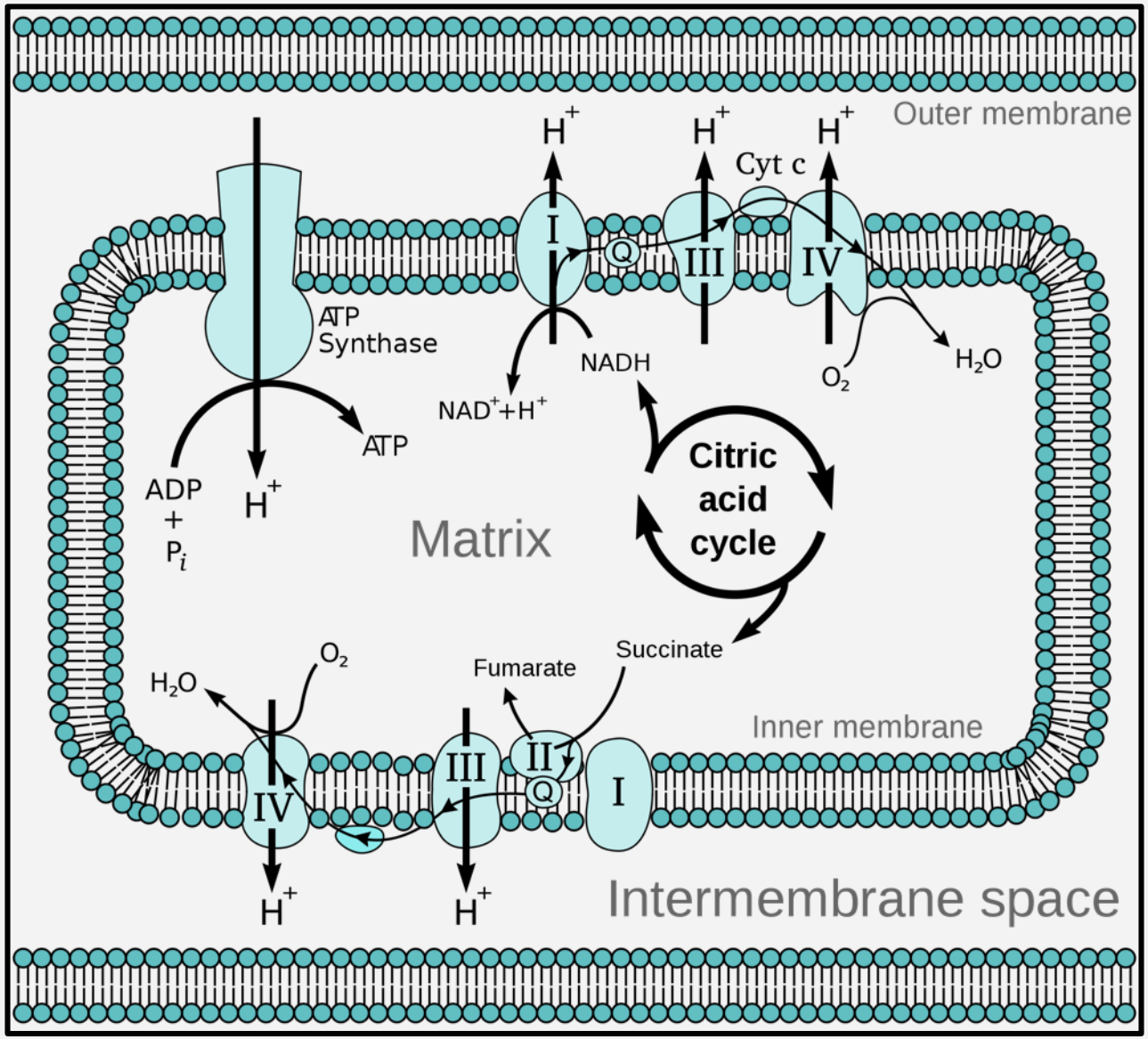
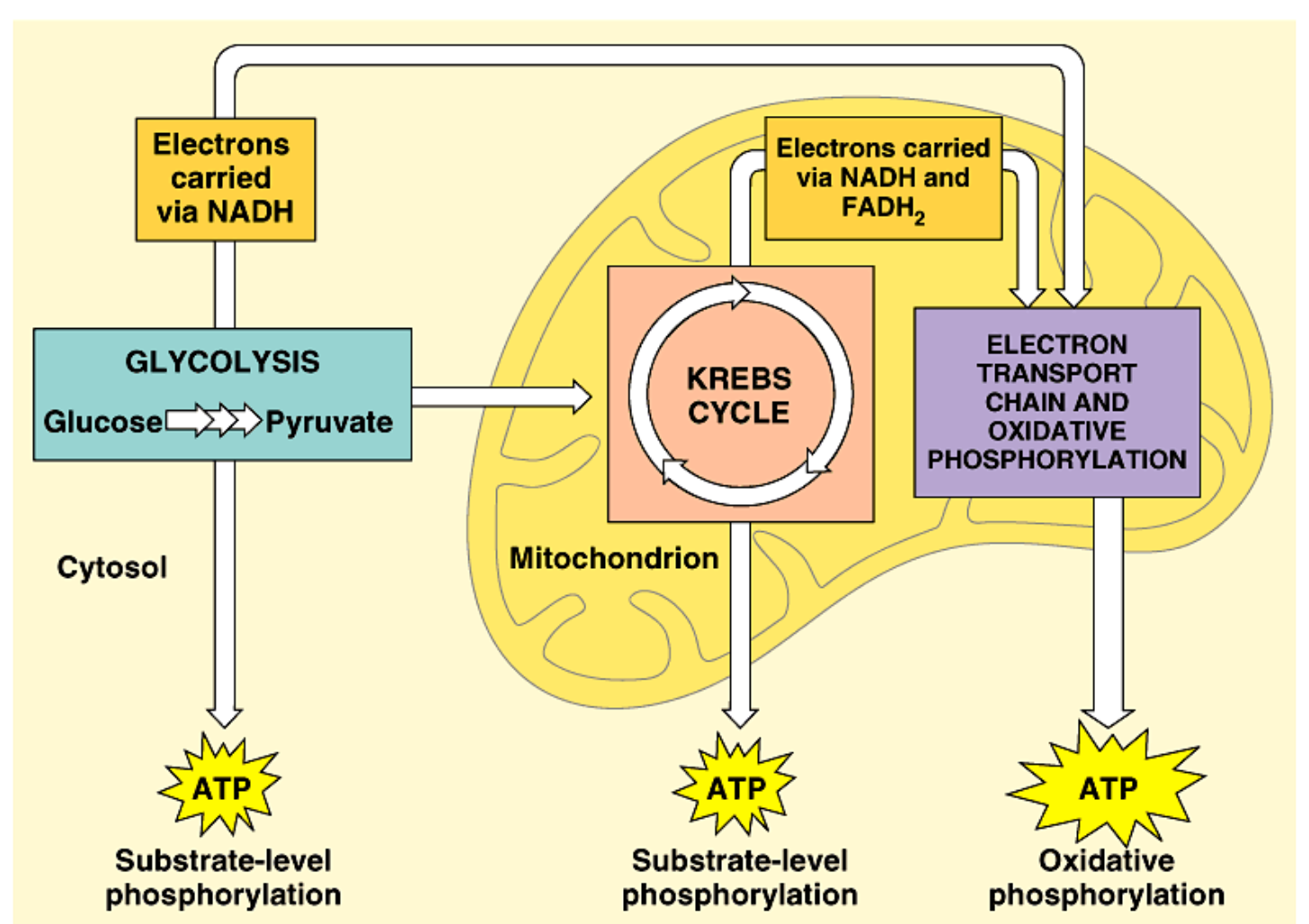
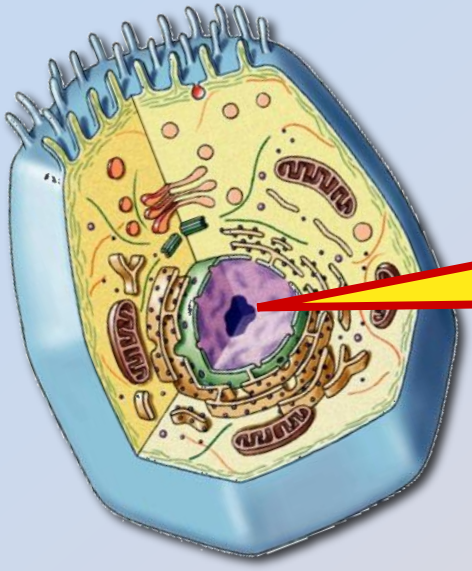
# Cellular Respiration

## Stage 4: Electron Transport Chain (Ch. 6)

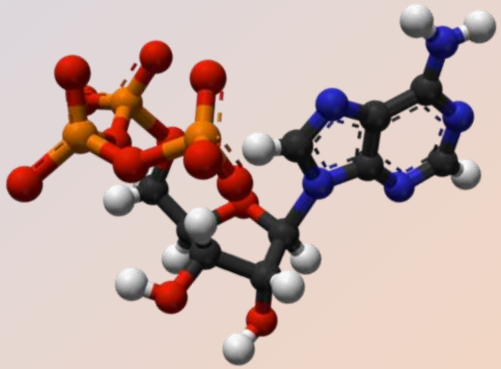


# Cellular respiration





What's the point?



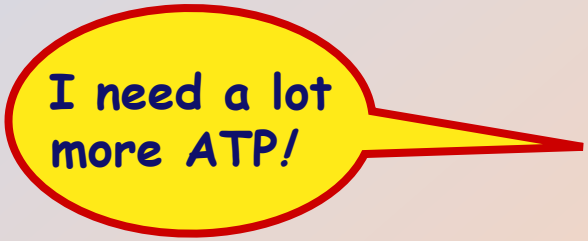
The point is to make **ATP**!

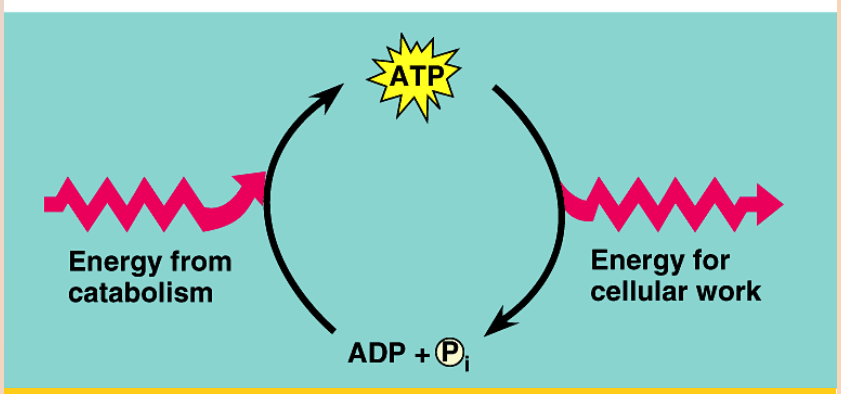
**ATP**

# ATP accounting so far…

- Glycolysis → 2 ATP
- Kreb's cycle → 2 ATP
- Life takes a lot of energy to run, need to extract more energy than 4 ATP!

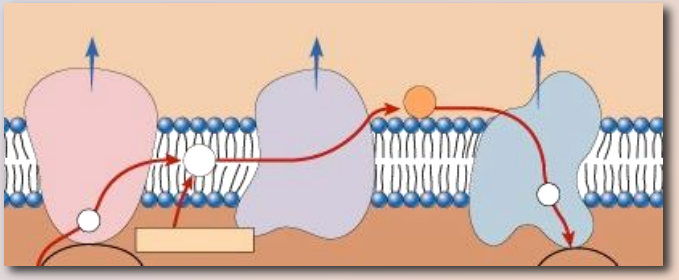
**There's got to be a better way!**




**A working muscle recycles over 10 million ATPs per second**

# There *is* a better way!

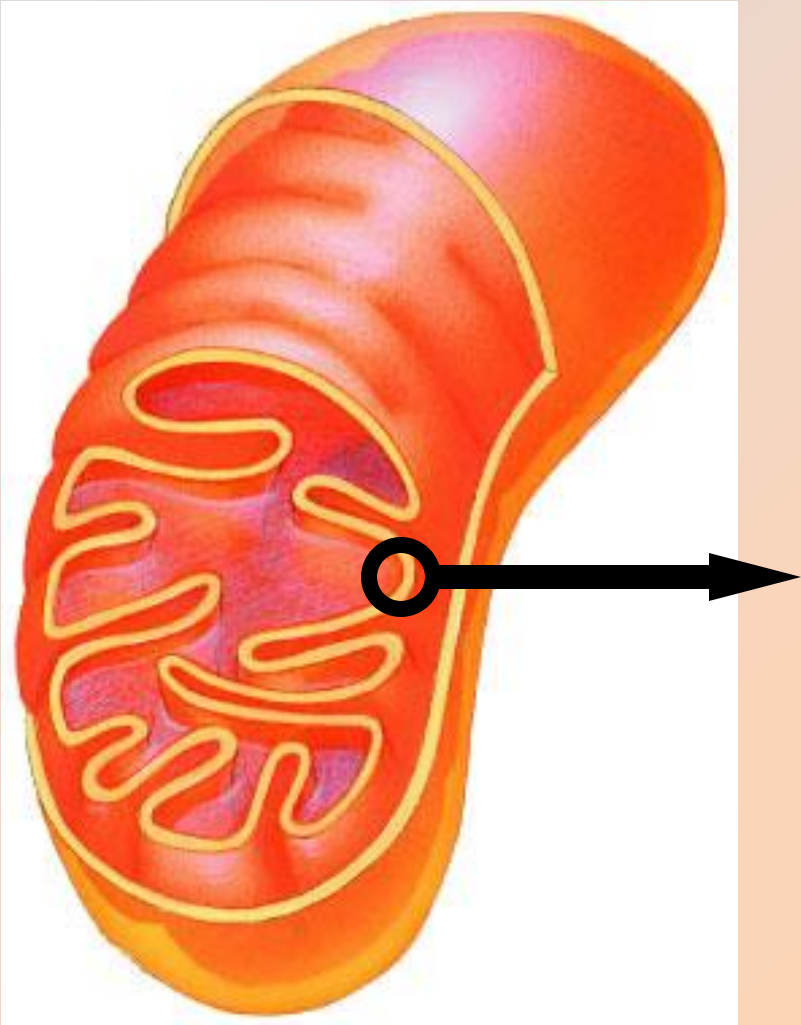


- Electron Transport Chain
  - series of proteins built into inner mitochondrial membrane
    - along cristae
    - transport proteins & enzymes
  - transport of electrons down ETC linked to pumping of $H^+$ to create $H^+$ gradient
  - yields ~36 ATP from 1 glucose*!*
  - only in presence of $O_2$ (aerobic respiration)

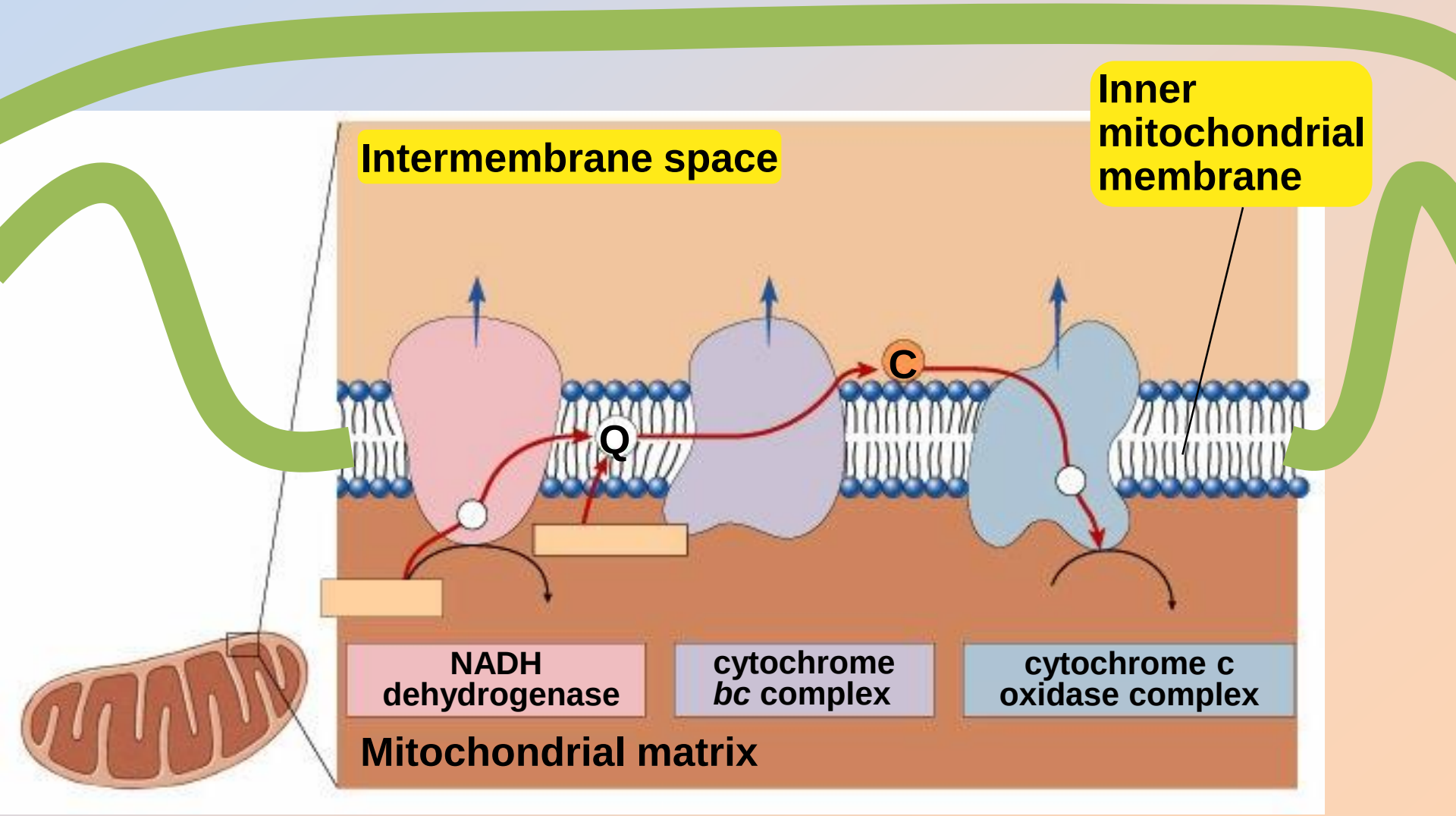

$O_2$

# Mitochondria

- Double membrane
  - outer membrane
  - <u>inner membrane</u>
    - highly folded <u>cristae</u>
    - enzymes & transport proteins
  - <u>intermembrane space</u>
    - fluid-filled space between membranes



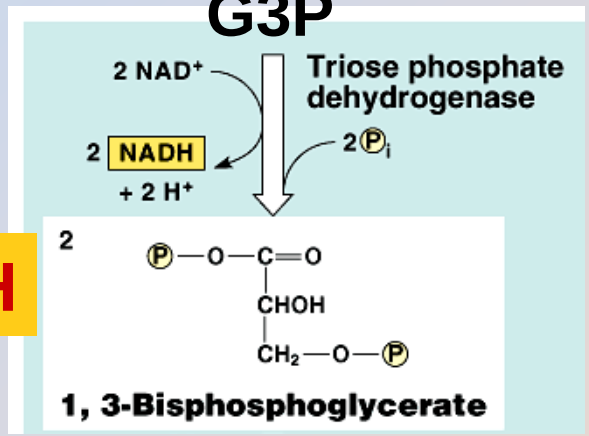
# Electron Transport Chain



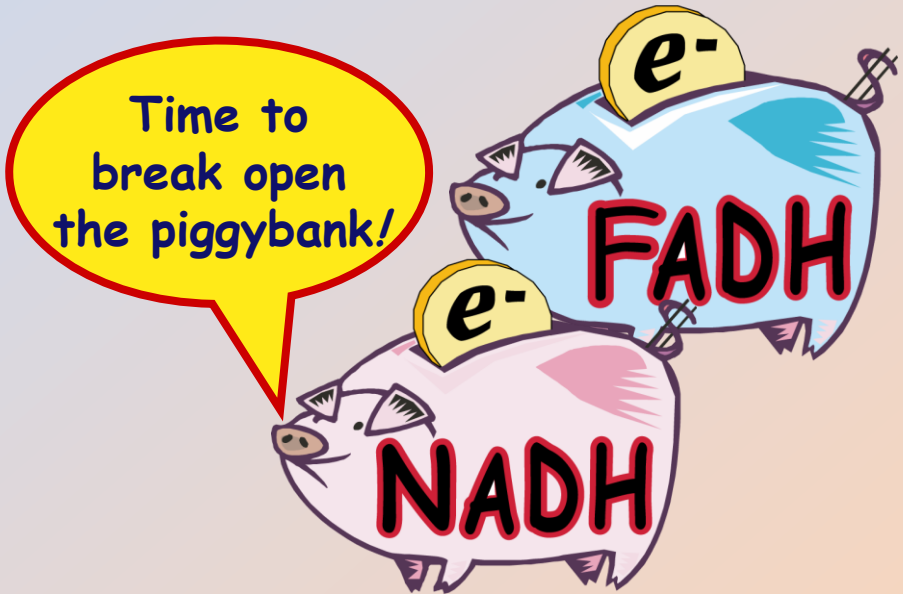
# Remember the Electron Carriers?

**Glycolysis**

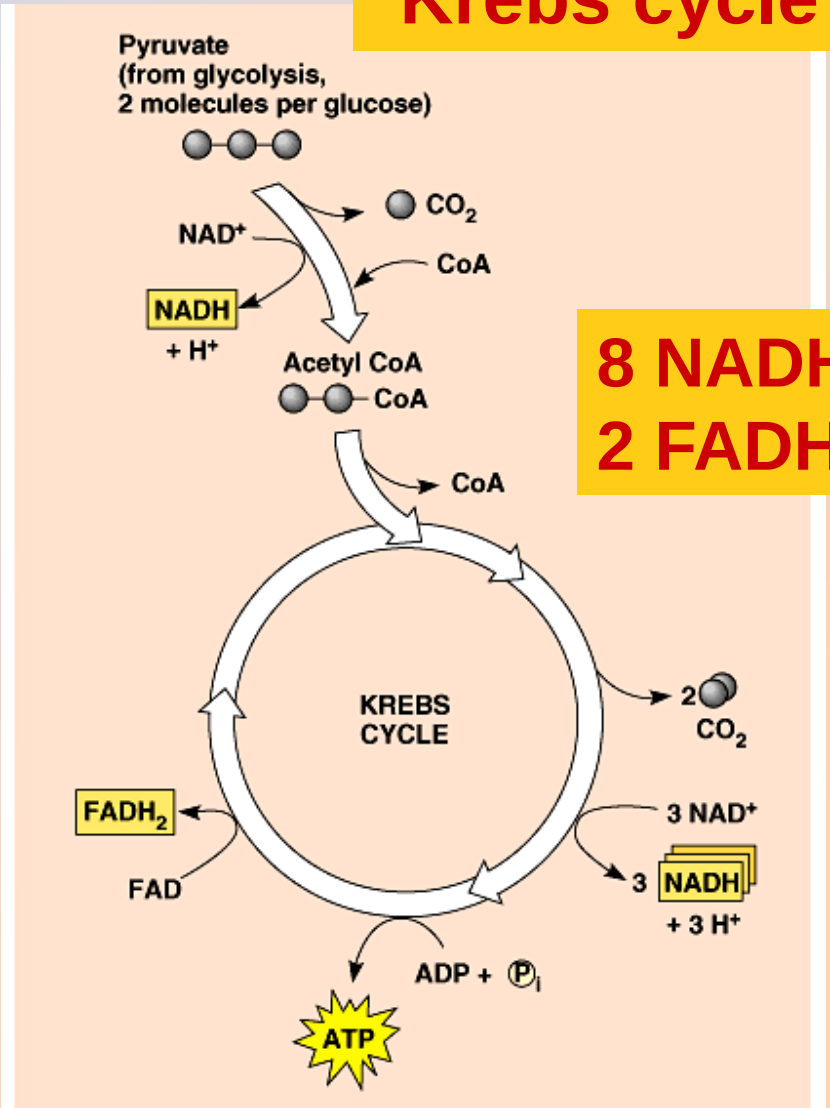
glucose
↓
G3P




**2 NADH**



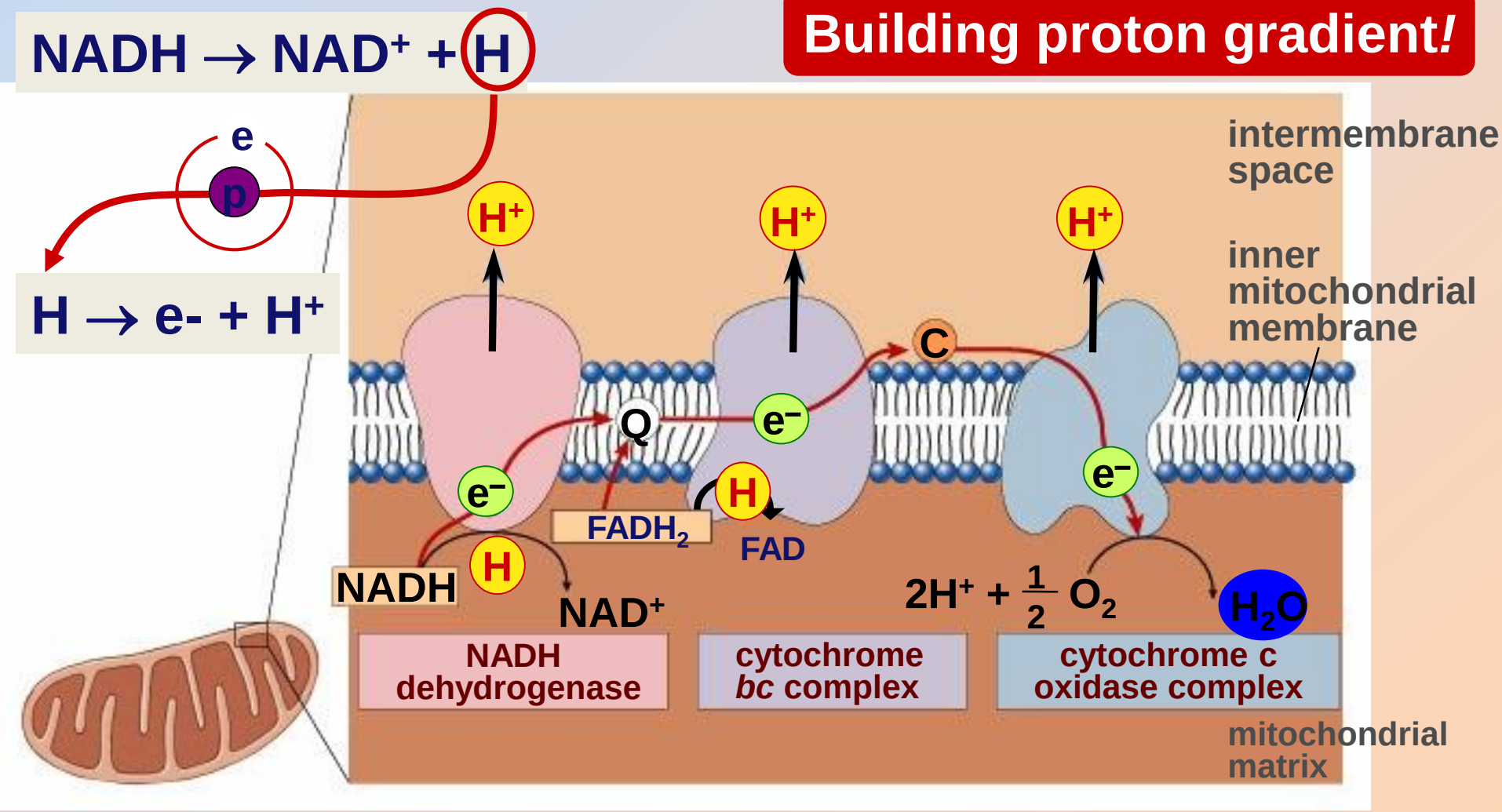

**Krebs cycle**




**8 NADH**
**2 $FADH_2$**

# Electron Transport Chain

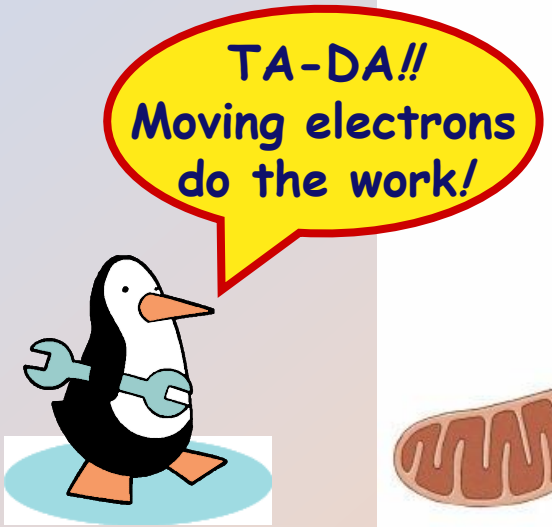
**Building proton gradient!**

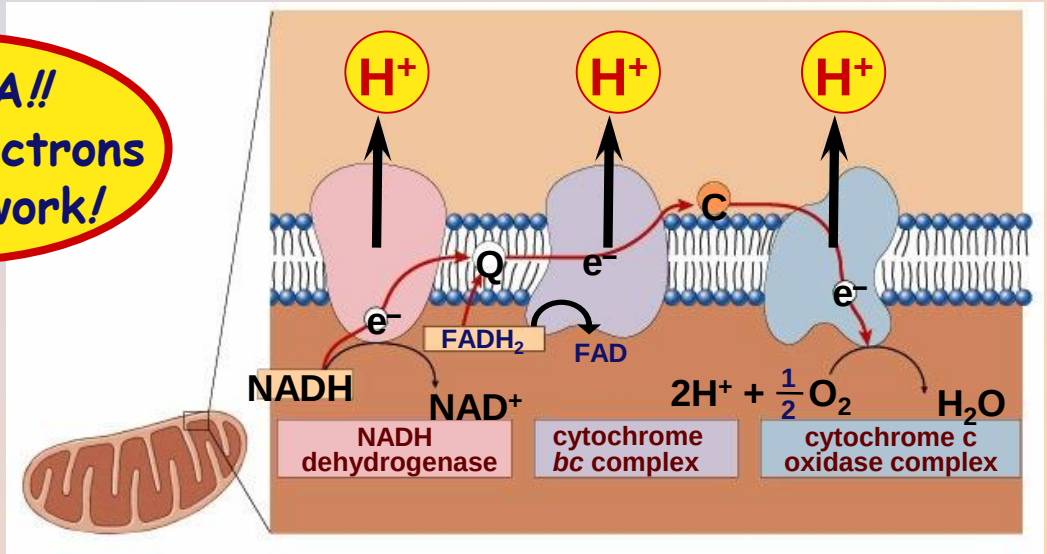


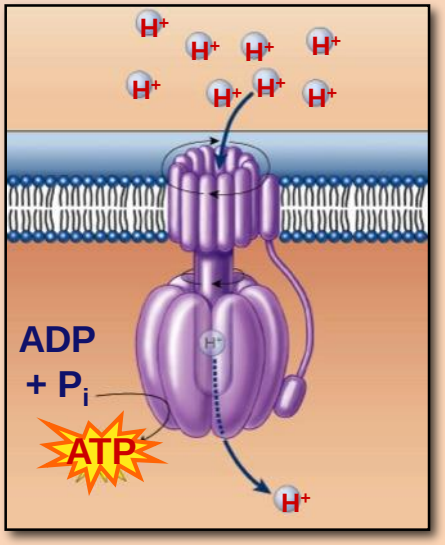

**What powers the proton ($H^+$) pumps?…**

# Stripping H from Electron Carriers

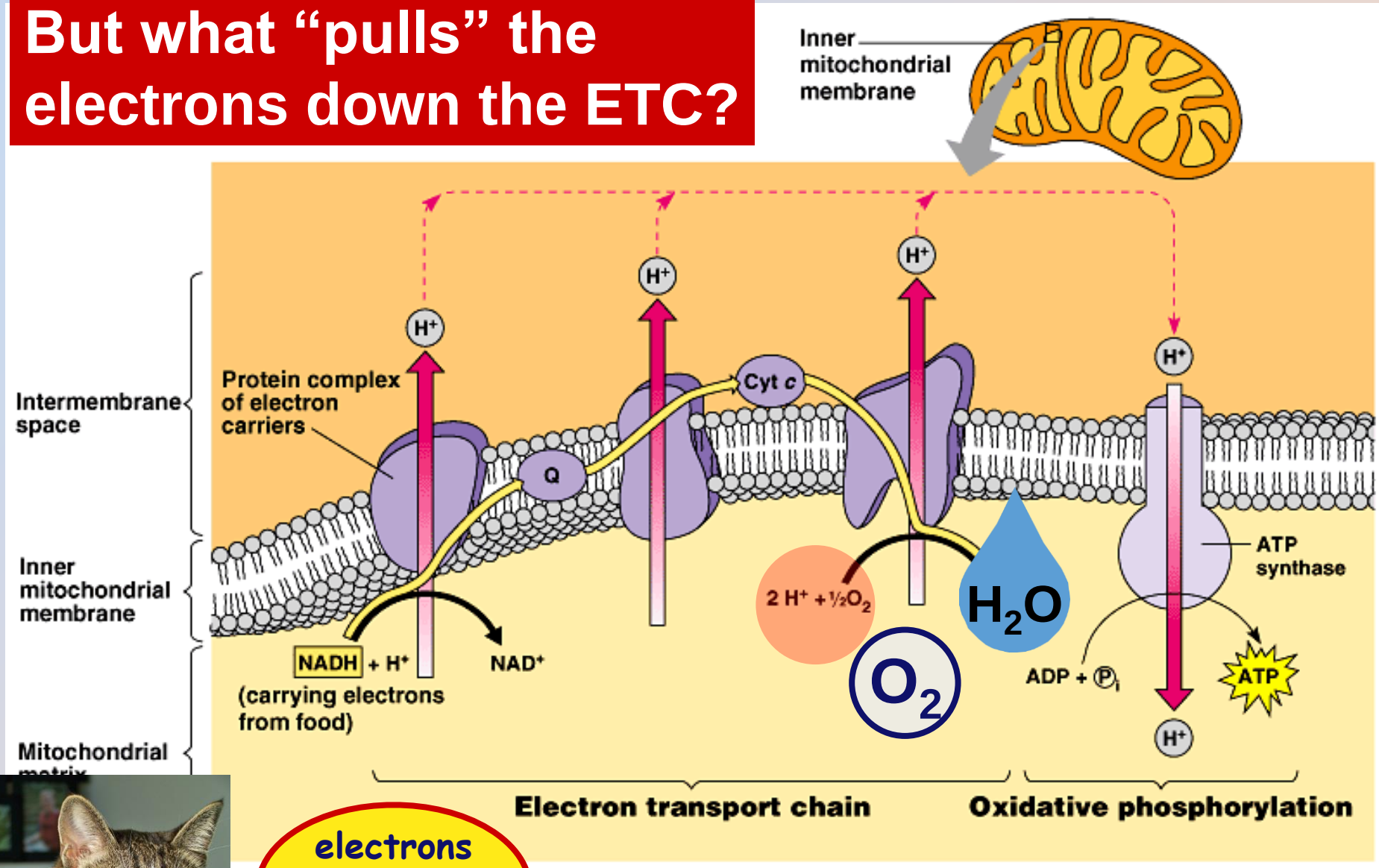
- Electron carriers pass electrons & $H^+$ to ETC
  - H cleaved off NADH & $FADH_2$
  - electrons stripped from H atoms → $H^+$ (protons)
    - electrons passed from one electron carrier to next in mitochondrial membrane (ETC)
    - flowing electrons = energy to do work
  - transport proteins in membrane pump $H^+$ (protons) across inner membrane to intermembrane space



# But what "pulls" the electrons down the ETC?

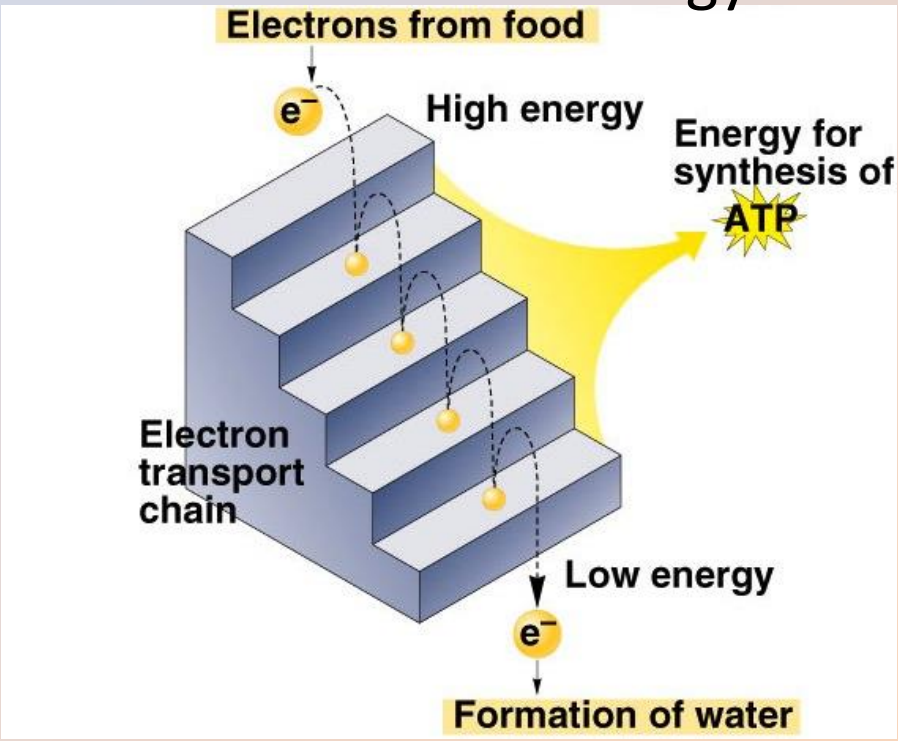


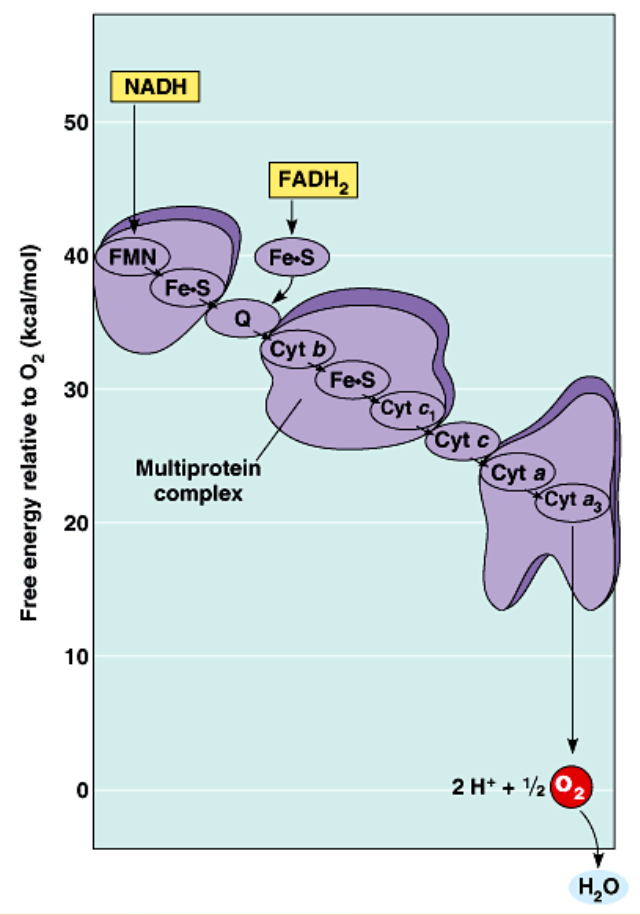

electrons flow downhill to $O_2$

**oxidative phosphorylation**

# Electrons flow downhill

- Electrons move in steps from carrier to carrier downhill to oxygen
  - each carrier more electronegative
  - controlled oxidation
  - controlled release of energy

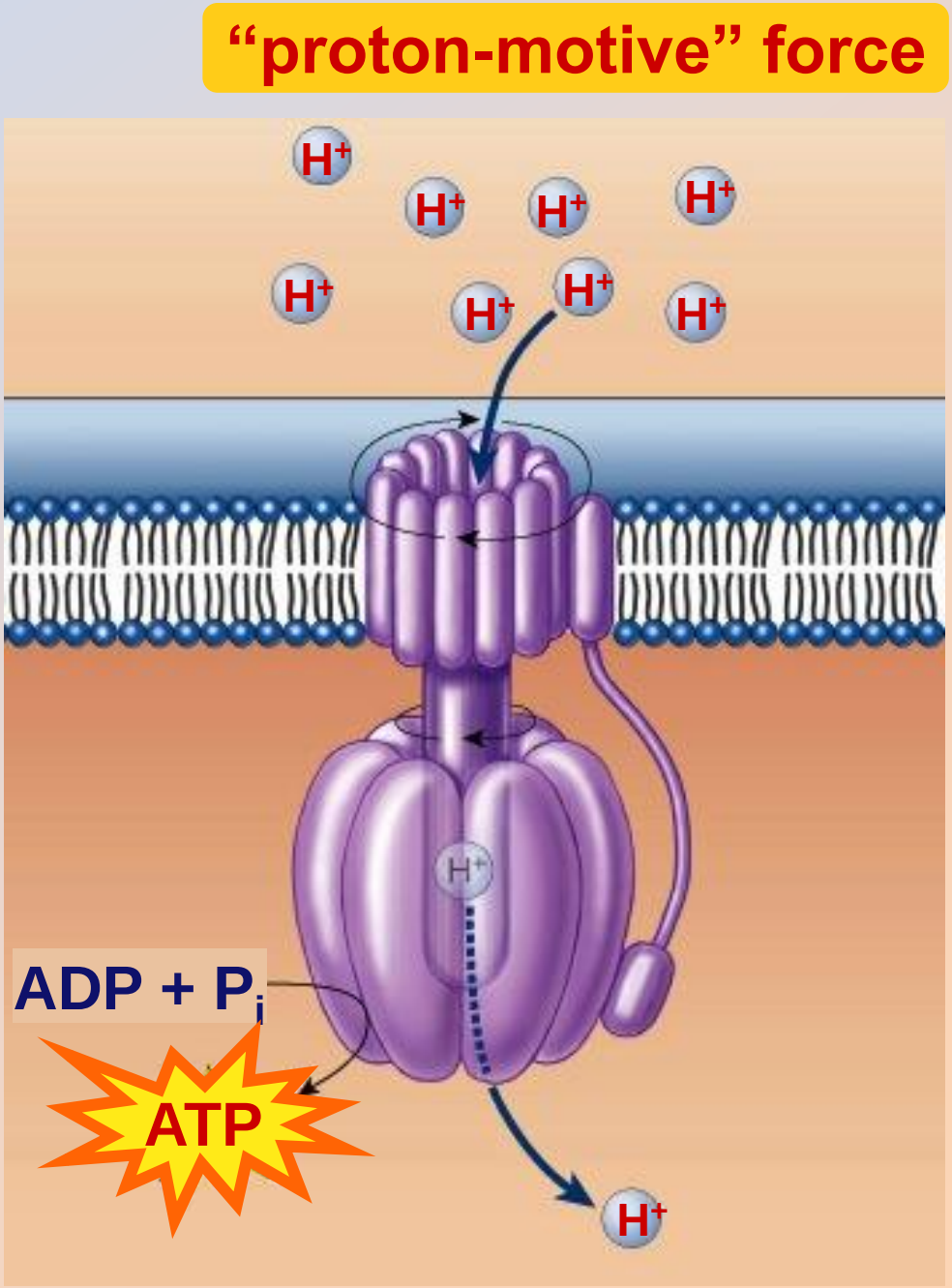


# We did it!

- Set up a $H^+$ gradient
- Allow the protons to flow through ATP synthase
- Synthesizes ATP

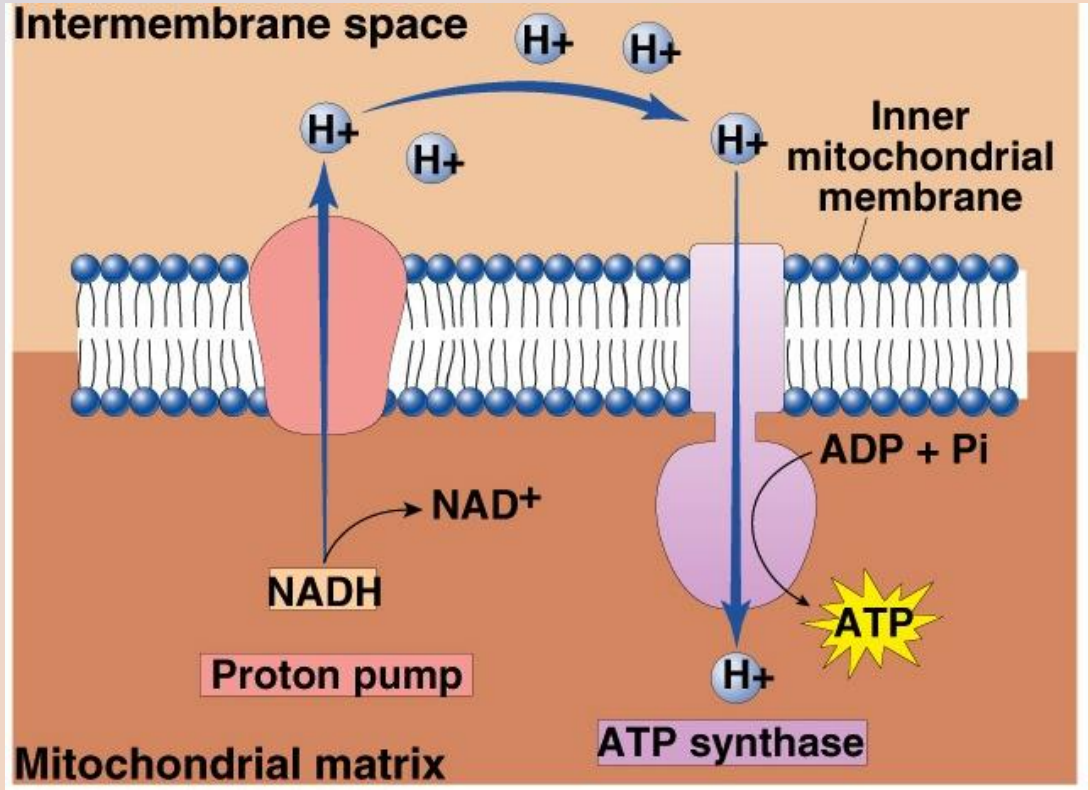
$ADP + P_i \rightarrow ATP$




# Chemiosmosis

- The diffusion of ions across a membrane
  - build up of proton gradient just so H+ could flow through ATP synthase enzyme to build ATP

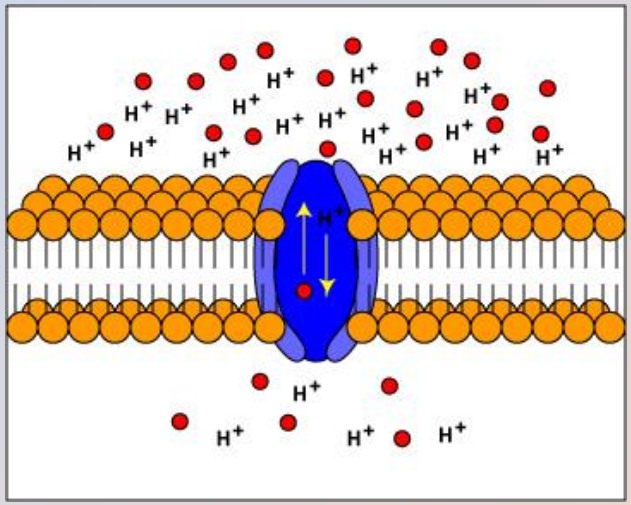
**Chemiosmosis links the Electron Transport Chain to ATP synthesis**




# Peter Mitchell

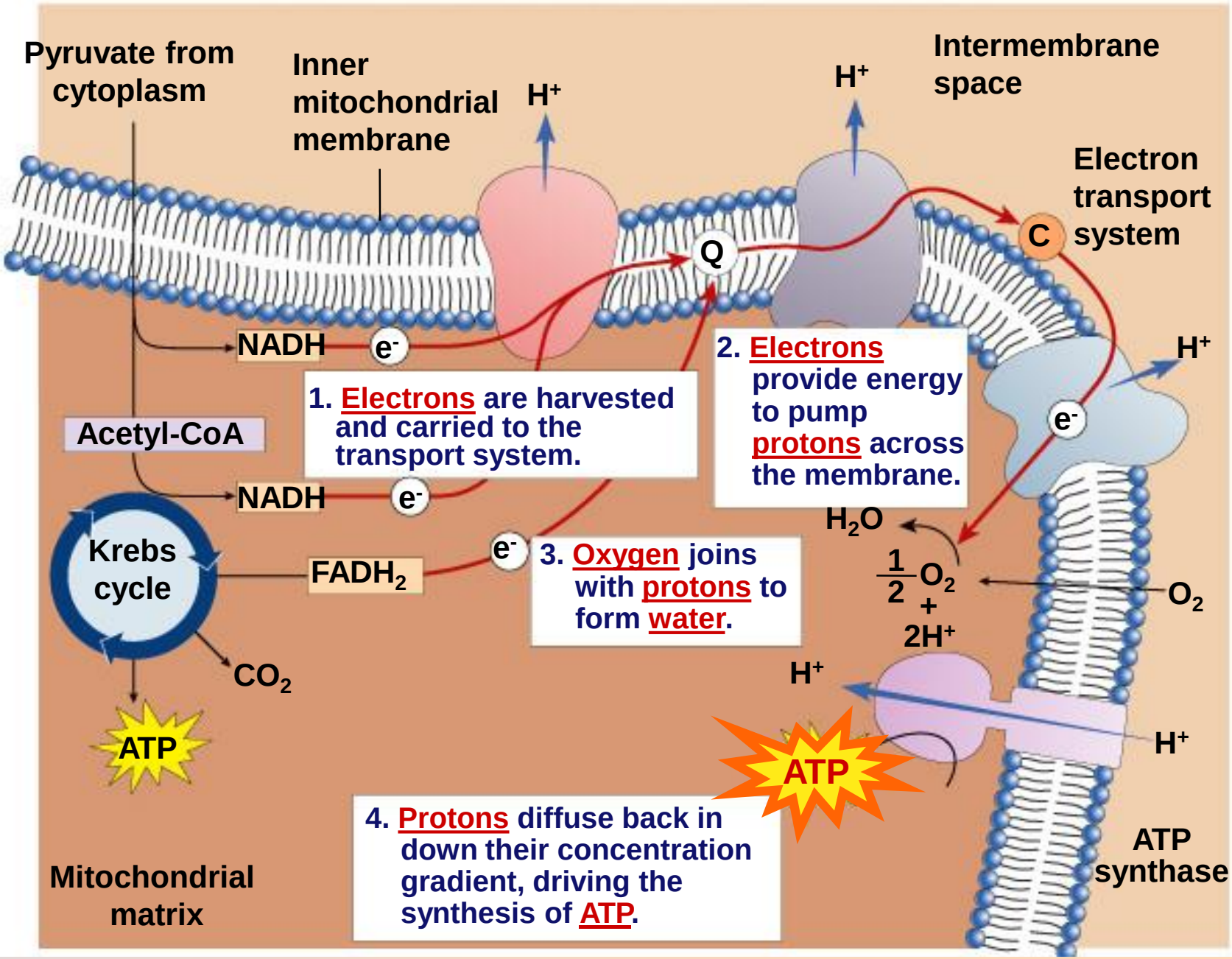
**1961 | 1978**

- Proposed chemiosmotic hypothesis
  - revolutionary idea at the time




**proton motive force**

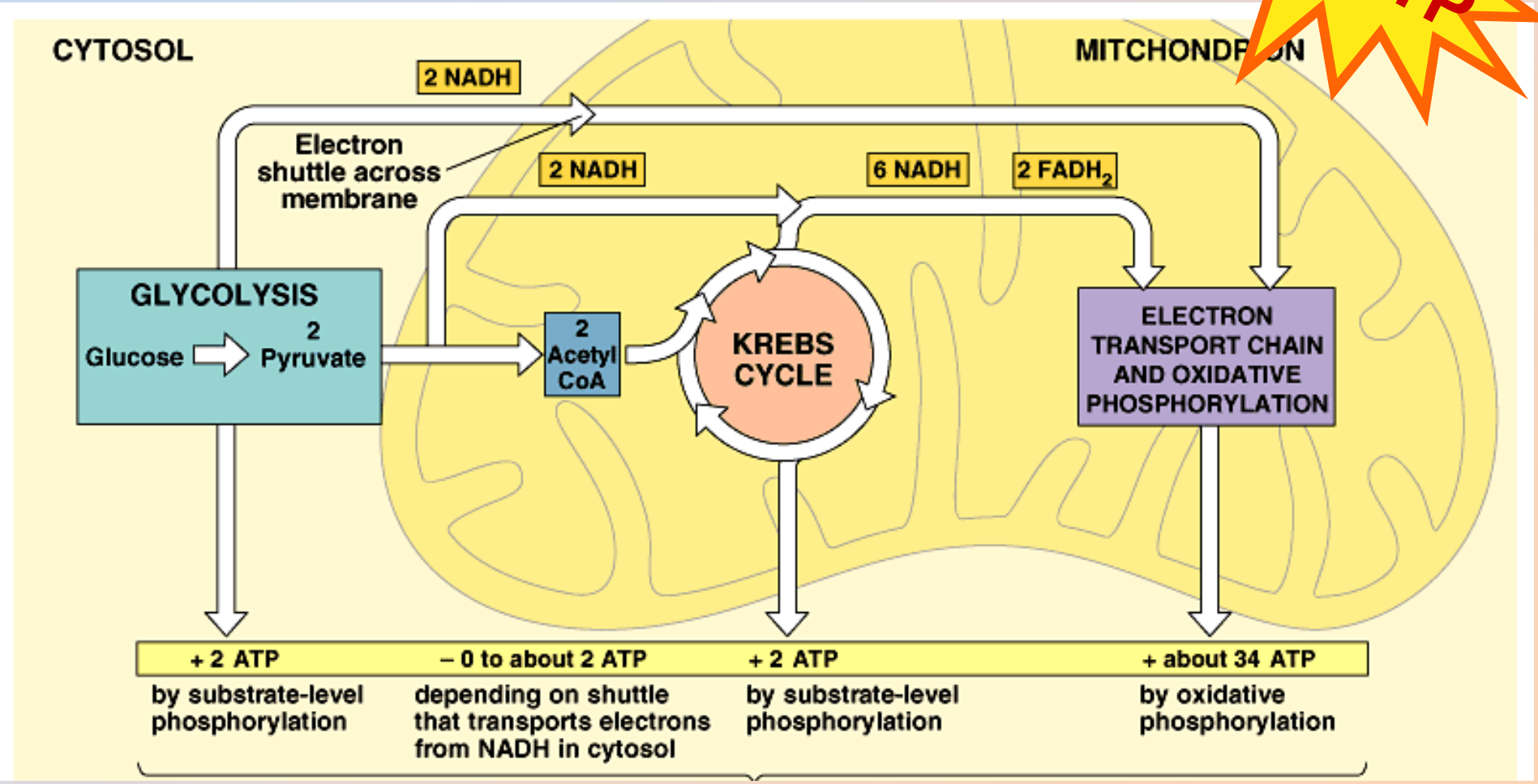
**1920-1992**


Pyruvate from cytoplasm
Inner mitochondrial membrane
H+
H+
Intermembrane space
Electron transport system
C
Q
NADH
e-
1. Electrons are harvested and carried to the transport system.
2. Electrons provide energy to pump protons across the membrane.
H+
e-
Acetyl-CoA
NADH
e-
Krebs cycle
FADH2
e-
3. Oxygen joins with protons to form water.
H2O
1/2 O2 + 2H+
O2
CO2
H+
ATP
ATP
H+
4. Protons diffuse back in down their concentration gradient, driving the synthesis of ATP.
Mitochondrial matrix
ATP synthase

# Show the Mitochondria Clip!

# Cellular respiration

~40 ATP




2 ATP + 2 ATP + ~36 ATP

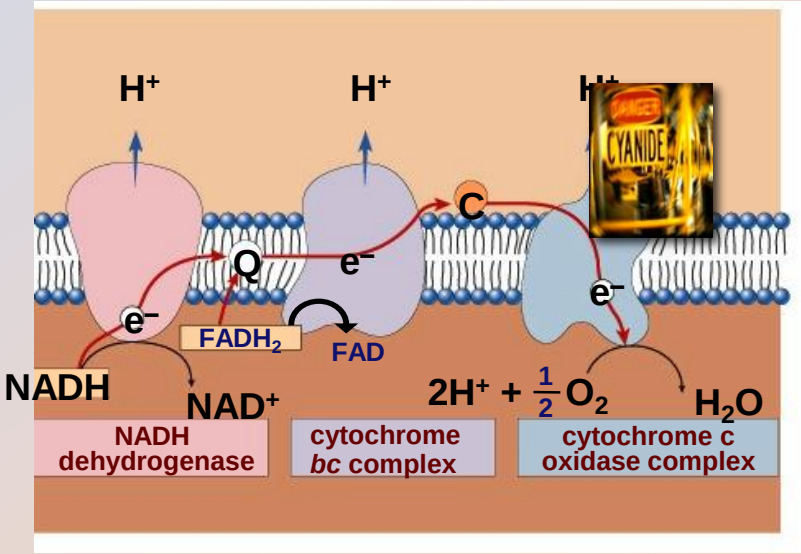
# Summary of cellular respiration

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \sim 40\ ATP$$

- Where did the glucose come from?
- Where did the $O_2$ come from?
- Where did the $CO_2$ come from?
- Where did the $CO_2$ go?
- Where did the $H_2O$ come from?
- Where did the ATP come from?
- What else is produced that is not listed in this equation?
- Why do we breathe?

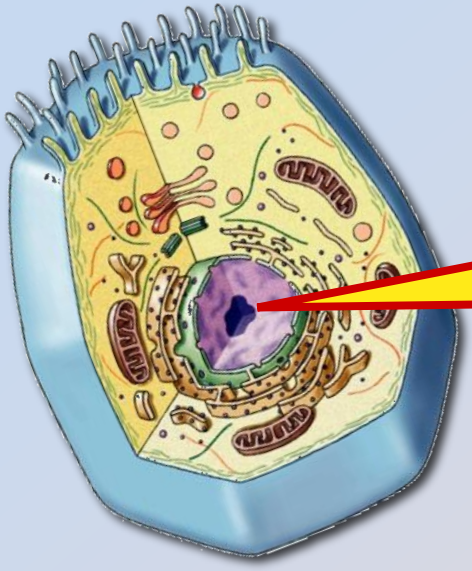
# Taking it beyond…

- What is the final electron acceptor in Electron Transport Chain?




$O_2$

- **So what happens if $O_2$ unavailable?**
  - **ETC backs up**
    - **nothing to pull electrons down chain**
    - **NADH & $FADH_2$ can't unload H**
  - **ATP production ceases**
  - **cells run out of energy**
  - **and you die*!***



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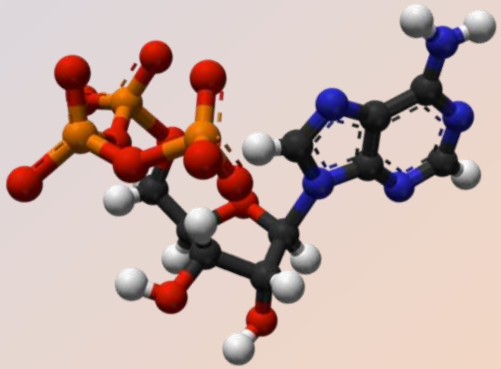

The point is to make **ATP**!

**ATP**

# Review Questions

1. Cyanide is a poison that blocks the passage of electrons along the electron transport chain. Which of the following is a metabolic effect of this poison?
   A. The lower pH of the intermembrane space is much lower than normal.
   B. Electrons are passed directly to oxygen, causing cells to explode.
   C. Alcohol would build up in the cells.
   D. NADH supplies would be exhausted, and ATP synthesis would cease.
   E. No proton gradient would be produced, and ATP synthesis would cease.

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2. You have a friend who lost 15 pounds of fat on a diet. Where did the fat go (how was it lost)? *

A. It was released as $CO_2$ and $H_2O$.
B. Chemical energy was converted to heat and then released.
C. It was converted to ATP, which weighs much less than fat.
D. It was broken down to amino acids and eliminated from the body.
E. It was converted to urine and eliminated from the body.

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# You Would Like a Rap Song?