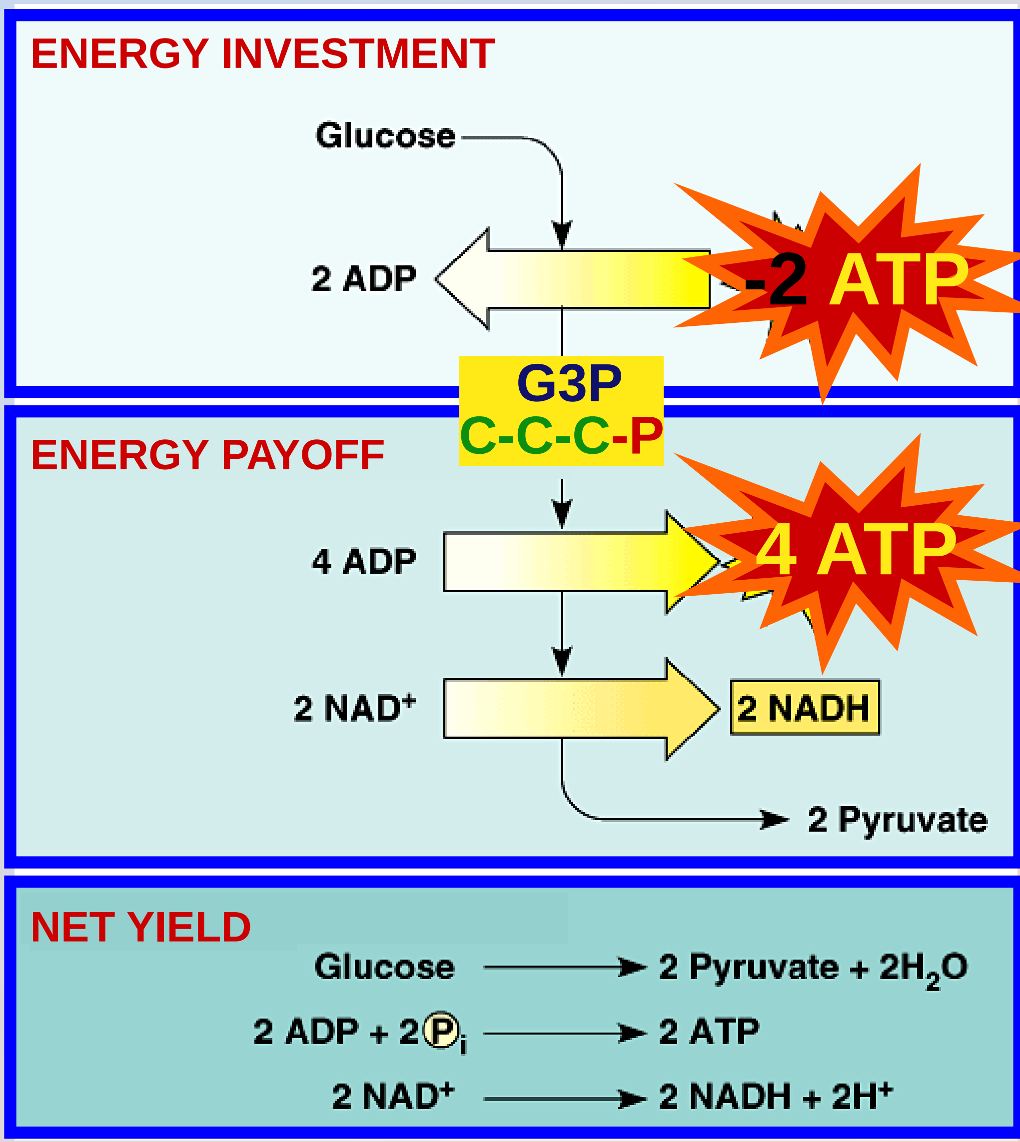
10 reactions

- convert
  glucose (6C) to
  2 pyruvate (3C)
- produces:
  4 ATP & 2 NADH
- consumes:
  2 ATP
- net yield:
  2 ATP & 2 NADH



DHAP = dihydroxyacetone phosphate
G3P = glyceraldehyde-3-phosphate

Glycolysis summary



endergonic

invest some ATP

exergonic

harvest a little ATP & a little NADH

net yield

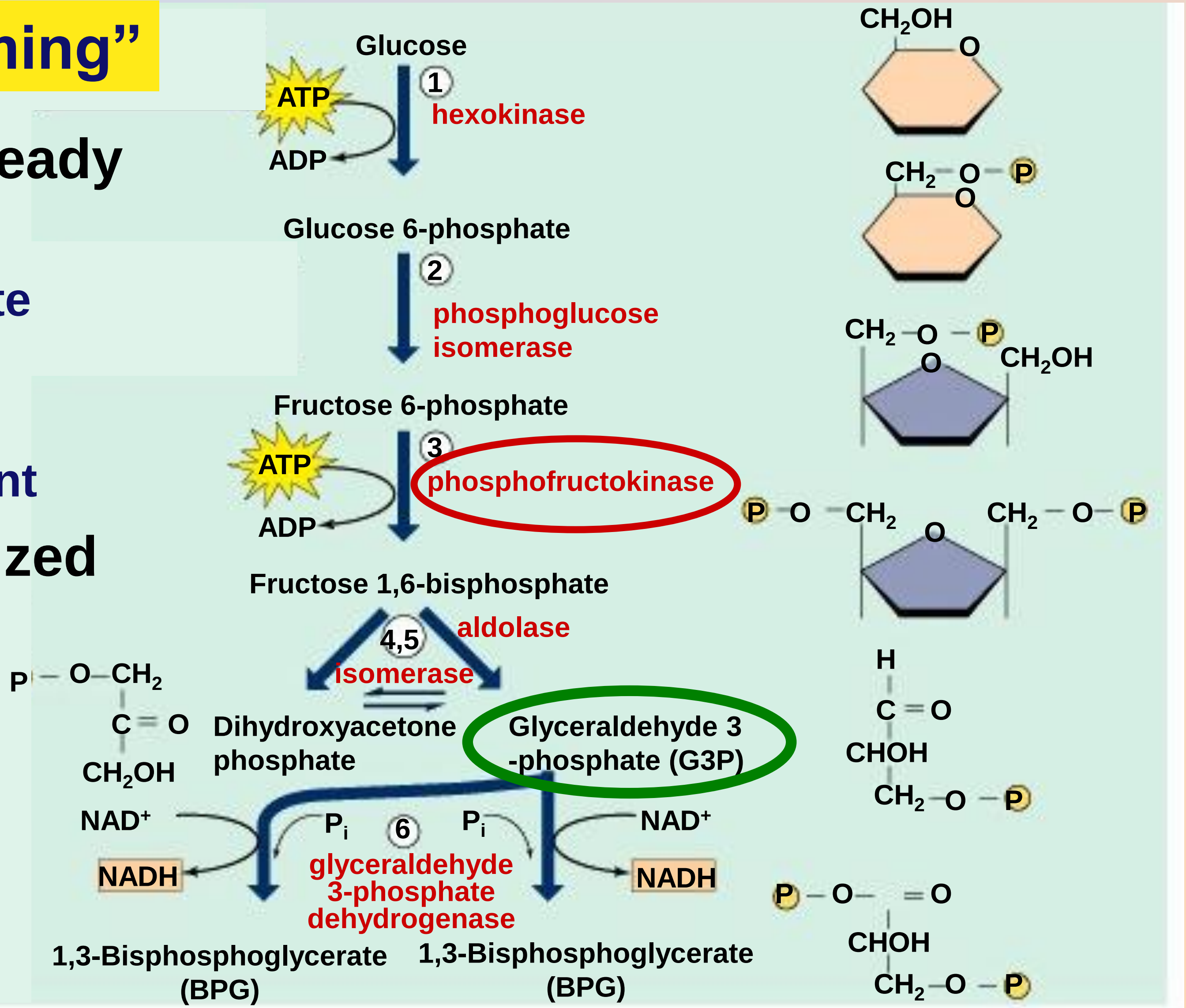
✓2 ATP

✓2 NADH

1st half of glycolysis (5 reactions)

Glucose "priming"

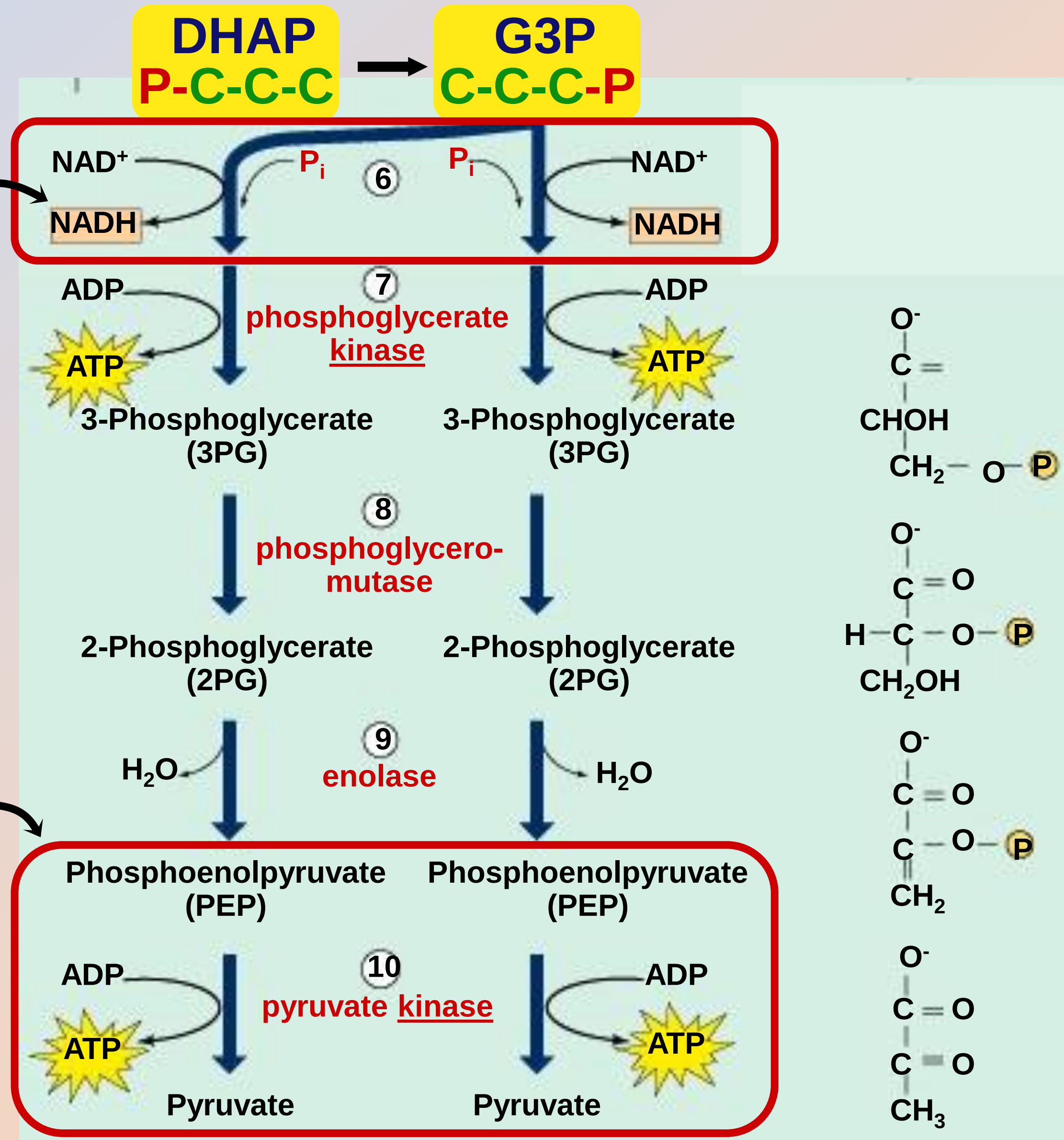
- **get glucose ready to split**
  - **phosphorylate glucose**
  - **molecular rearrangement**
- **split destabilized glucose**



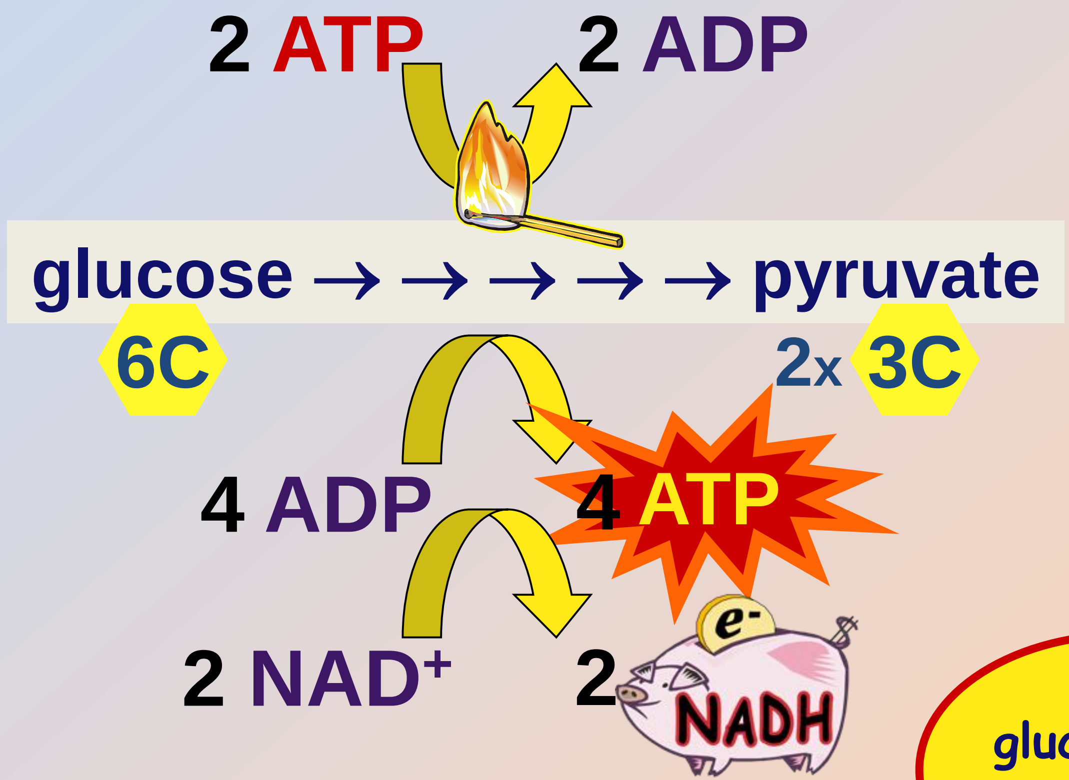
2nd half of glycolysis (5 reactions)

Energy Harvest

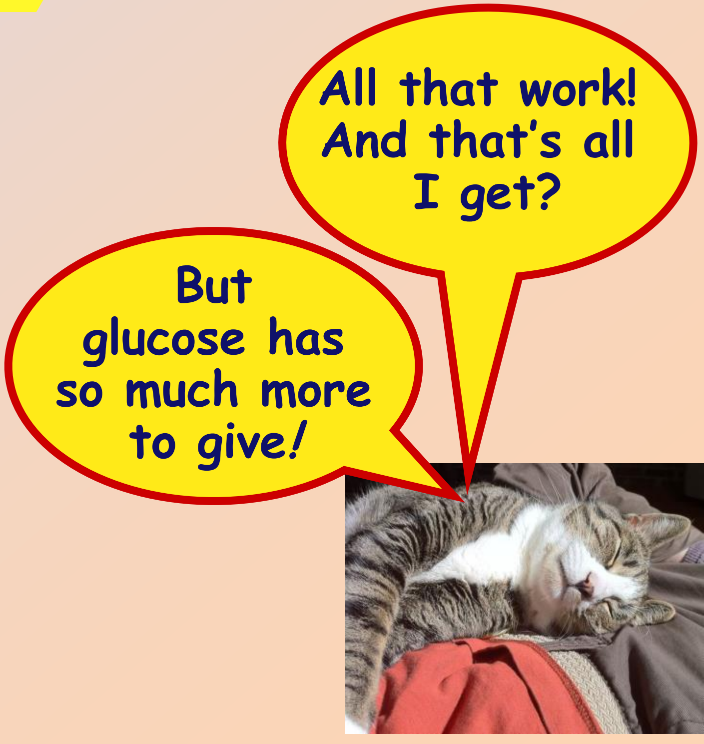
- NADH production
  - G3P donates H
  - oxidizes the sugar
  - reduces NAD^+
  - $NAD^+ \rightarrow$ NADH
- ATP production
  - G3P $\rightarrow \rightarrow \rightarrow$ pyruvate
  - PEP sugar donates P
    - "substrate level phosphorylation"
  - ADP $\rightarrow$ ATP



Energy accounting of glycolysis



- Net gain = 2 ATP + 2 NADH
  - some energy investment (-2 ATP)
  - small energy return (4 ATP + 2 NADH)
- 1 6C sugar → 2 3C sugars



Is that all there is?

- Not a lot of energy…
  - for 1 billon years[+] this is how life on Earth survived
    - no O_2 = slow growth, slow reproduction
    - only harvest 3.5% of energy stored in glucose
      - more carbons to strip off = more energy to harvest

glucose → → → → pyruvate

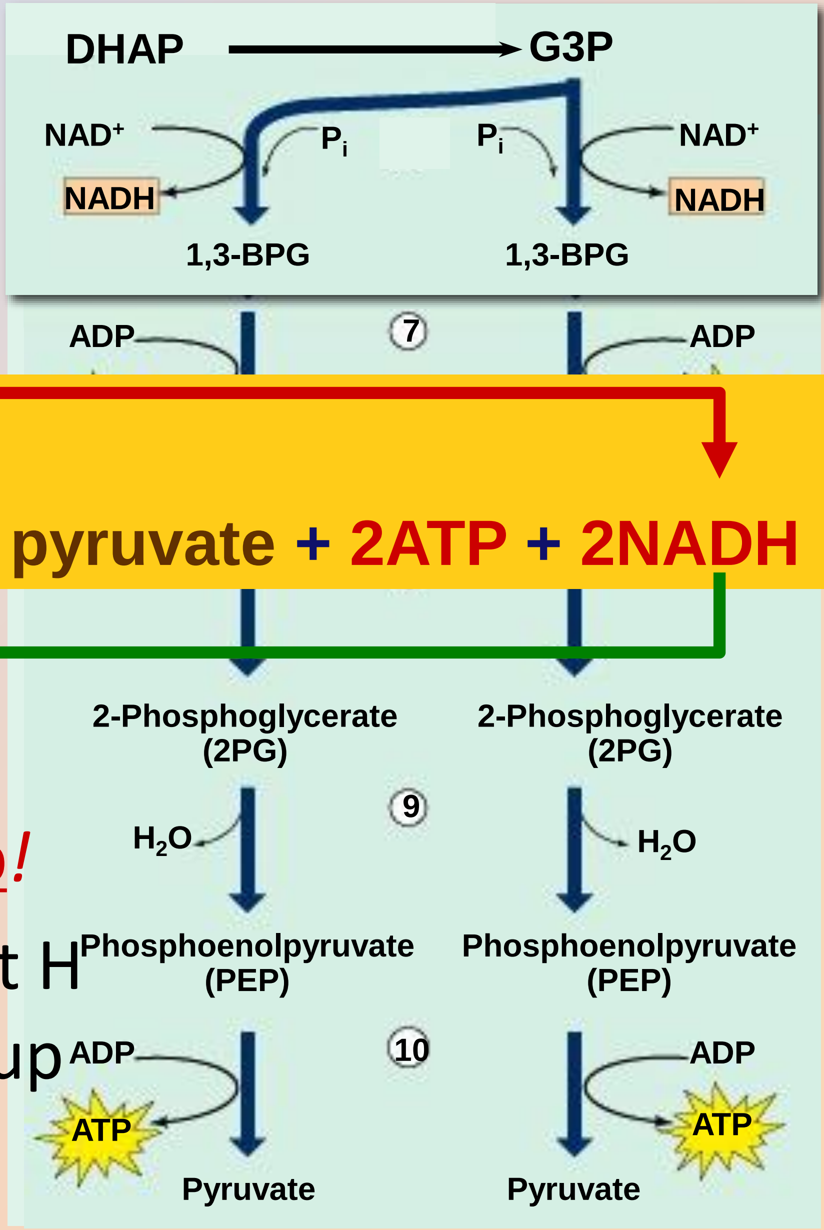
6C 2x 3C

But can't stop there!

raw materials → products

Glycolysis

glucose + 2ADP + 2P_i + 2 NAD^+ → 2 pyruvate + 2ATP + 2NADH

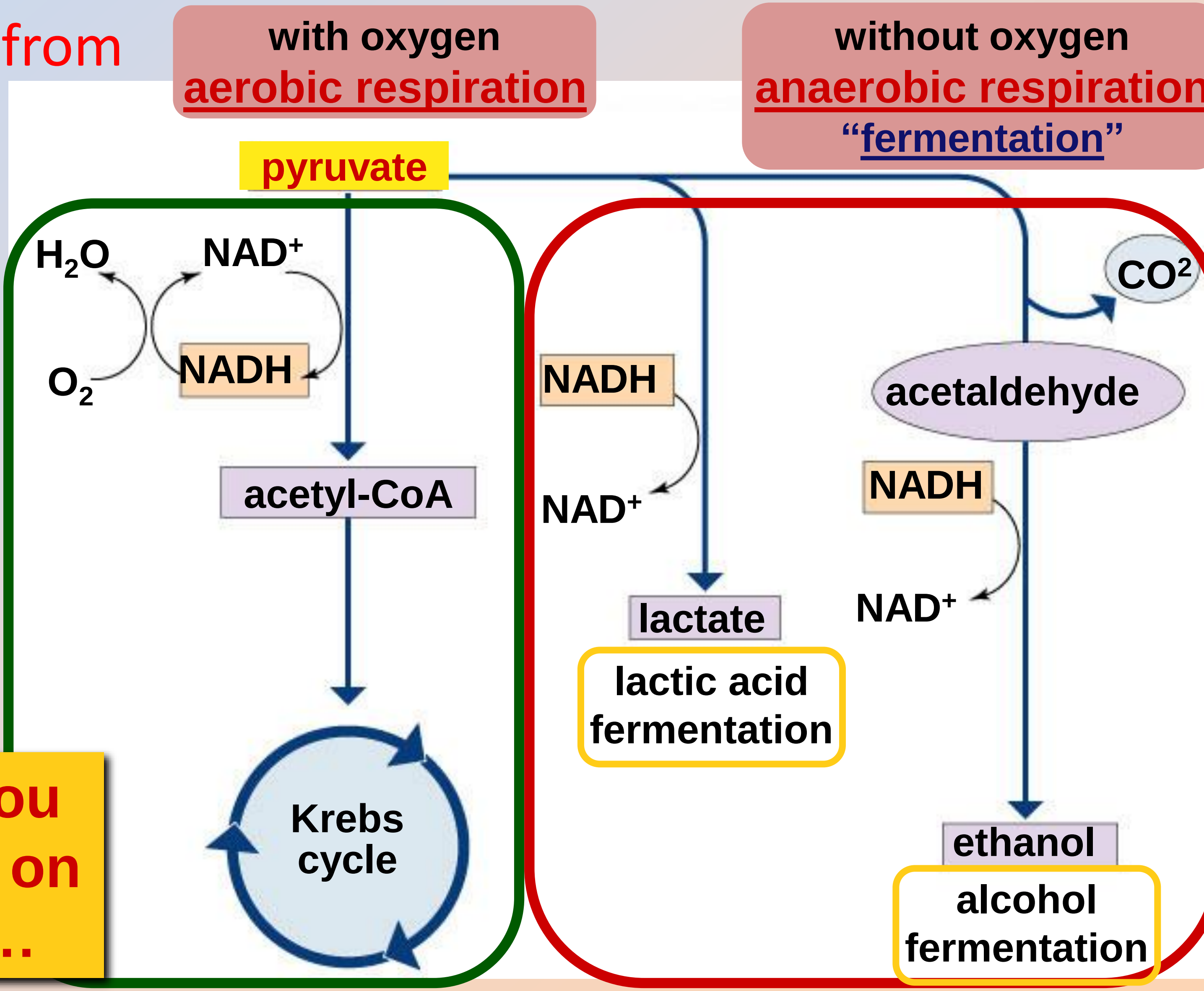


- Going to run out of NAD^+
  - without regenerating NAD^+, energy production would stop!
  - another molecule must accept H from NADH, so NAD^+ is freed up for another round

How is NADH recycled to NAD$^+$?

Another molecule must accept H from NADH

recycle NADH



which path you use depends on who you are…

Fermentation (anaerobic)

- Bacteria, yeast

pyruvate → ethanol + CO_2

3C → 2C, 1C

NADH → NAD^+ back to glycolysis→→

- beer, wine, bread

- **Animals, some fungi**

pyruvate → lactic acid

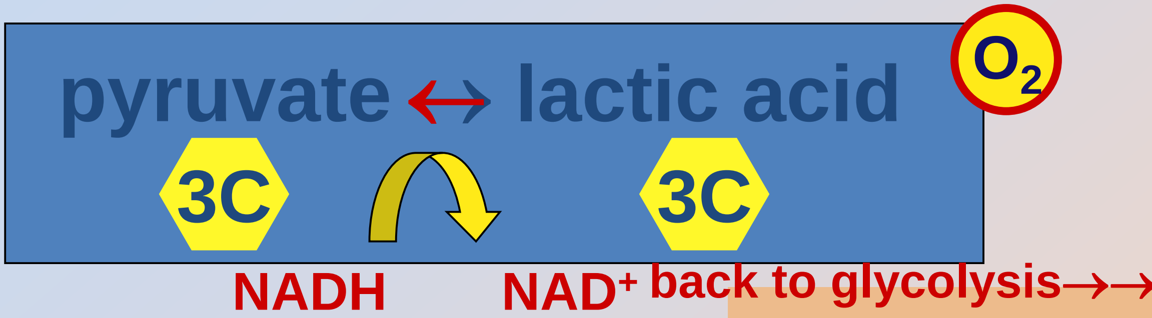
3C → 3C

NADH → NAD^+ back to glycolysis→→

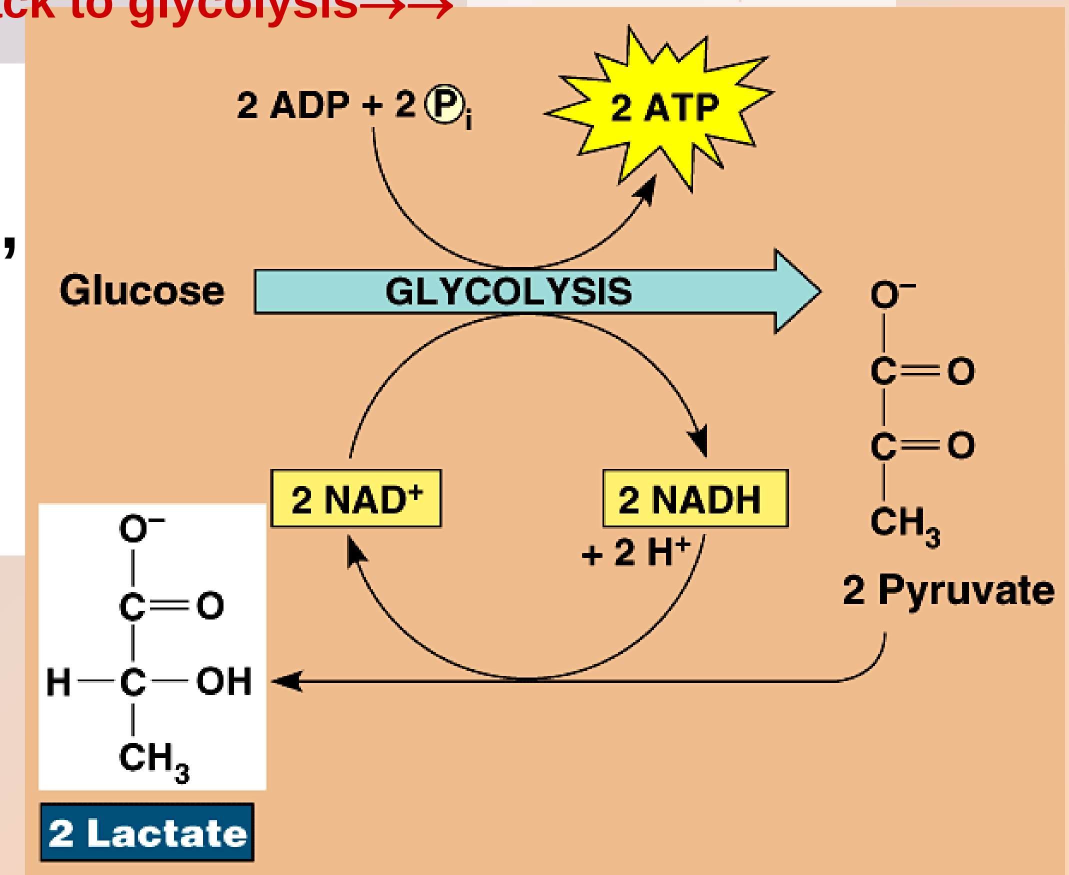
- cheese, anaerobic exercise (no O_2)

Lactic Acid Fermentation

animals
some fungi



- **Reversible process**
  - **once O_2 is available, lactate is converted back to pyruvate by the liver**



Alcohol Fermentation

bacteria
yeast

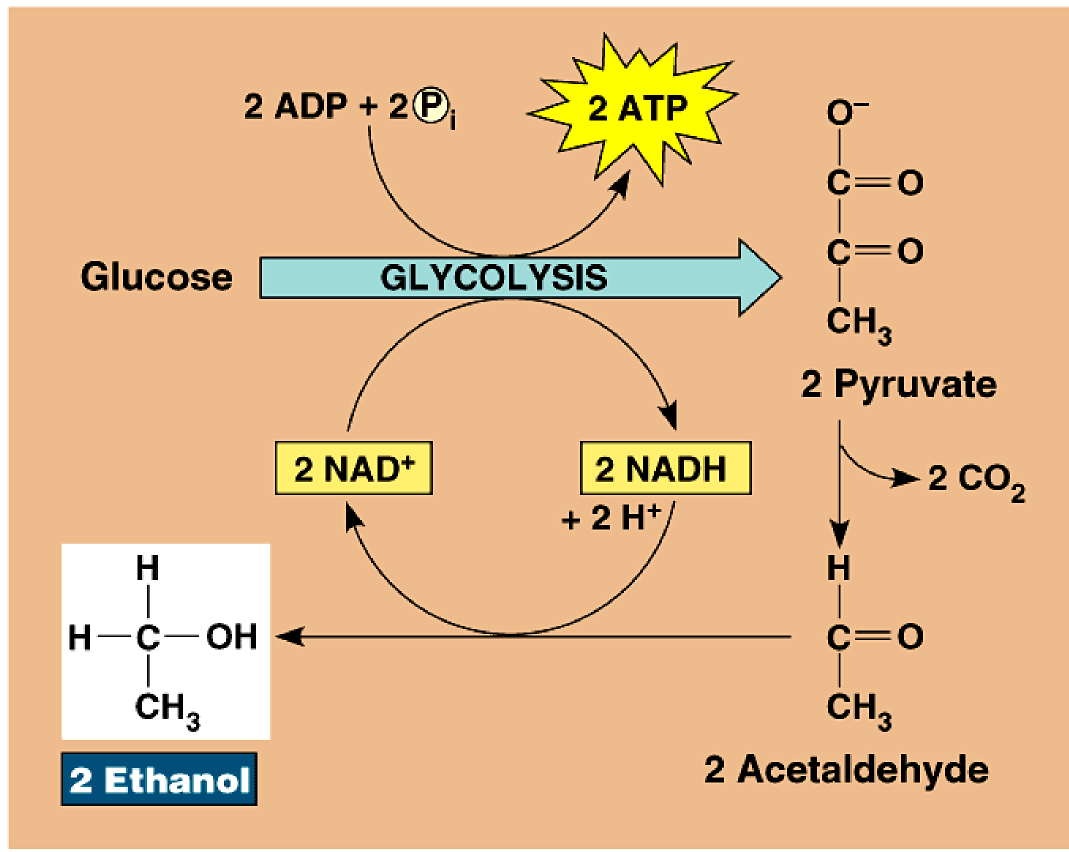
pyruvate → ethanol + CO_2

3C → 2C 1C

NADH NAD$^+$ back to glycolysis→→

recycle NADH

- **Dead end process**
  - **at ~12% ethanol, kills yeast**
  - **can't reverse the reaction**

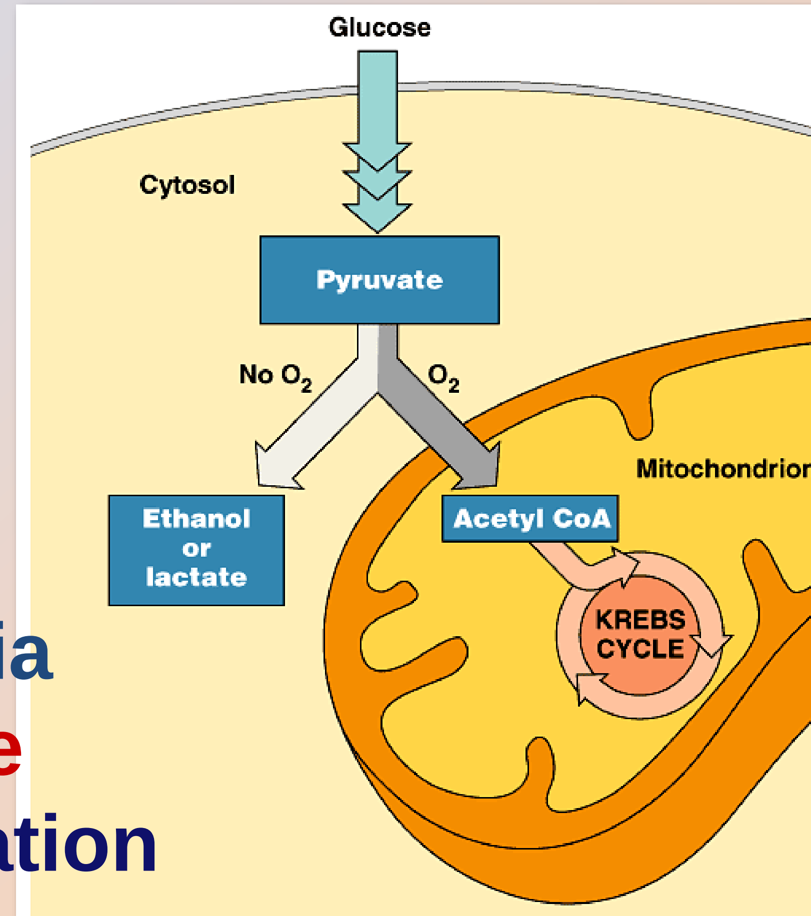


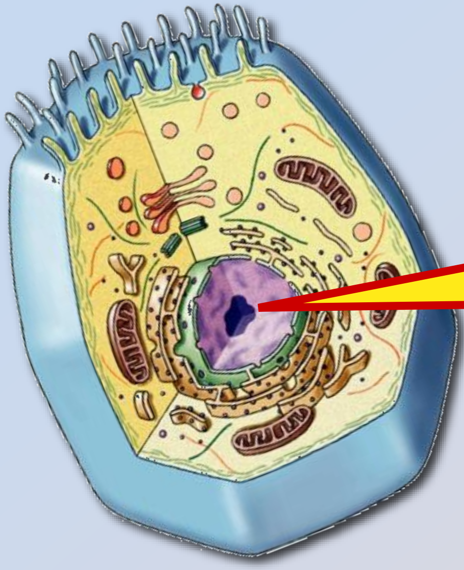
Pyruvate is a branching point

Pyruvate

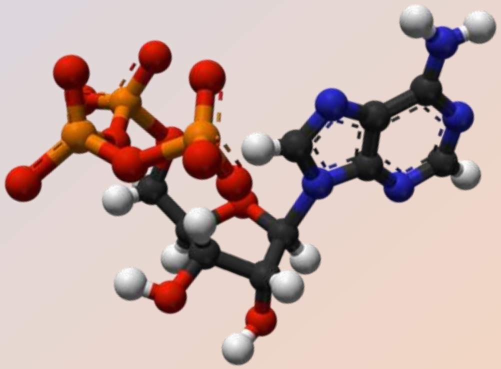
No O_2 → **fermentation**
anaerobic respiration

O_2 → **mitochondria**
Krebs cycle
aerobic respiration





What's the point?



The point is to make ATP!

ATP