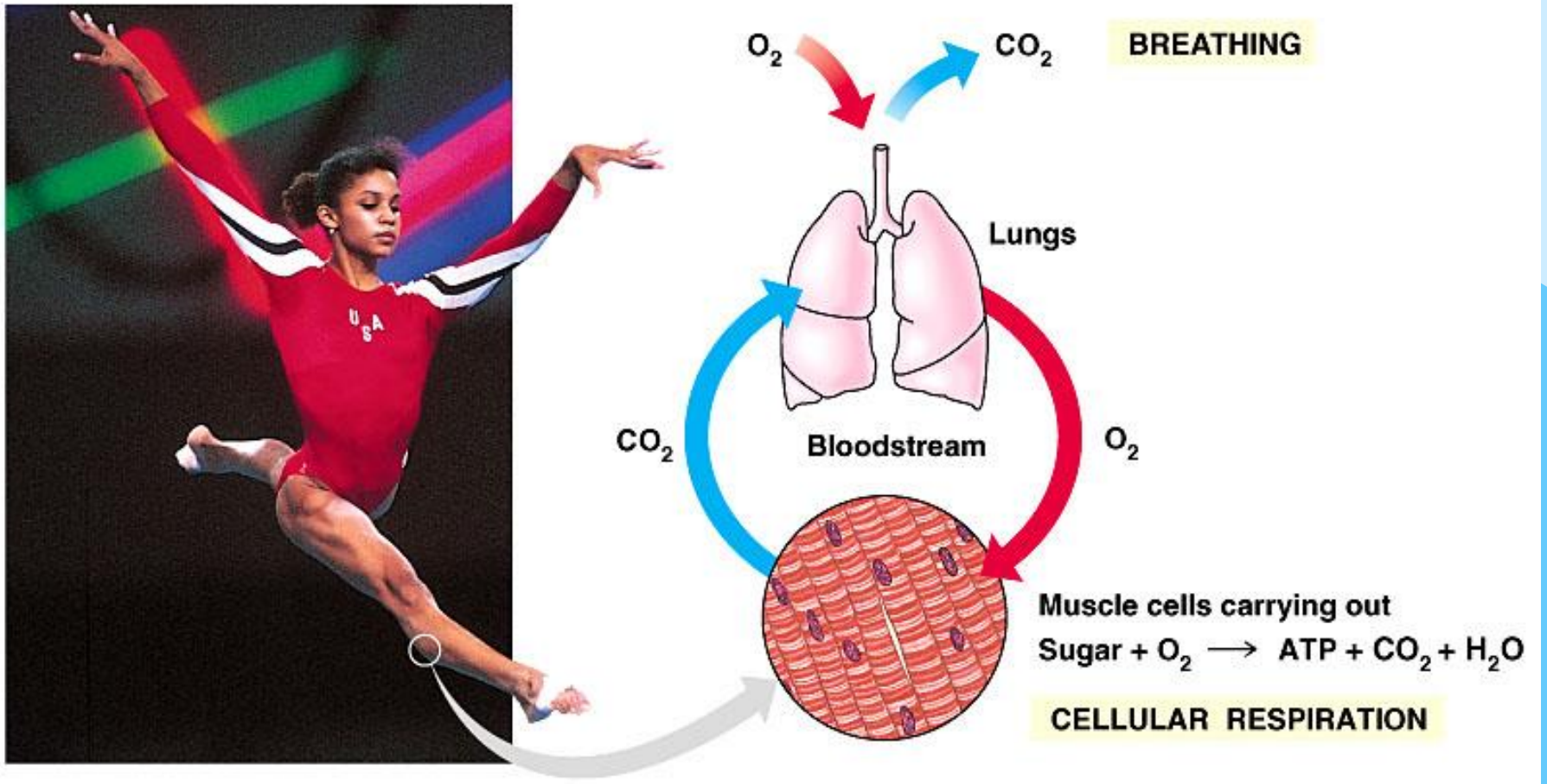
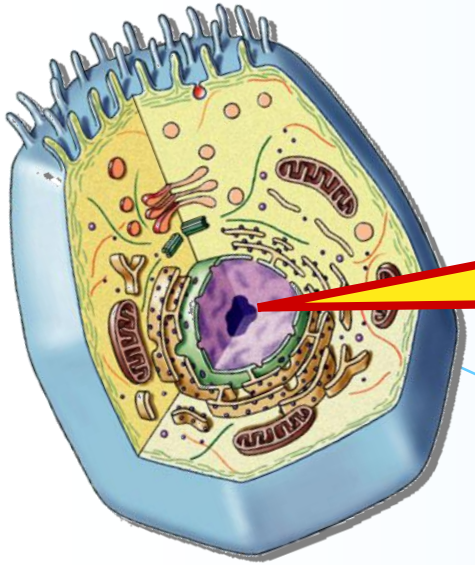
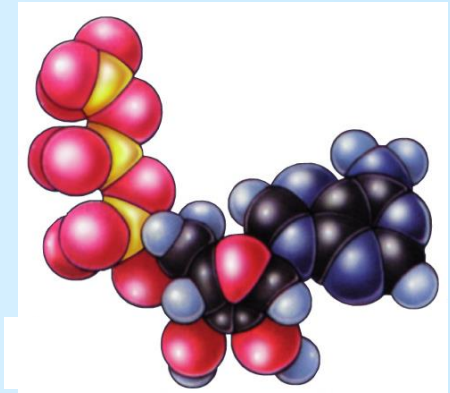
Cellular Respiration
How Cells Get ATP from Glucose





What's the point?



The point is to make **ATP**!

ATP

All living things get their energy from sun energy stored in food

- **Autotrophs** do photosynthesis to make food
- **Heterotrophs** eat to get food
- **ALL** must break down the food, transform the energy stored in the bonds of food into energy stored in ATP (phosphate bonds)

– The energy in an ATP molecule is in the bonds between phosphate groups

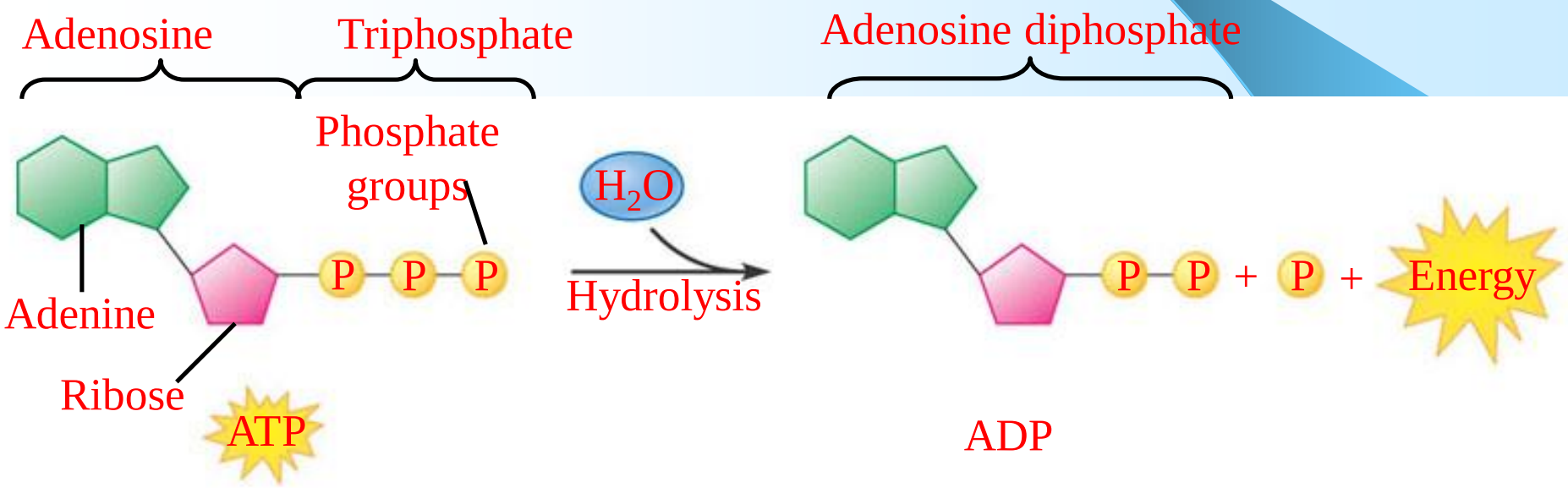
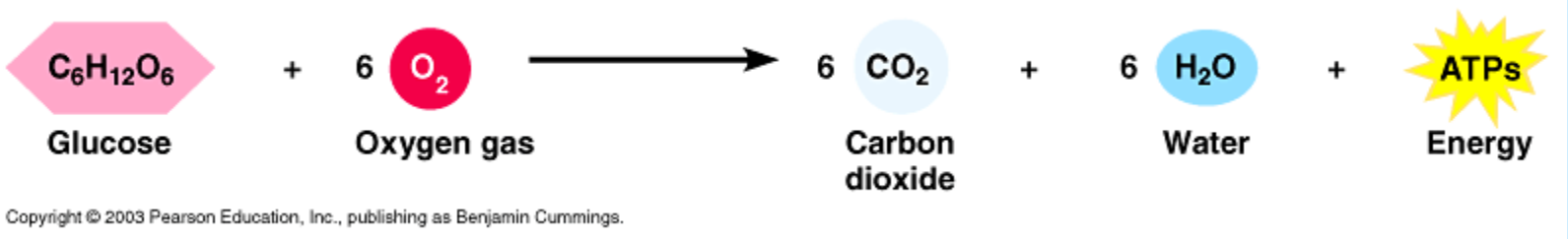


Figure 5.4A

All Cells get ATP from glucose



- ATP not stable so energy is stored as sugar
- Sugar must be broken apart to get the energy out of the bonds

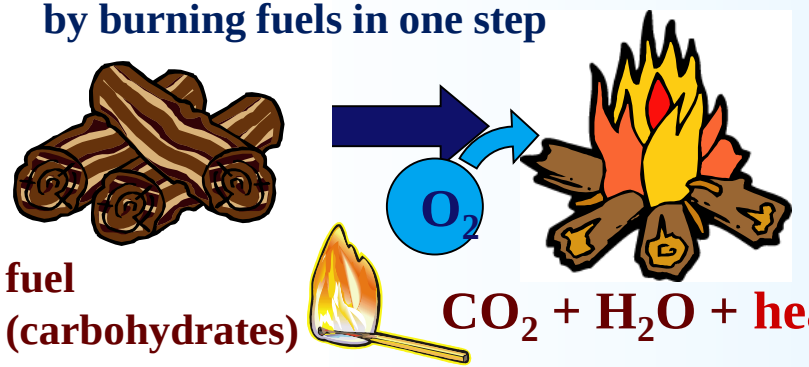
Catabolism of glucose to produce ATP

respiration

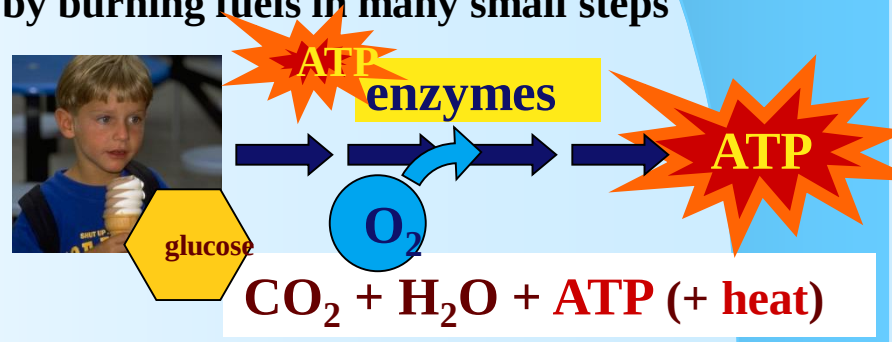
glucose + oxygen → energy + water + carbon dioxide

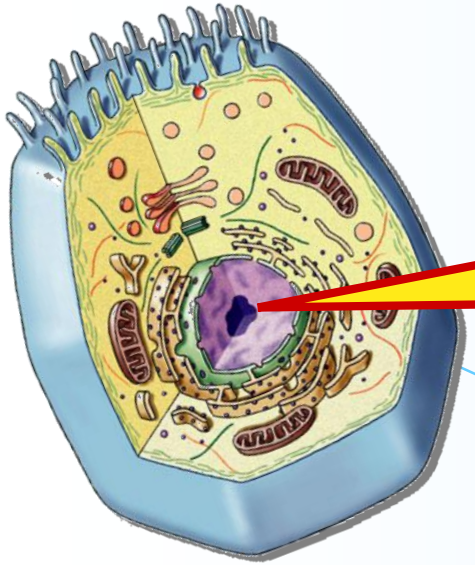
$$C_6H_{12}O_6 + 6O_2 \rightarrow ATP + 6H_2O + 6CO_2 + heat$$

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

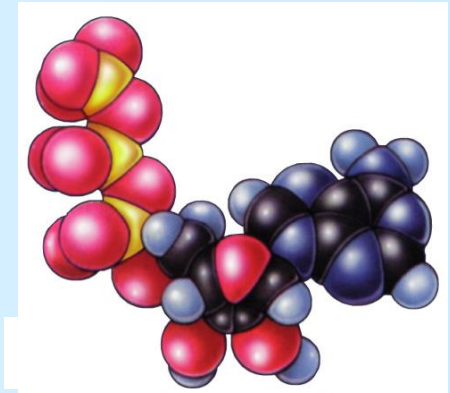


RESPIRATION = making ATP (& some heat) by burning fuels in many small steps





What's the point?

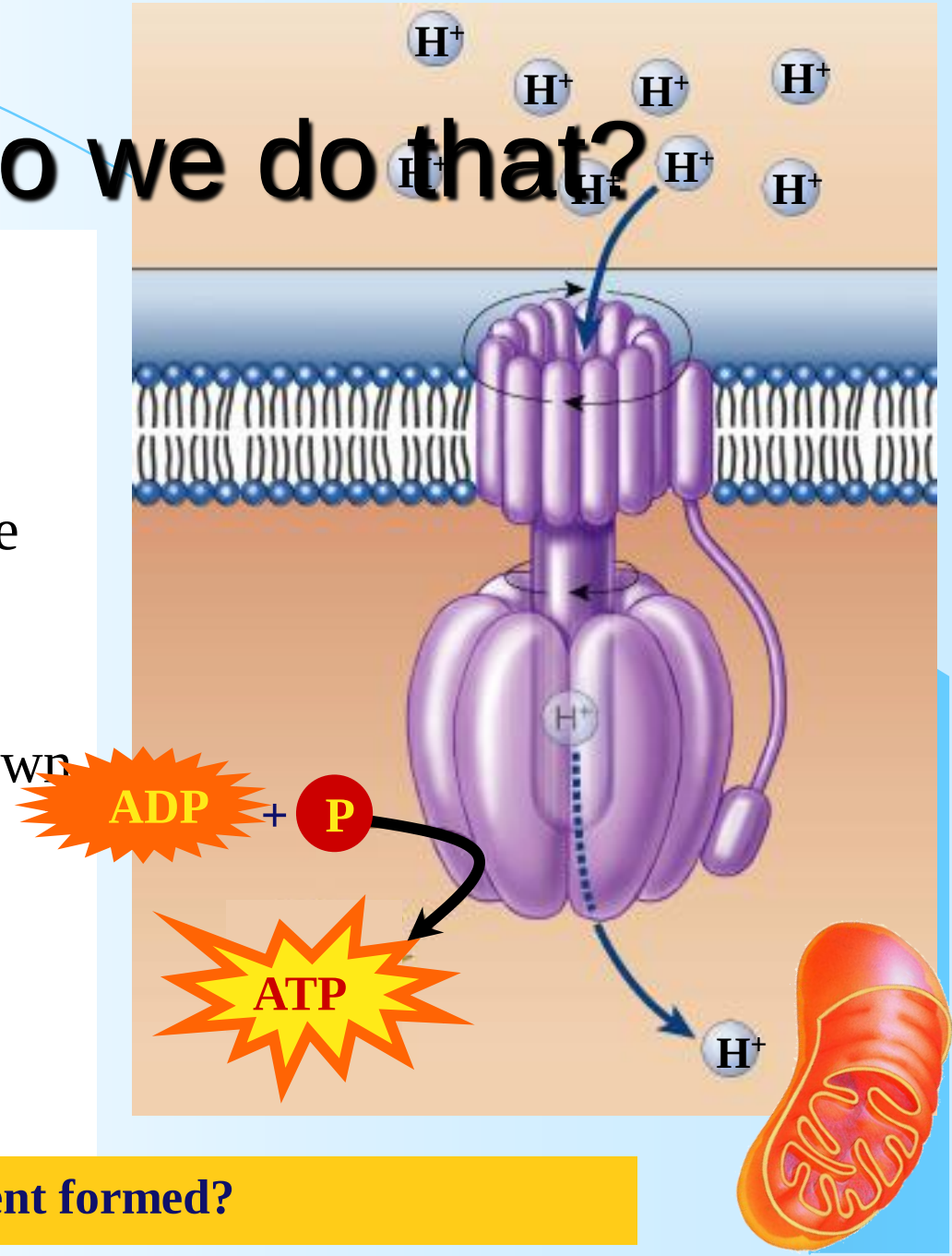


The point is to make **ATP**!

ATP

And how do we do that?

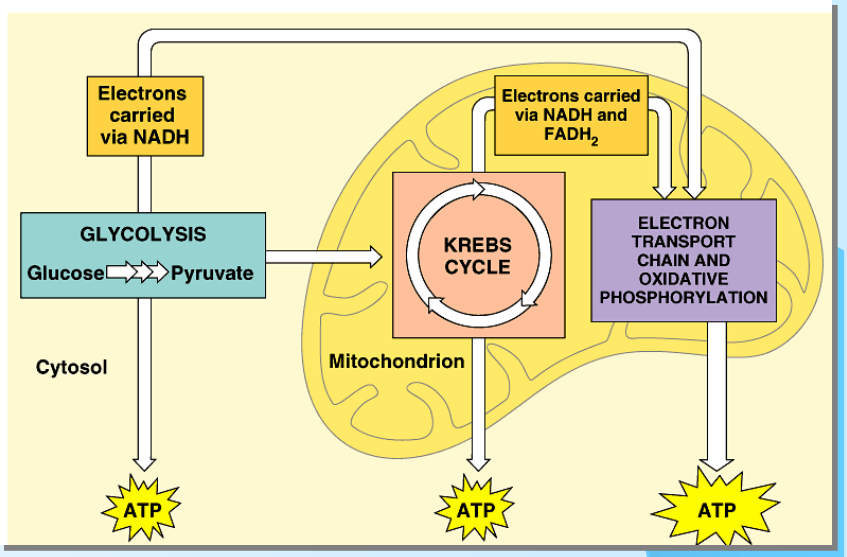
- ATP synthase enzyme
  - H^+ flows through it
    - Shape changes
    - bond P_i to ADP to make ATP
  - set up a H^+ gradient
    - allow the H^+ to flow down concentration gradient through ATP synthase
    - $ADP + P_i \rightarrow ATP$



But… How is the proton (H^+) gradient formed?

Overview of cellular respiration

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



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

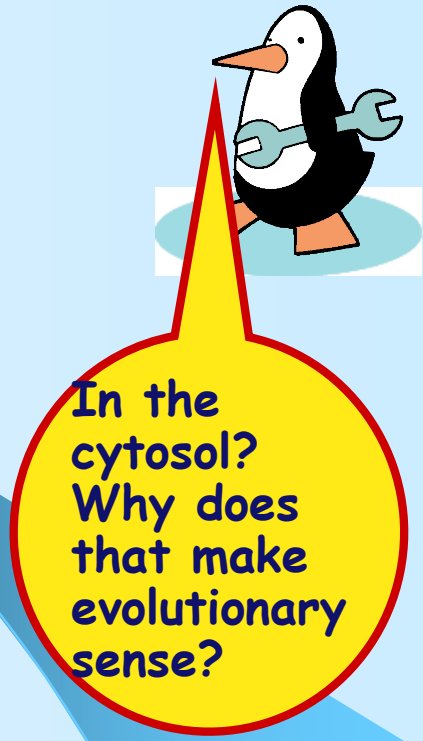
STEP 1 – Glycolysis

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

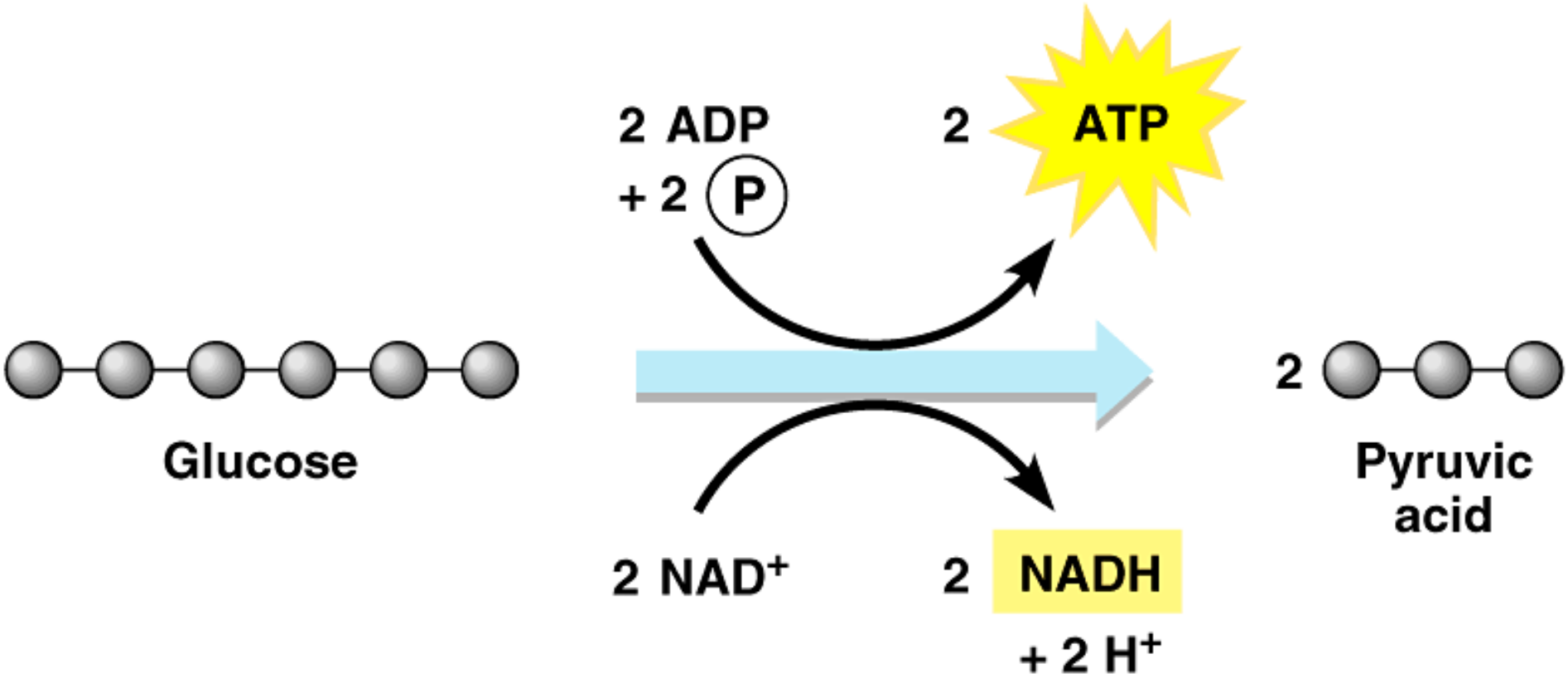
glucose → → → → → pyruvate

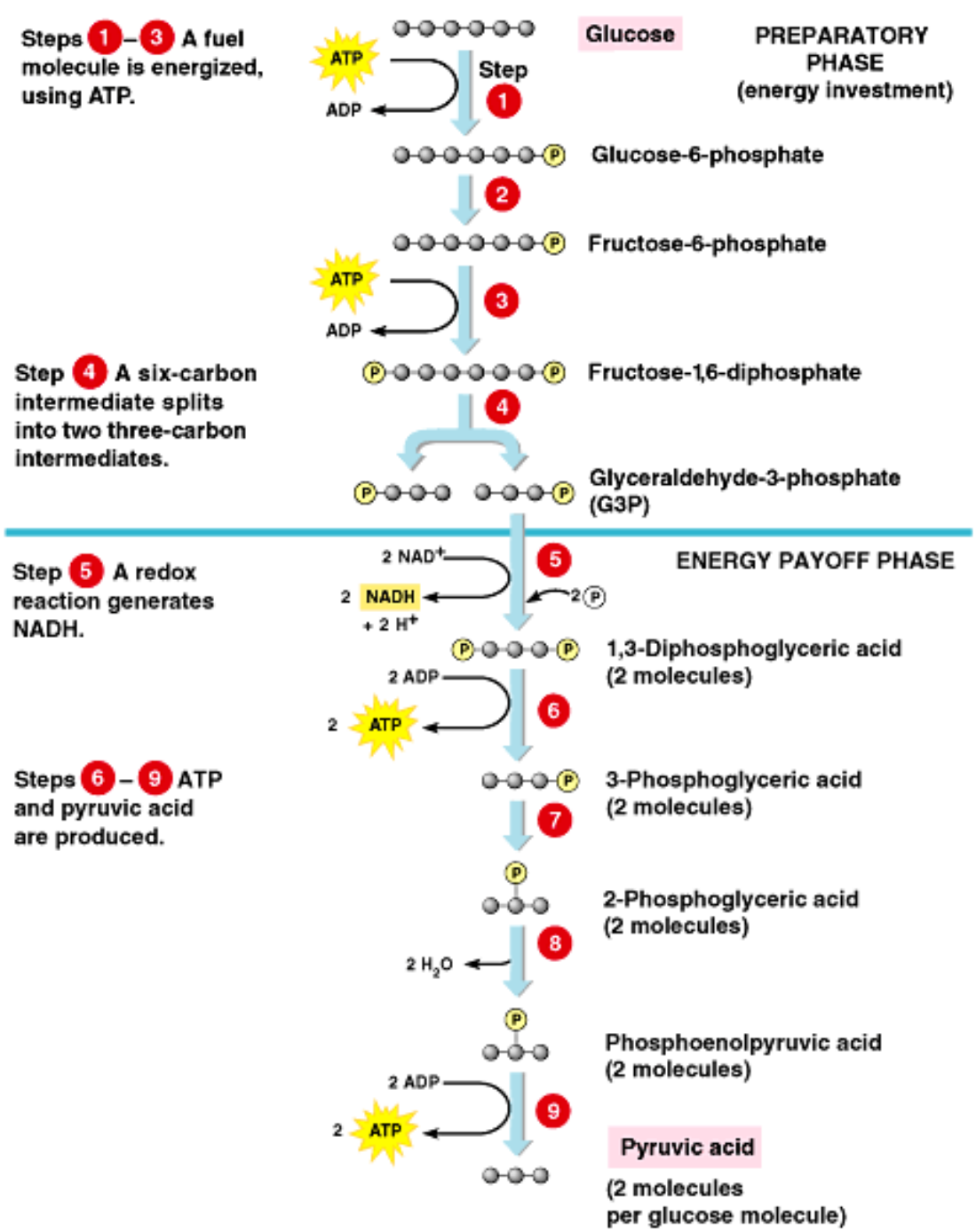
6C **2x 3C**

  - Ancient pathway which harvests energy
    - Starting point for ALL cellular respiration
  - Inefficient
    - generates only 2 ATP for every 1 glucose
  - Occurs in cytoplasm
  - Need 2 ATP to start, get 4 ATP out
  - NO oxygen needed



Glycolysis Overview





Glycolysis is only the start

- Glycolysis

glucose → → → → → pyruvate

6C **2x 3C**

- Pyruvate has more energy to yield
  - 3 more C to strip off
  - **if O_2 is available**, pyruvate enters mitochondria
  - full breakdown of sugar to CO_2

pyruvate → → → → → → CO_2

3C **1C**

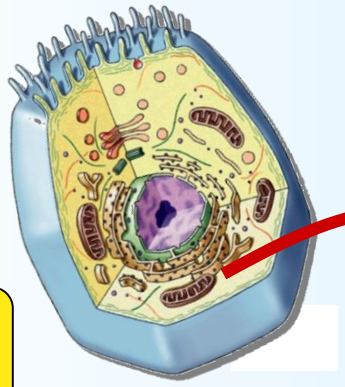
Aerobic Respiration – **with oxygen**

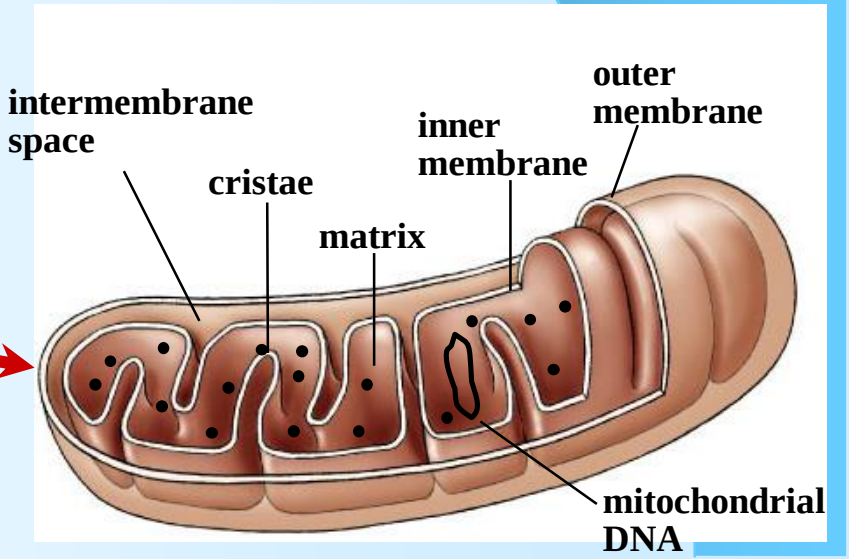
- **In the mitochondria**
- **Requires oxygen, but releases the most ATP (32-36)**
- **Completely breaks down glucose to Carbon dioxide and water**

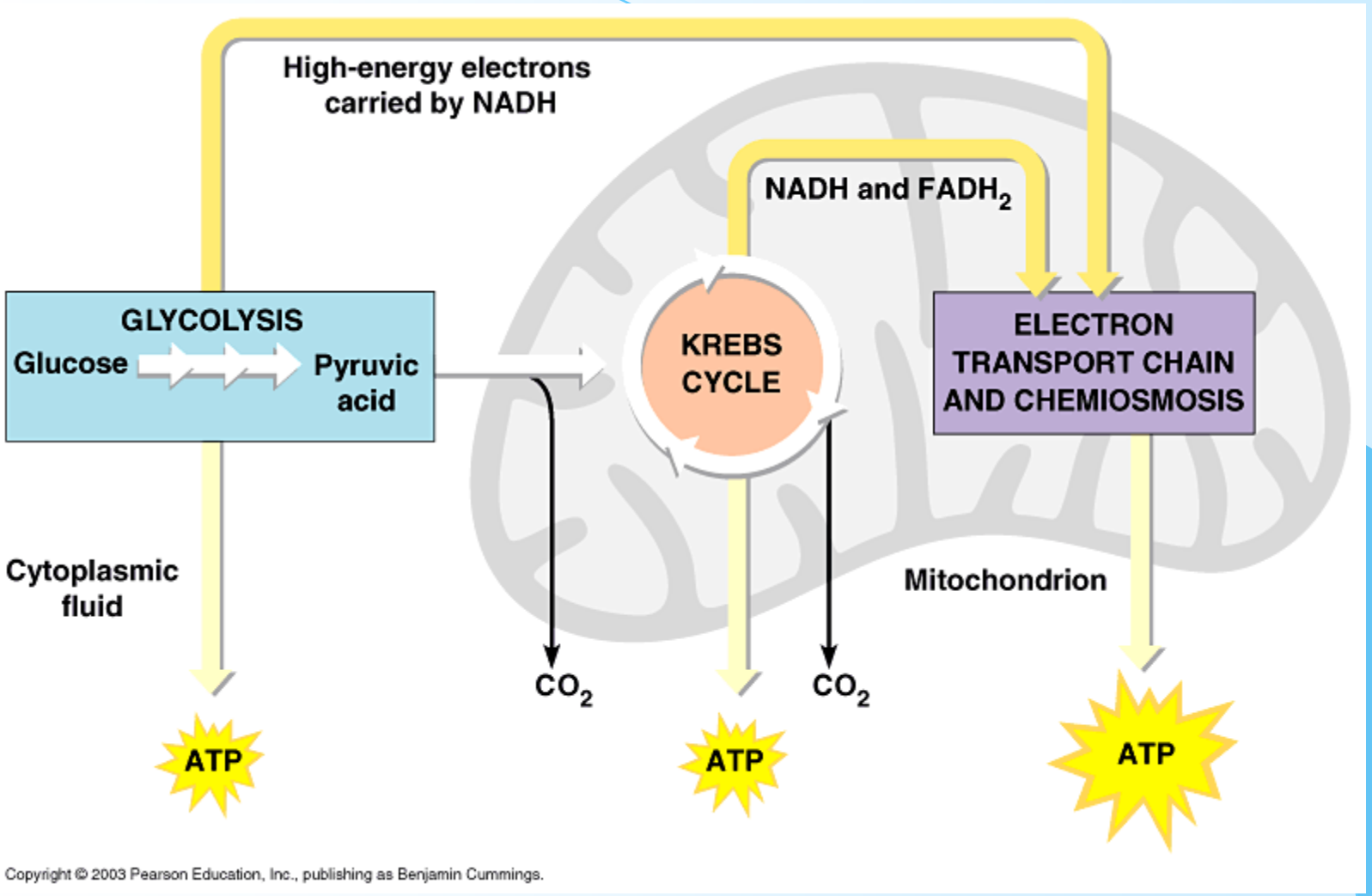
Mitochondria — Structure

- Double membrane energy harvesting organelle
  - smooth outer membrane
  - highly folded inner membrane
    - cristae
  - intermembrane space
    - fluid-filled space between membranes
  - matrix
    - inner fluid-filled space

What cells would have a lot of mitochondria?

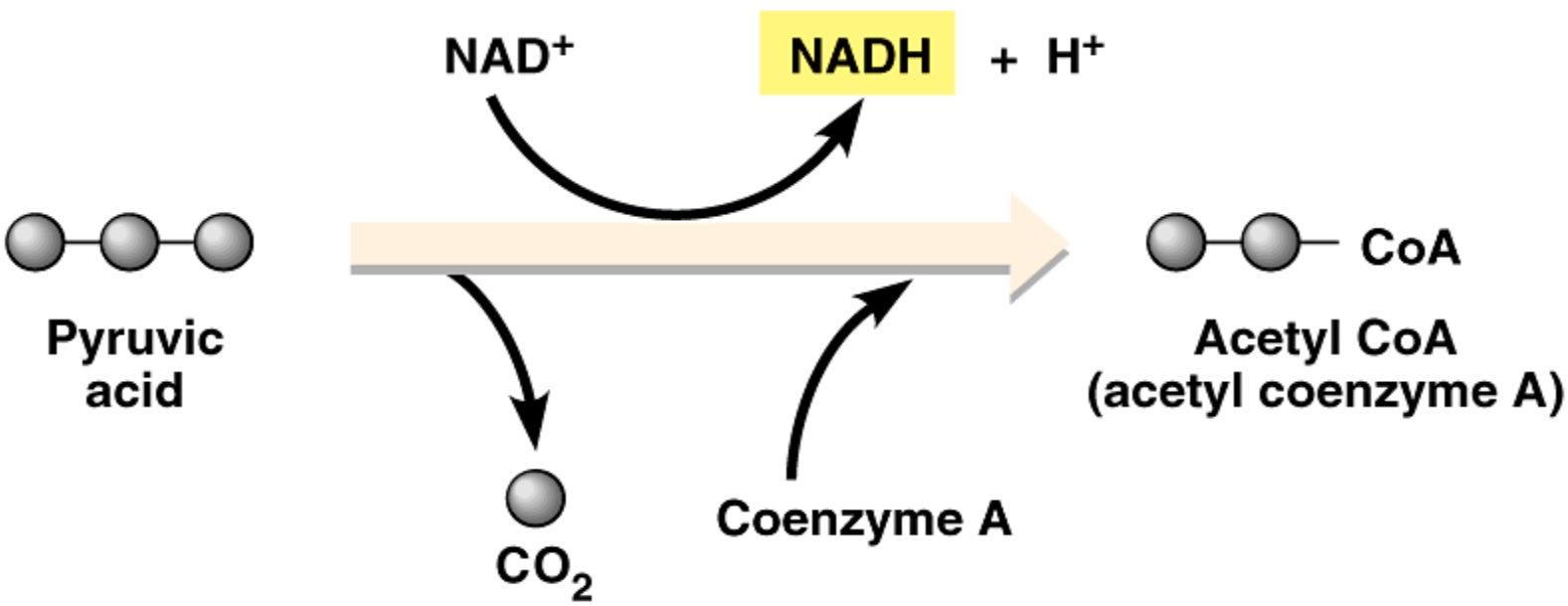






Pyruvate Prep step breaks off a Carbon dioxide

– Making a 2 C molecule and one NADH



Krebs or Citric Acid Cycle

- In the mitochondria inner compartment
- Break down pyruvate to Carbon dioxide which is released into the air
- Produce NADH, FADH, and some 2ATP

Whassup?

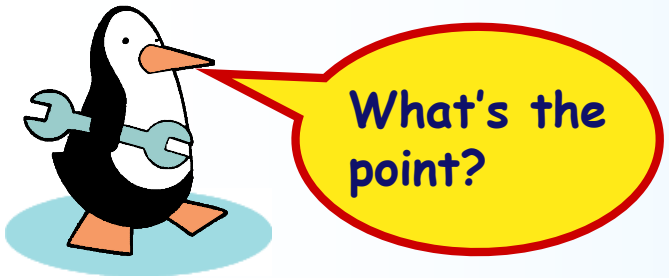
So we fully oxidized glucose

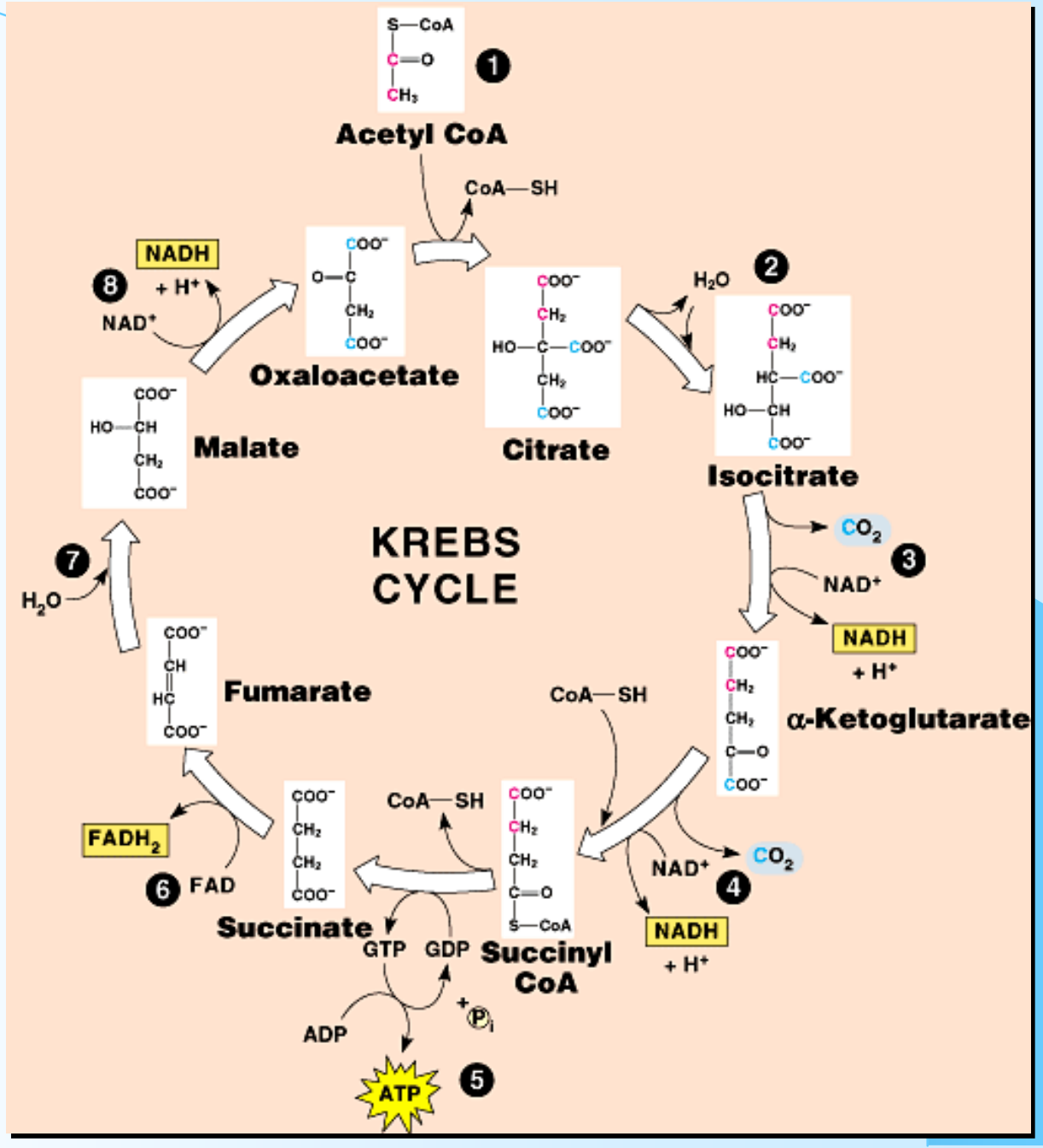
$C_6H_{12}O_6$

↓

CO_2

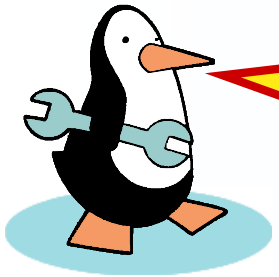
& ended up with <u>4 ATP</u>!



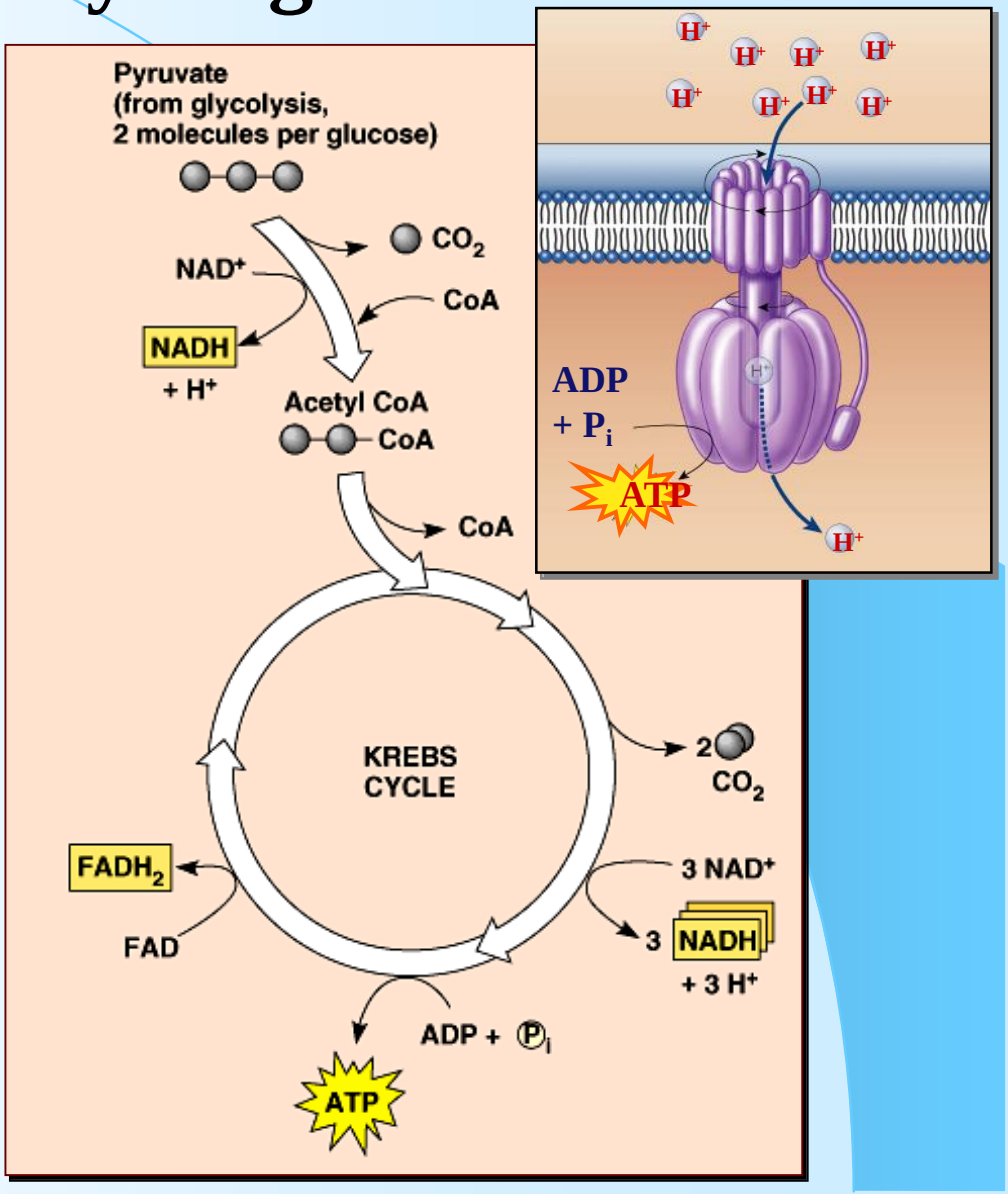


Electron Carriers = Hydrogen Carriers

- Krebs cycle produces large quantities of <u>electron carriers</u>
  - NADH
  - $FADH_2$
  - go to <u>Electron Transport Chain!</u>

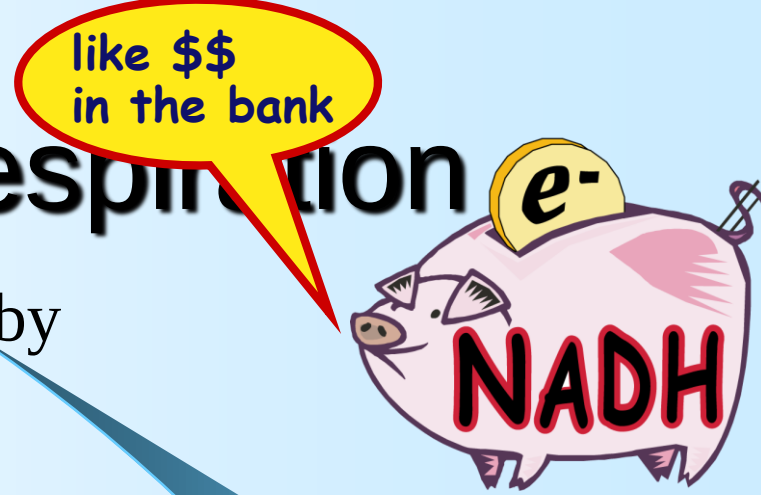


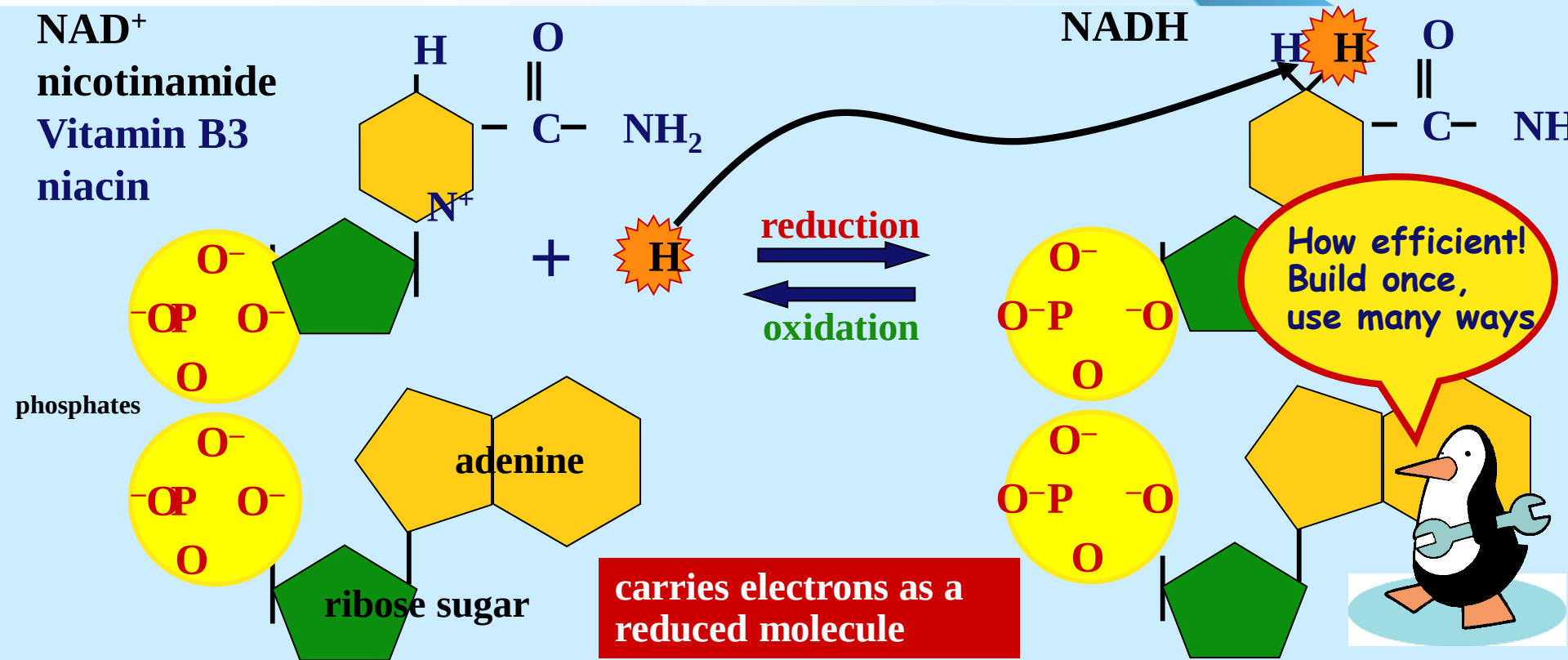
What's so important about electron carriers?

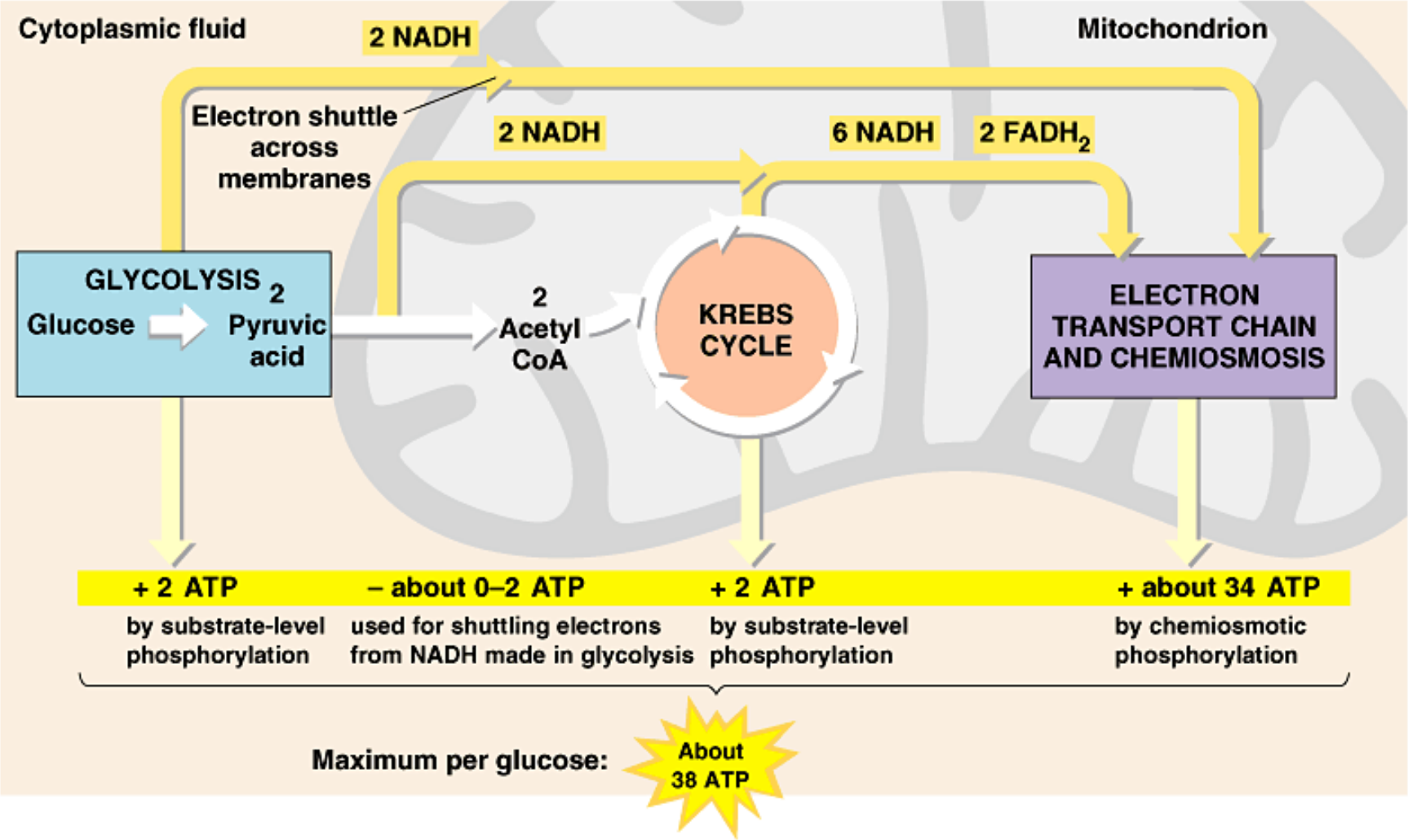


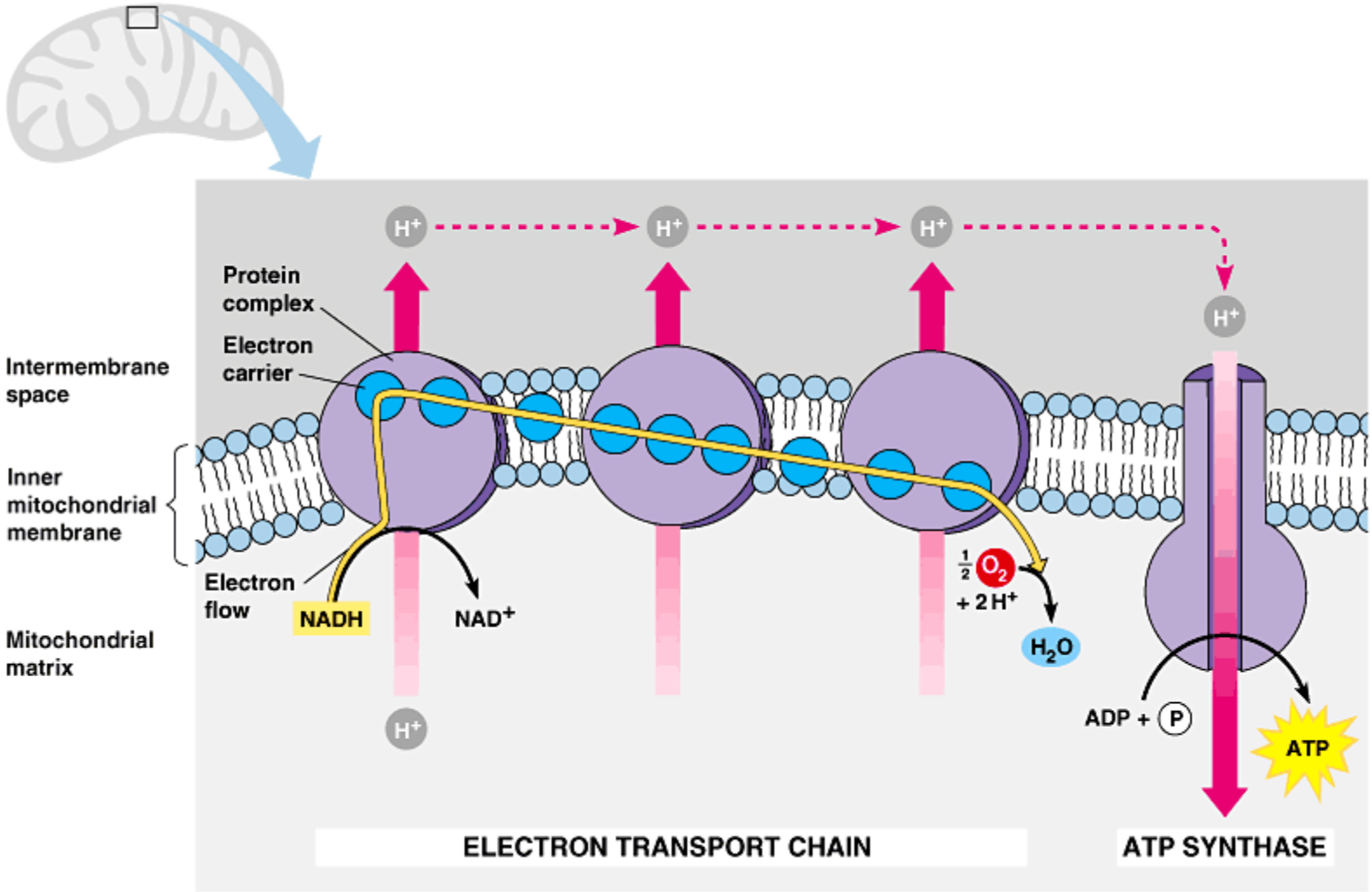
Moving electrons in respiration

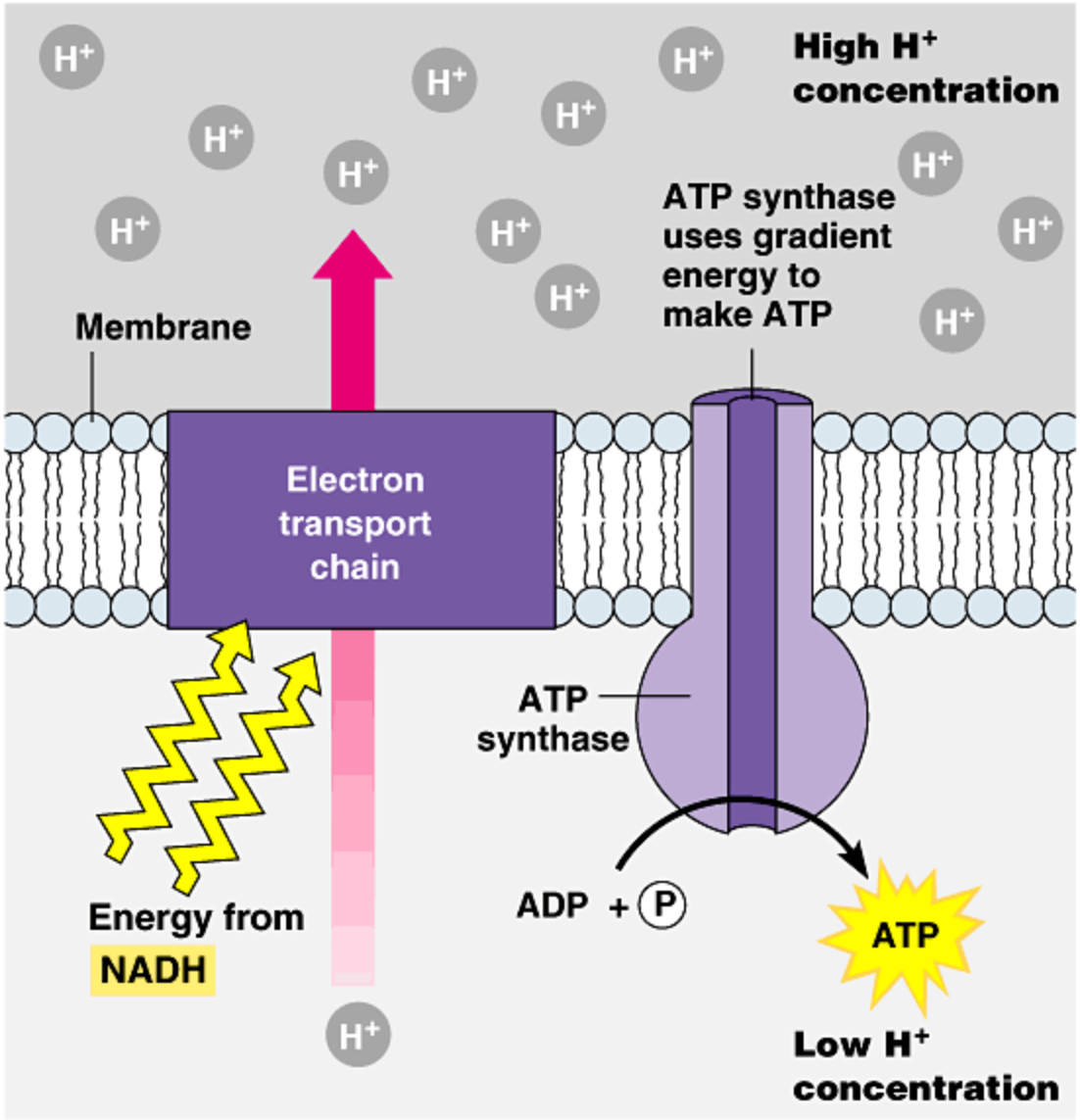
- Electron carriers move electrons by shuttling H atoms around
  - $NAD^+ \rightarrow$ NADH (reduced)
  - $FAD^{+2} \rightarrow FADH_2$ (reduced)











Electron Transport Phosphorylation

- NADH and FADH2 give excited electrons to proteins in the mitochondria's inner membrane
- H+ released from NADH and FADH2 are pumped into the inner membrane space of the mitochondria
- H+ flows back to inner compartment(matrix) throught ATP synthase forming 32ATP – chemiosmosis

- **Oxygen joins with electrons and H^+ to yield water.**

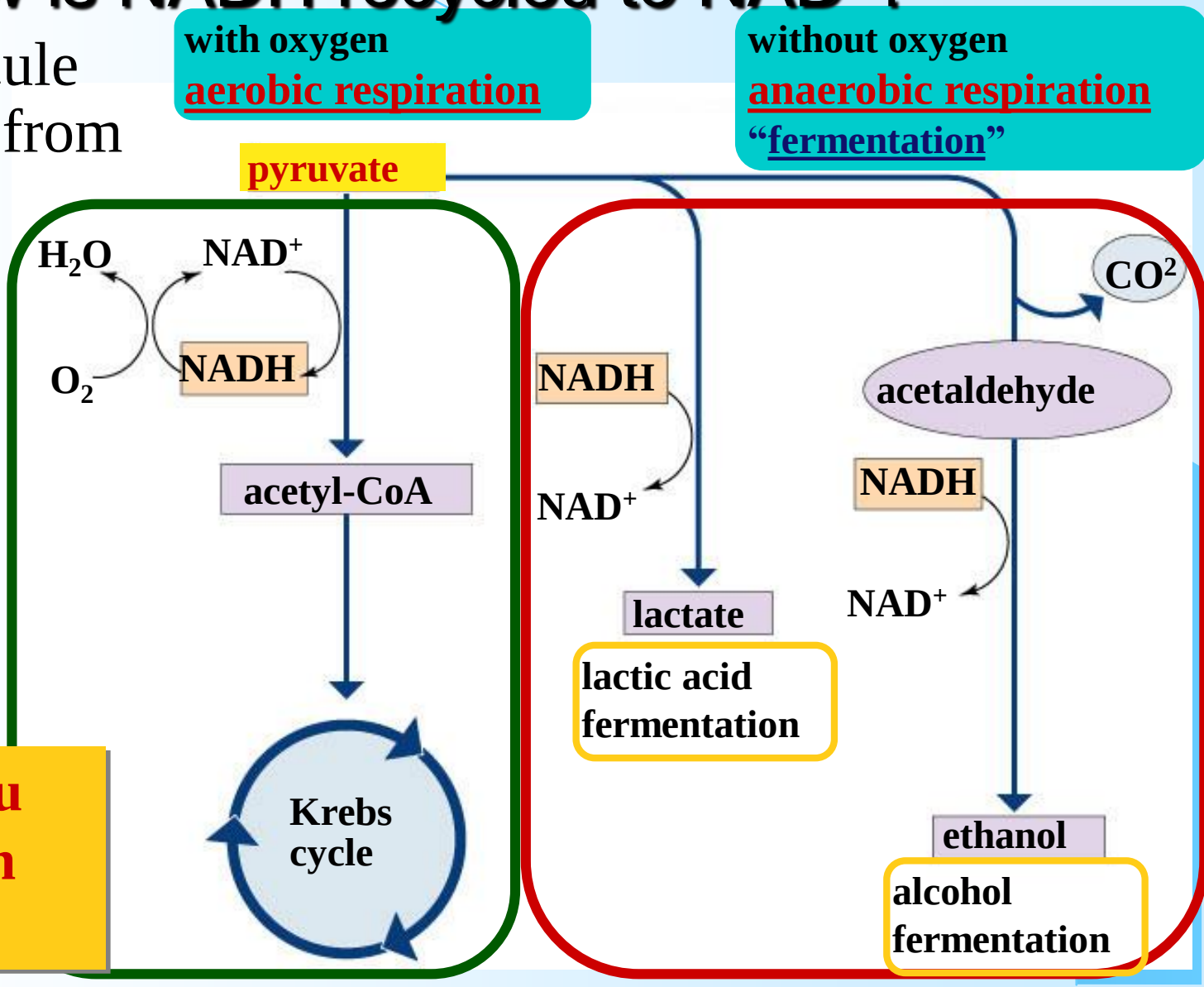
- **Without Oxygen the H+ gradient is lost and chemiosmosis stops**

Fermentation – ATP without Oxygen

- **Release small amounts of ATP(2) without oxygen.**
- **TWO TYPES – Lactic Acid and Alcoholic**

How is NADH recycled to NAD^+?

Another molecule must accept H from NADH



which path you use depends on who you are…

Fermentation (anaero

- 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)**

Alcoholic Fermentation

- In Yeast (carbon dioxide makes dough rise) and in alcoholic beverage production. w/ bacteria
- Enzymes convert pyruvate to acetaldehyde, which then accepts electrons from NADH to become alcohol.

Alcohol Fermentation

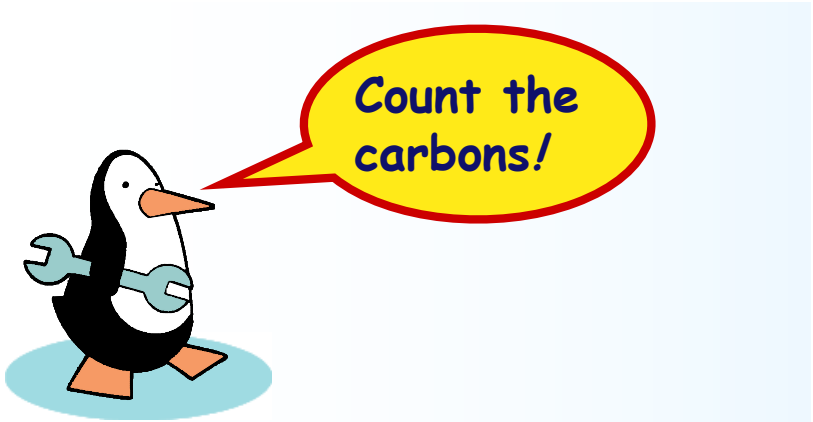
pyruvate → ethanol + CO_2

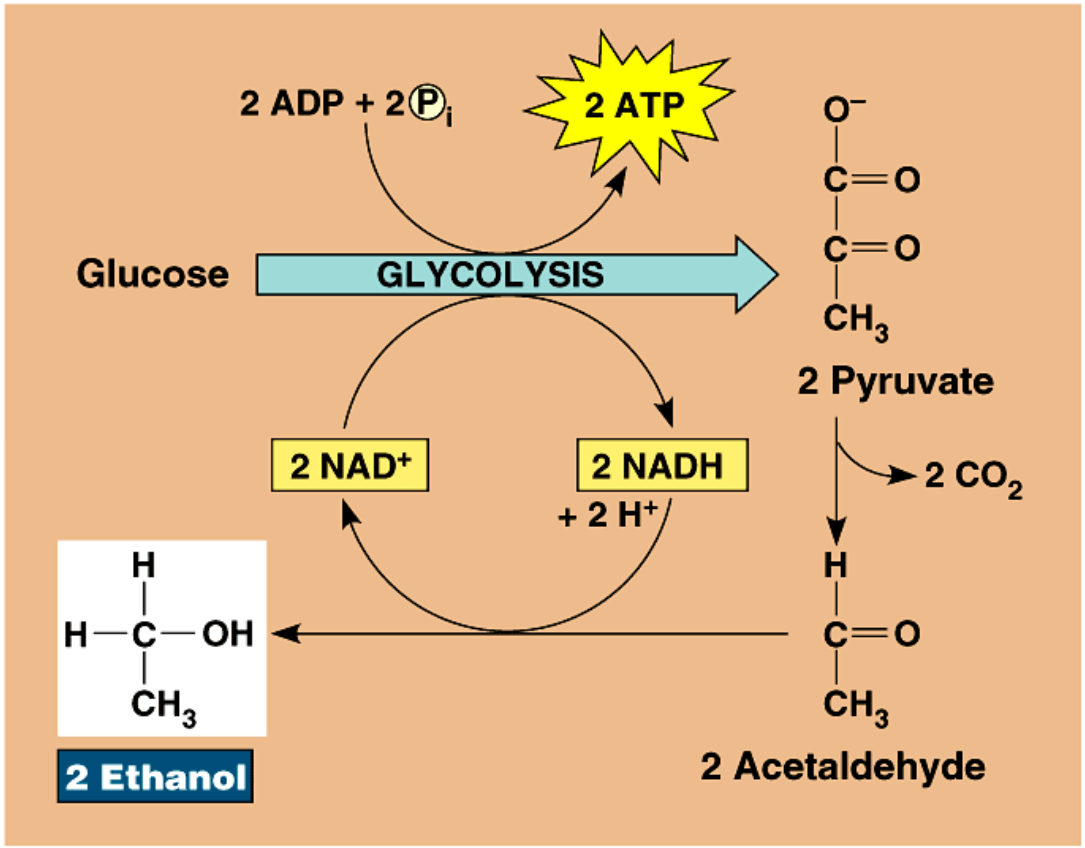
3C → 2C + 1C

NADH → NAD^+

back to glycolysis→→

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





Lactic Acid Fermentation

animals
some fungi

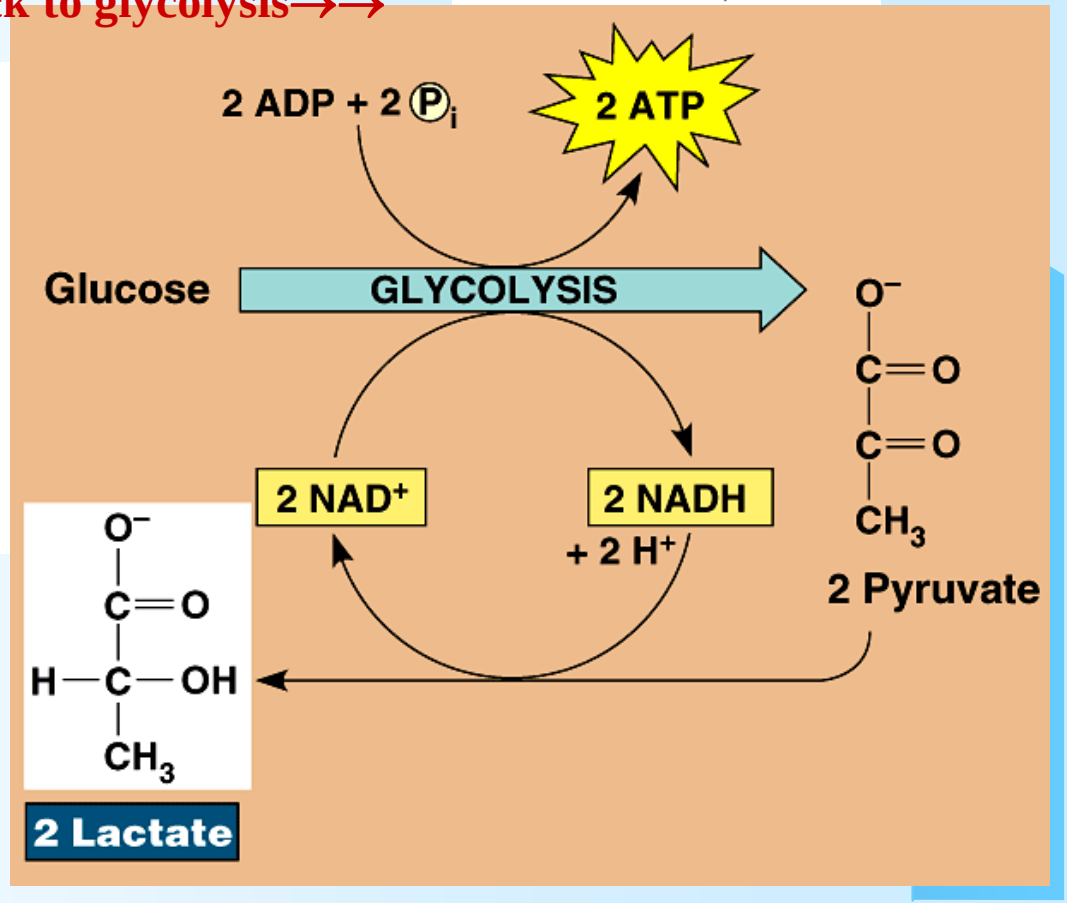
pyruvate ← lactic acid

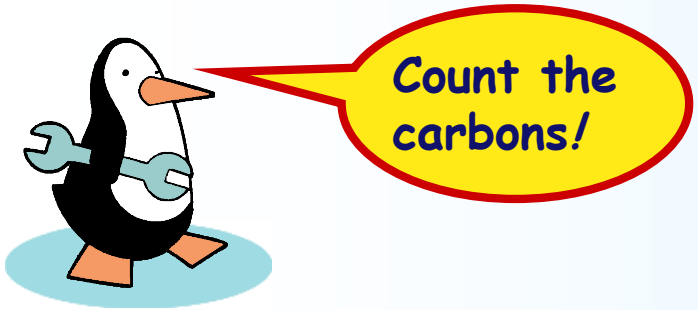
3C 3C

NADH NAD+ back to glycolysis→→

O_2

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





Lactic Acid Fermentation

- Pyruvate molecules are converted to lactic acid to get NAD back for more glycolysis
- Sour milk, cheese, yogurt, & sauerkraut produced this way by bacteria
- If muscle cells very active(run out of oxygen), they make lactate temporarily.
  - Makes Muscles “burn”

Pyruvate is a branching point

Pyruvate

$\cancel{O_2}$

O_2

fermentation
anaerobic respiration

mitochondria
Krebs cycle
aerobic respiration