Cellular Respiration: Obtaining Energy from Food (Slide 13)

§1 Energy Flow and Chemical Cycling in the Biosphere (生物圈)

1. All life requires energy

1° In almost all ecosystems on Earth, this energy originates with the sun.

2° During photosynthesis, plants convert the energy of sunlight to the chemical energy of sugar and other organic molecules.

3° Humans and other animals depend on this conversion for food and more.

2. Producers and Consumers

1° Autotrophs (自养生物)

Plants and other autotroph are organisms that make all their own organic matter (carbohydrates, lipids, proteins ......) from nutrients (营养物) that are entirely inorganic:

① carbon dioxide from the air and water

② minerals (矿物质) from the soil.

2° Hetertrophs (异养生物)

Cannot make organic molecules from inorganic ones.

Include humans and other animals

3. Chemical cycling between photosynthesis and cellular respiration

1° Photosynthesis

① The chemical ingredients for photosynthesis are carbon dioxide (CO_2) and water (H_2O)

(1) CO_2 passes from the air into a plant via tiny pores.

(2) H_2O is absorbed from the soil by the plant's roots.

② Inside leaf cells, chloroplast use light energy to rearrange the atoms of these ingredients to produce sugar, most importantly glucose ($C_6H_{12}O_6$), and other organic molecules.

③ A by-product of photosynthesis is oxygen gas (O_2)

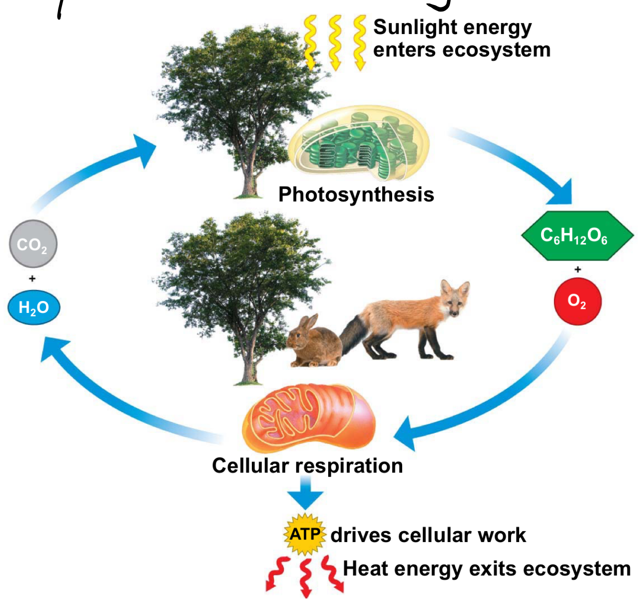
2° Cellular respiration

① Cellular respiration harvests energy that is stored in sugars and other organic molecules.

② Cellular respiration uses O_2 to help convert the energy stored in the chemical bonds of organic fuels to another source of chemical energy called ATP.

(1) Cells use ATP for almost all their work.

(2) In plants and animals, the production of ATP during cellular respiration occurs mainly in mitochondria



3° Plants usually make more organic molecules than they need for fuel.

This photosynthetic surplus

① provides material for the plant to grow

② can be stored, as starch for example.

§2 Cellular Respiration: Aerobic Harvest of Food Energy

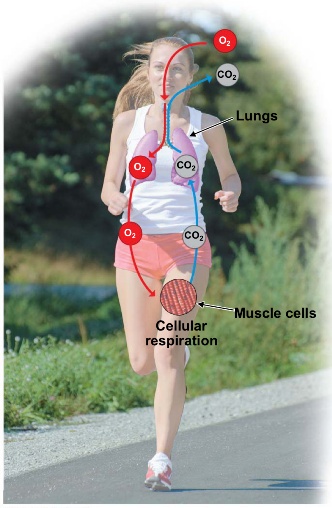
1. Brief introduction

Cellular respiration is

① an aerobic (需氧的) process — it requires oxygen

② aerobic harvesting of chemical energy from organic fuel molecules.

③ the main way that chemical energy is harvested from food and converted to ATP.



2. Redox reaction (氧化还原反应)

Reduction	Oxidation
$A + e^- + H^+ \rightarrow AH$	$AH \rightarrow A + H^+ + e^-$
"gaining" electrons	"losing" electron
"gaining" protons (H^+)	"losing" proton (H^+)
Oxidation number ↓	Oxidation number ↑

3. An overview of cellular respiration

1° The overall equation

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \sim 32\ ATPs + Heat$$

$$\overset{0}{C_6} \xrightarrow{oxidation} 6\overset{+4}{C} + 24e^- \text{ (high energy state)}$$

Heat

~32ATP

$\overset{-2}{O}_6 + 6\overset{0}{O}_2 + 24e^-$ (high energy state) $\xrightarrow{\text{reduction}} 6\overset{2-}{O}_2 + 6\overset{2-}{O}$

2° Electron carriers

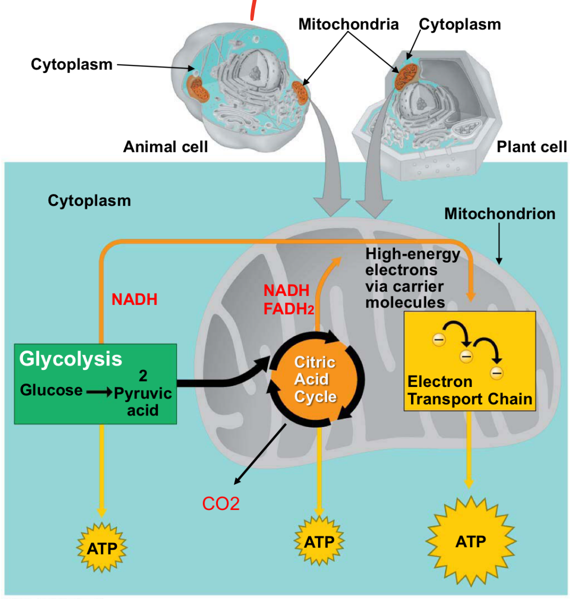
$$\begin{cases} NAD^+ + 2e^- + 2H^+ \rightleftharpoons \overset{\ominus\ominus}{NADH} + H^+ \\ FAD + 2e^- + 2H^+ \rightleftharpoons \overset{\ominus\ominus}{FADH_2} \end{cases}$$

① In stage 1 and 2, much more ATPs are generated indirectly, via reactions that transfer electrons from fuel molecules to a molecule called NAD^+ (nicotinamide adenine dinucleotide)
(烟酰胺腺嘌呤二核苷酸;辅酶)

② The electron transfer forms a molecule called NADH, which acts as a shuttle carrying high-energy electrons from one area to another.

3° Different Stages

- glycolysis (糖酵解)
- citric acid cycle (三羧酸循环/柠檬酸循环)
- electron transport



4. Stage 1: Glycolysis

1° Located in cytoplasm

2° A molecule of glucose is split into two molecules of pyruvic acid (丙酮酸)

3° The three-carbon molecules the donate high energy electrons to NAD^+, forming NADH

4° ① Need 2 ATP molecules to start this process

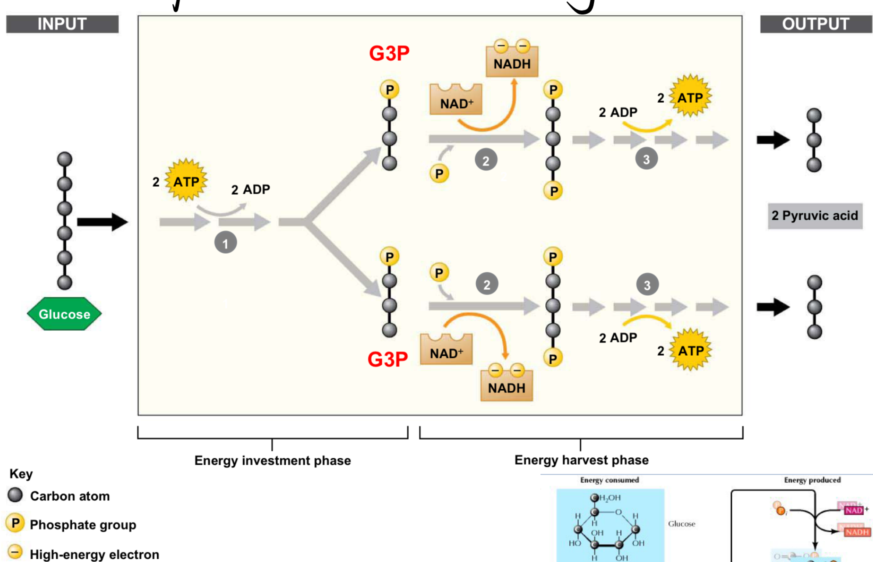
② Generate 4 ATP molecules directly when enzymes transfer phosphate groups from fuel molecule to ADP.

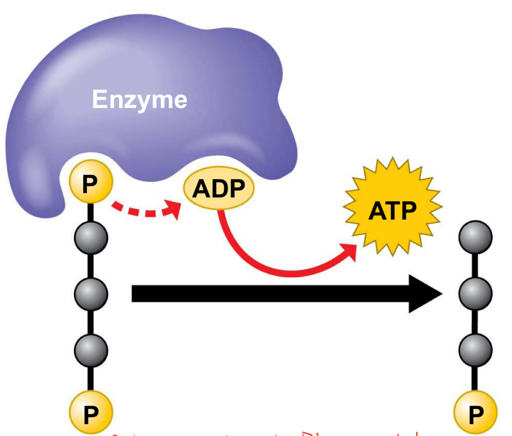
③ In total generate 2 net ATP molecules

This process is called substrate level phosphorylation.

5° Evolved when no O_2

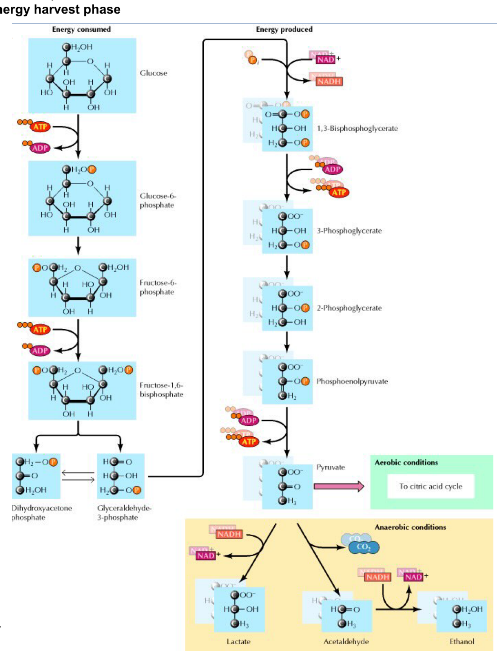
6° Can be found in bacteria, yeasts (酵母), animals ......





Substrate Level Phosphorylation

ATP synthesis by direct phosphate transfer



5. Stage 2 A : a preparation stage

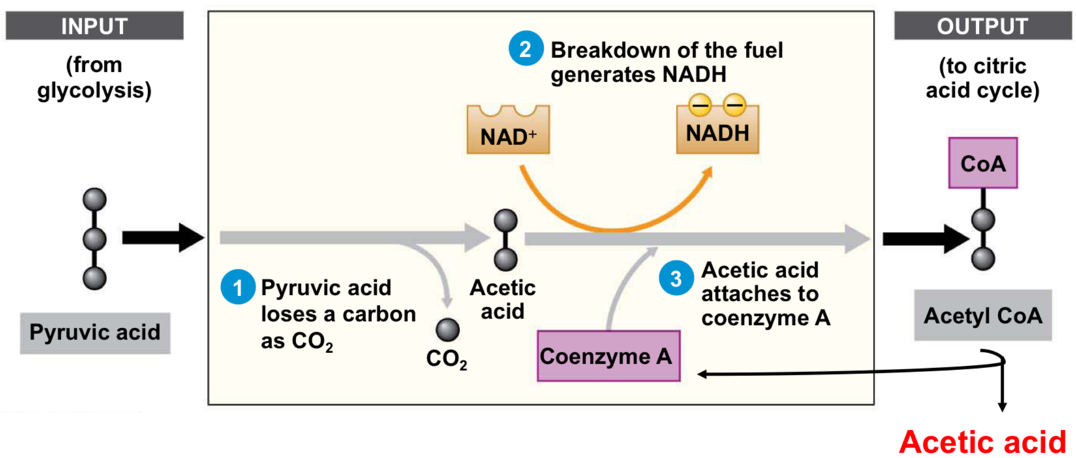
The pyruvic acid must be converted to a form that citric acid cycle can use.

1° Each pyruvic acid loses a carbon as CO_2.

The remaining fuel molecules, with only two carbons left, are called acetic acid (乙酸)

2° Electrons are striped from each molecule and transferred to 1 molecule of NAD^+

3° Finally, each acetic acid is attached to a molecule called coenzyme A (辅酶A) (CoA) to form acetyl CoA (乙酰辅酶A). The CoA escorts the acetic acid into the first reaction of the citric acid cycle and is then stripped and recycled.



6. Stage 2B: The citric acid cycle (or Krebs cycle)

1° Located in mitochondrial matrix (线粒体基质)

2° Finishes extracting the energy of sugar by dismantling the acetic acid molecules all the way down to CO_2.

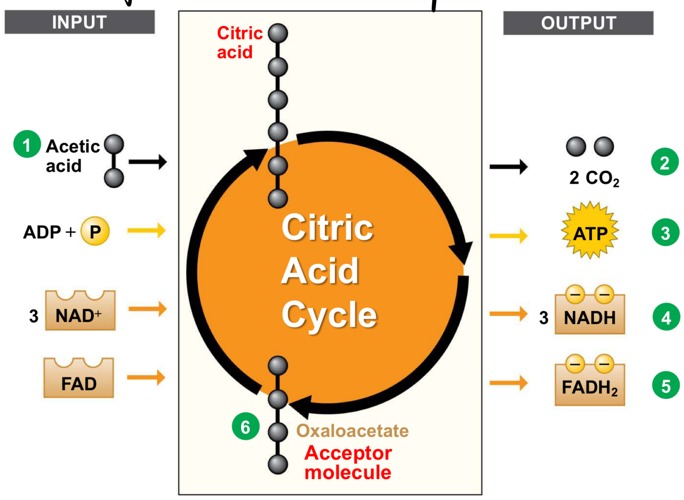
3° Acetic acid joins a four carbon acceptor molecules to form a six-carbon product called citric acid (柠檬酸)

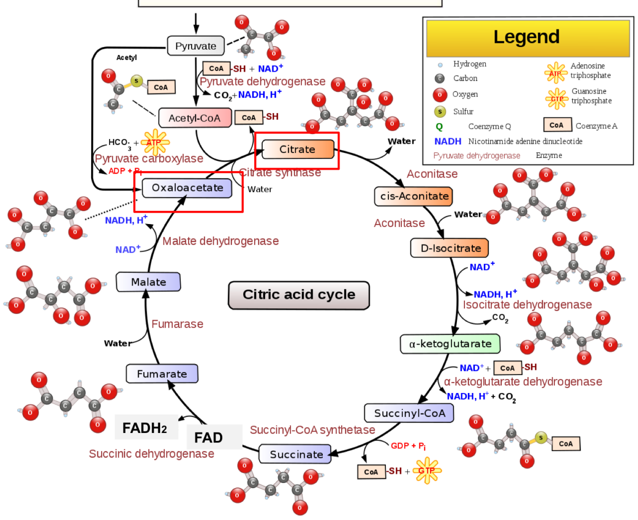
4° For every acetic acid molecule that enters the cycle as fuel, 2 CO_2 molecules eventually exit as a waste product. Along the way, the cycle harvests energy from the fuel.

5° Some of the energy is used to produce ATP directly.

6° The cycle captures much more energy in the form of NADH and a closely related electron carrier called $FADH_2$

7° The four-carbon acceptor molecule is recycled.





7. Chemiosmotic hypothesis (化学渗透假说)

1° Raised by Peter Mitchell, 1961

2° Mitochondria produce ATP by chemiosmosis

3° Three kinds of energy in cells

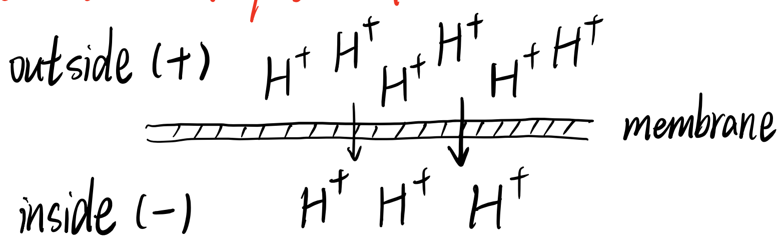
① Chemical bond

$$ATP \rightleftharpoons ADP + P_i$$

② Concentration gradient (浓度梯度)

High concentration ⟶ low concentration

③ Electronical potential



4° proton concentration gradient (ΔpH) + electronical potential (ΔV)

= electrochemical gradient (电化学梯度)

It can be used to drive the synthesis of ATP

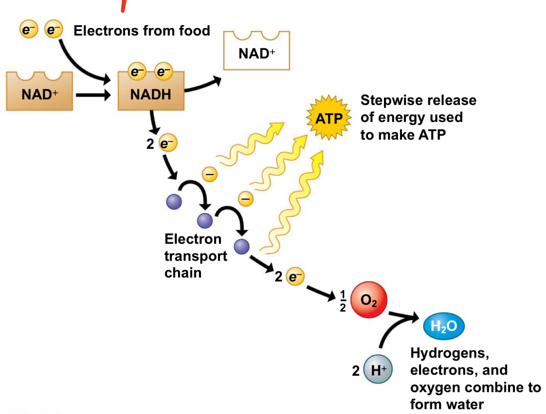
8. Stage 3: Electron transport

1° Located in mitochodrial inner membrane

2° During cellular respiration, the electrons gathered from food molecules "fall" in a stepwise cascade down an energy staircase, unlocking chemical energy in small amounts, bit by bit, that cells can put to productive use.

① The trasfer of electrons from organic fuel (food) to NAD^+ converts it to NADH.

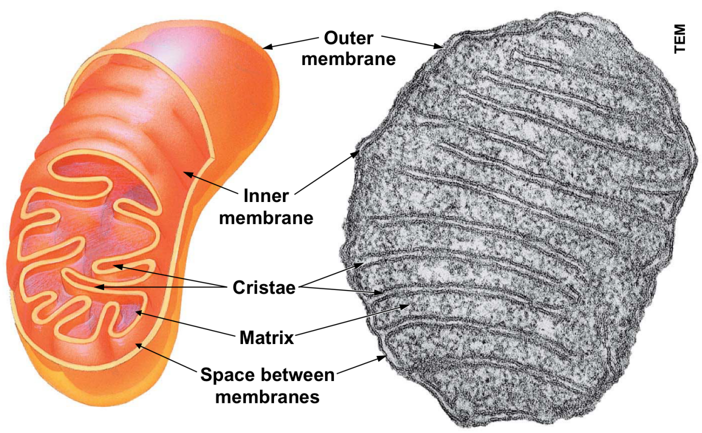
② The rest of staircase consists of an electron transport chain.



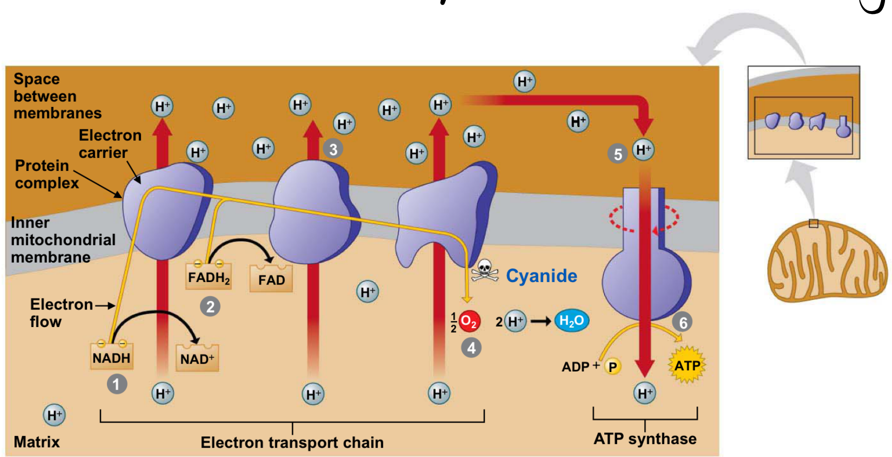
③ The transfer of electrons:

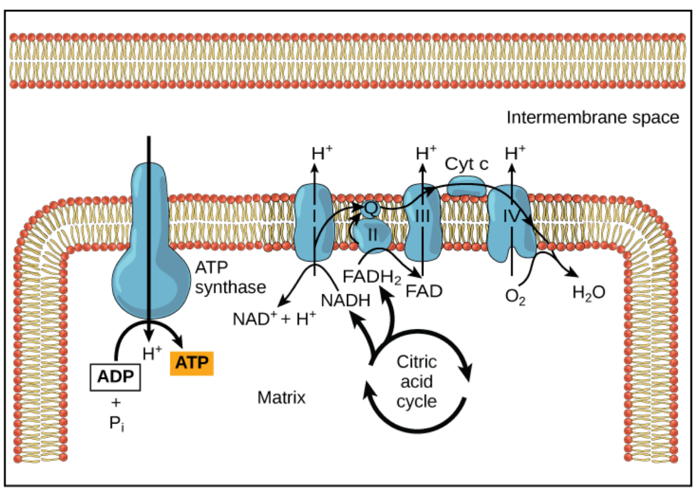
glucose ⟶ NADH ⟶ an electron transport chain ⟶ oxygen

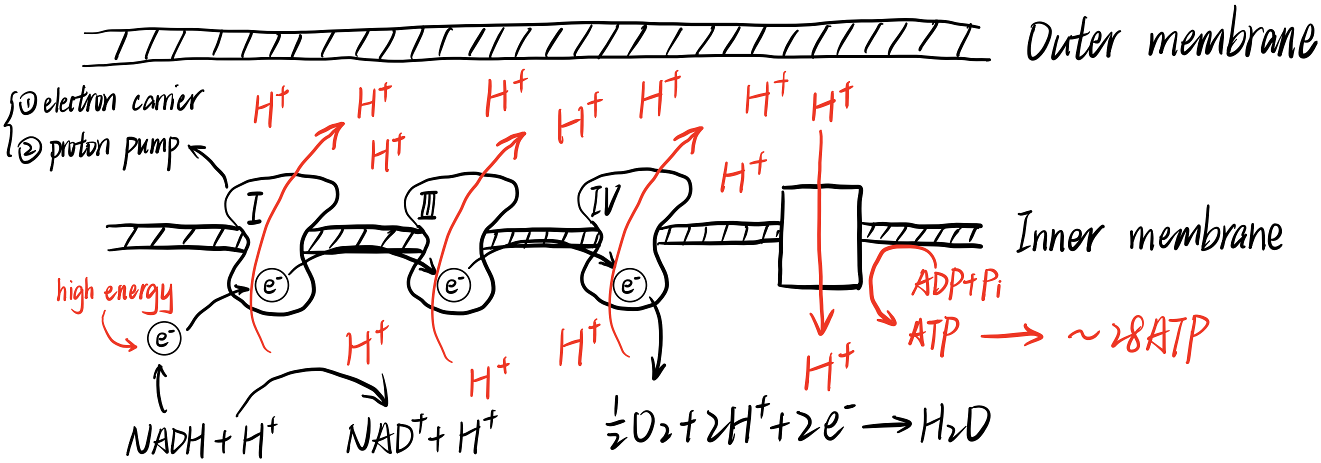
3° The inner membranes of mitochondria are highly folded, their large surface area can accommodate thousands of copies of the electron transport chain.



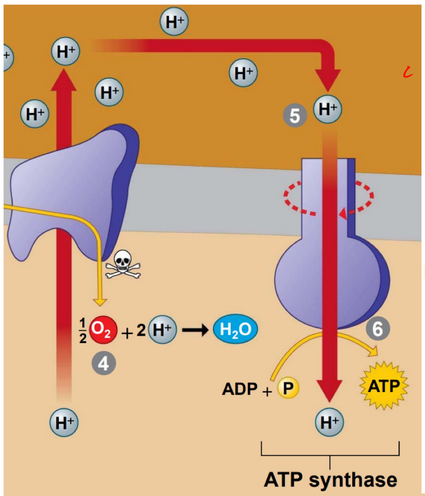
4° How electron transport drives ATP synthase machines:







5° Cyanide (氰化物) can effect electron transport chain



Amygdalin (cyanogenic glycoside)

↓

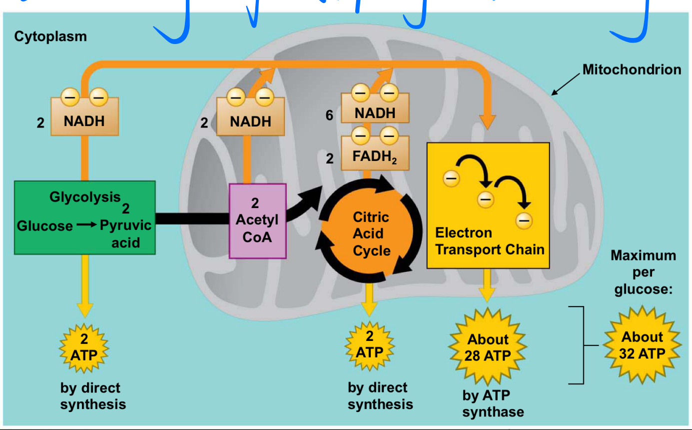
Toxic cyanide anion

↓

cyanide poisoning




9. A summary of ATP yield during cellular respiration



Stages	Products
C-C-C-C-C-C ↓ 2 C-C-C (pyruvates)	2 ATPs 2 NADH
↓	

↓ → CO_2 2 Acetyl-CoA ↓ → 2 CoA 2 C–C (2 Acetic acids)	2 NADH
↓ citric acid cycle ↓ 4 CO_2	2 ATPs 6 NADH 2 $FADH_2$
10 NADH 2 $FADH_2$ ↓ → $24e^-$ electron transport chain	~28 ATPs
Total	~32 ATPs 6 CO_2 6 H_2O

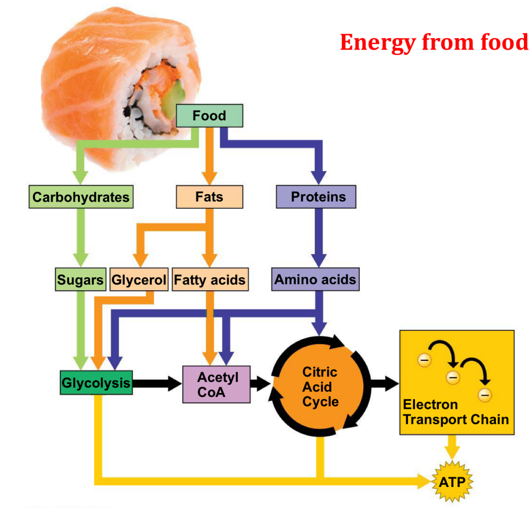
10. Energy from food

1°

amino acids (liver) → carbon skeleton → α-keto acids → citric acid cycle

amino acids (liver) → NH_4^+ → urea (尿素) (kidneys)

2° 18 C fatty acid → 9 C-C (acetyl-CoA) → citric acid cycle



§3 Fermentation : Anaerobic Harvest of Food Energy

1. Fermentation (发酵)

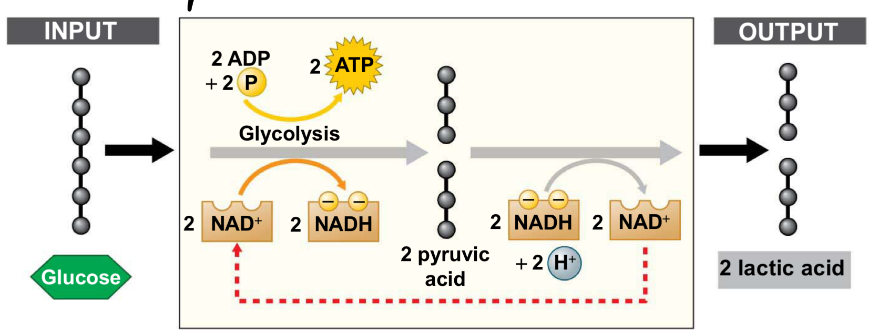
Fermentation is the anaerobic (无氧的) harvest of food energy.

2. Fermentation in human muscle cells

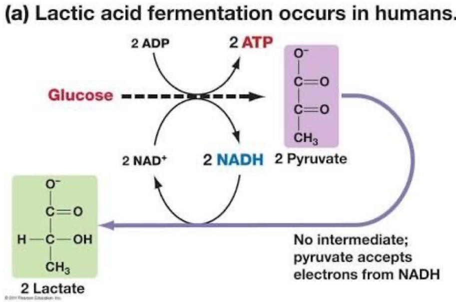
1° After functioning anaerobically for about 15 seconds, muscle cells begin to generate ATP by fermentation.

2° Fermentation relies on glycolysis to produce ATP (2 ATPs each glucose)

3° The addition of electrons to pyruvic acid produce a waste product called lactic acid (乳酸).



(a) Lactic acid fermentation occurs in humans.

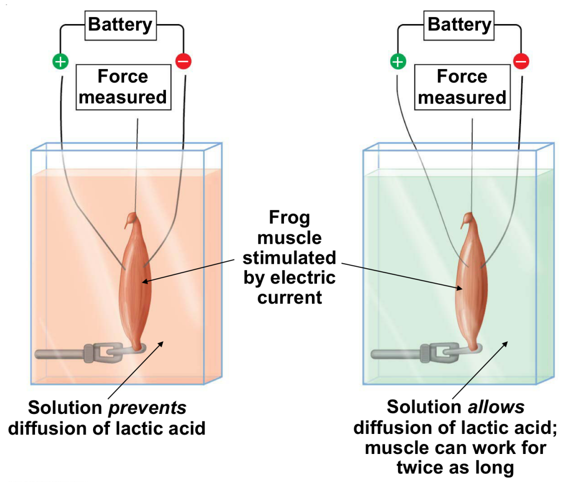


4° The lactic acid by-product is eventually transported to the liver, where liver cells convert it back to pyruvic acid.

3. What cause muscle burn

1° Hill's experiment

- **Observation:** Muscles produce lactic acid under anaerobic conditions.
- **Question:** Does the buildup of lactic acid cause muscle fatigue（肌肉疲劳）?
- **Hypothesis:** The buildup of lactic acid would cause muscle activity to stop.
- **Experiment:** Researchers tested frog muscles under conditions when lactic acid could and could not diffuse away from the muscle tissue.



- **Results:** When lactic acid was allowed to diffuse away, performance improved significantly.
- **Conclusion:** The buildup of lactic acid is the primary cause of muscle failure under anaerobic conditions.

2° Evidence began to accumulate that contradicted his results.

① The effect that Hill demonstrated did not appear to occur at human body temperature.

② Certain individuals who are unable to accumulate lactic acid have muscles that fatigue more rapidly.

③ Recent research indicates that increased levels of other ions may be to blame.

4. Fermentation in microorganisms

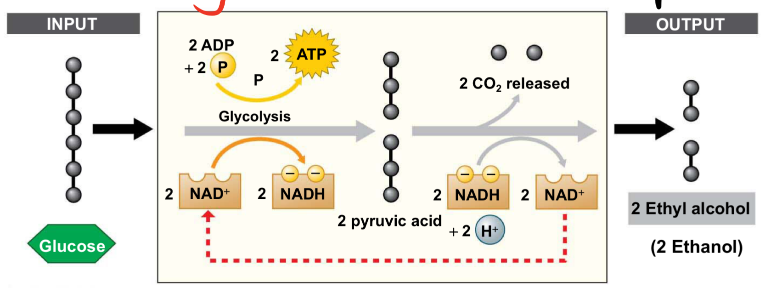
1° Fermentation alone is enough to sustain many microorganisms.

2° The lactic acid produced by yeast (酵母) using lactic acid fermentation is used to produce cheese, sour cream, yogurt ……

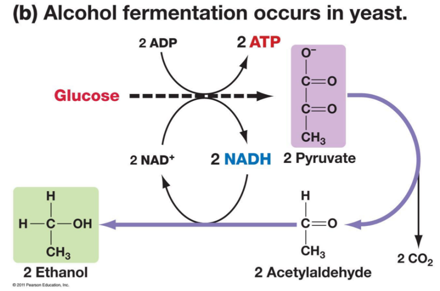
3° Yeast

① is capable of cellular respiration and fermentation.

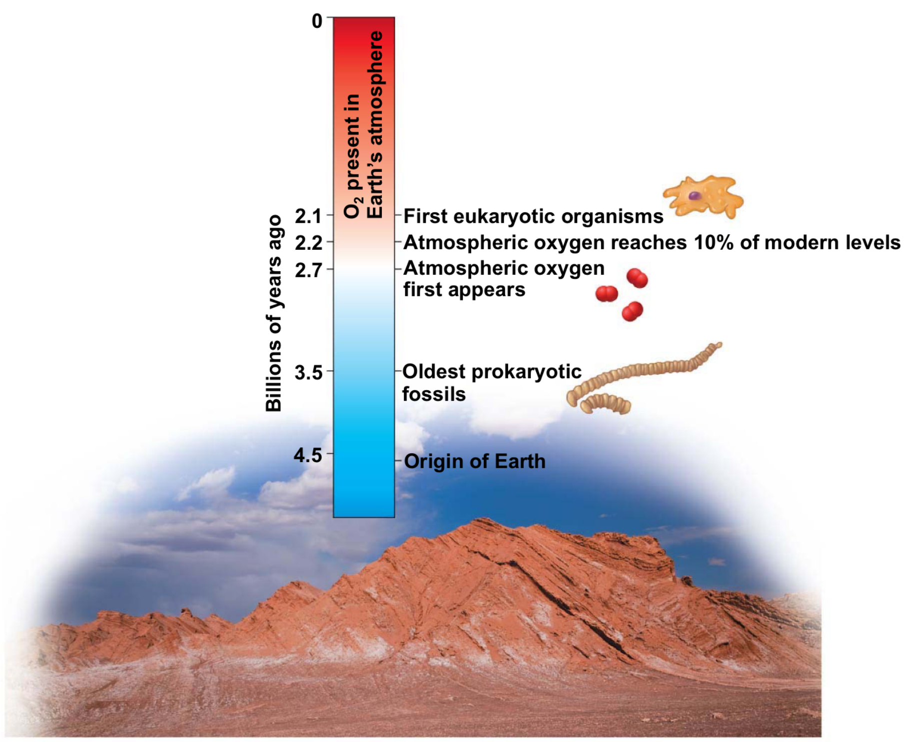
② can perform alcoholic fermentation to produce CO_2 and ethyl alcohol instead of lactic acid.

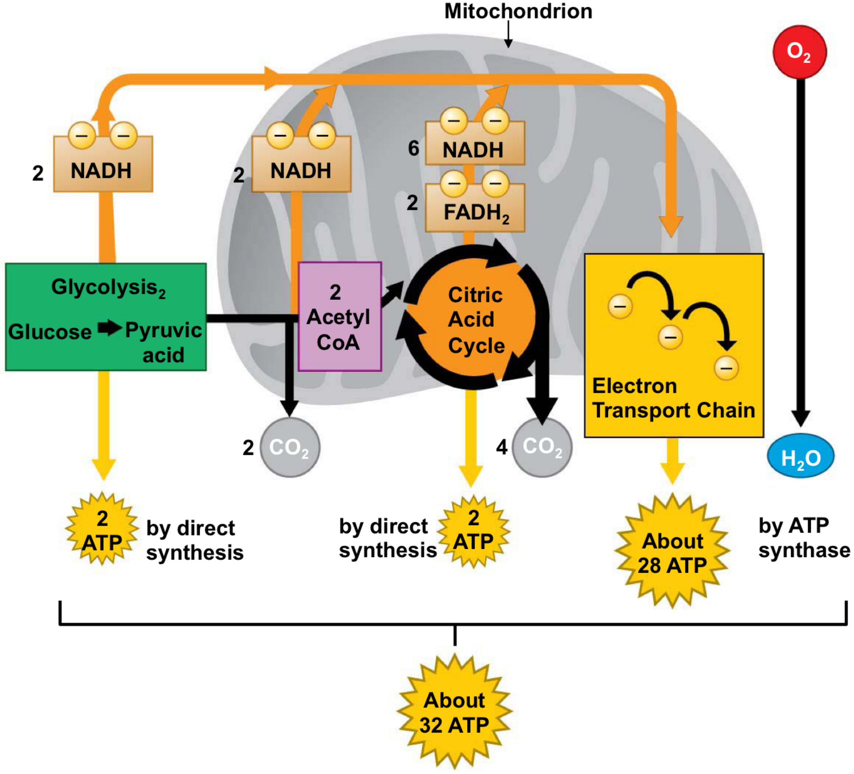


(b) Alcohol fermentation occurs in yeast.



§4 Evolution Connection: The Importance of Oxygen





Mitochondrion
O2
2 NADH
2 NADH
6 NADH
2 FADH2
Glycolysis2
Glucose Pyruvic acid
2 Acetyl CoA
Citric Acid Cycle
Electron Transport Chain
2 CO2
4 CO2
H2O
2 ATP
by direct synthesis
by direct synthesis
2 ATP
About 28 ATP
by ATP synthase
About 32 ATP