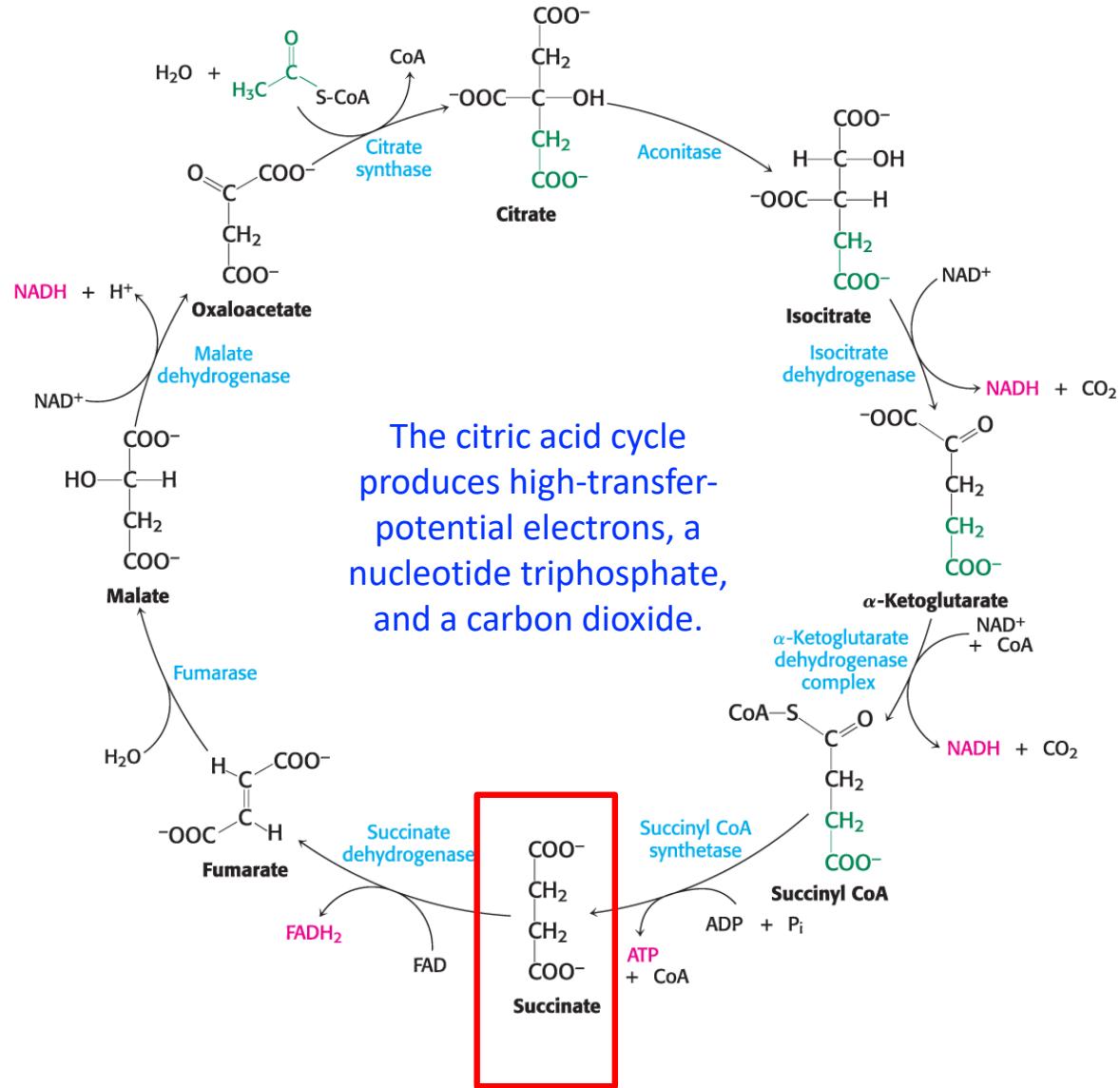


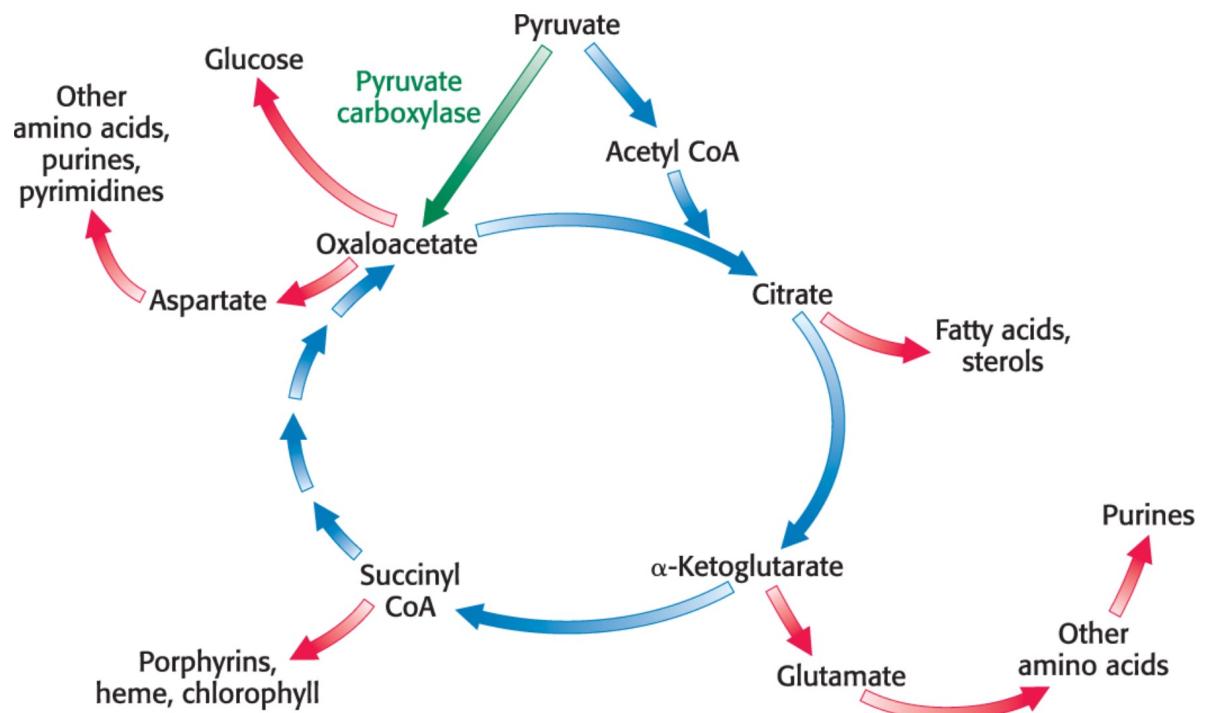
The Citric Acid Cycle

- All enzymes of the citric acid cycle form a supramolecular complex (physically associated structure).
- This close enzyme arrangement increases efficiency of the cycle.
- **Substrate channeling** : reaction products move directly between active sites via connecting channels.
- TCA demonstrates that enzymes organized into supramolecular structures for functional advantage.



The Citric Acid Cycle Is a Source of Biosynthetic Precursors

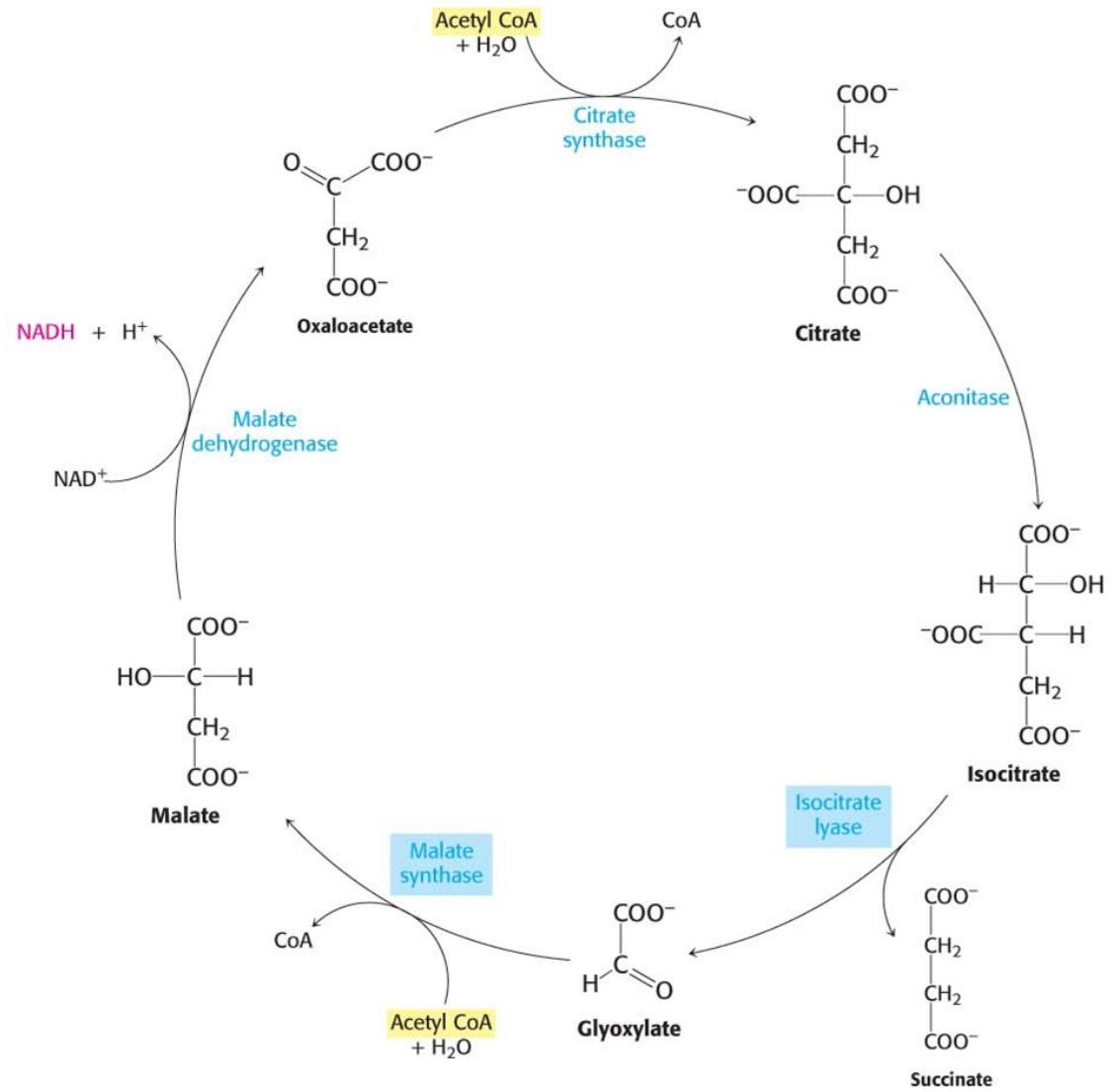
- The citric acid cycle must be capable of being rapidly replenished.
- Because the citric acid cycle provides precursors for biosynthesis, reactions to replenish the cycle components are required if the energy status of the cells changes.
- These replenishing reactions are called **anaplerotic** reactions.
- A prominent anaplerotic reaction is catalyzed by pyruvate carboxylase. Recall that this reaction is also used in gluconeogenesis and is dependent on the presence of acetyl CoA.



The Metabolic Hub of the Cell

The Glyoxylate Cycle Enables Plants and Bacteria to Convert Fats into Carbohydrates

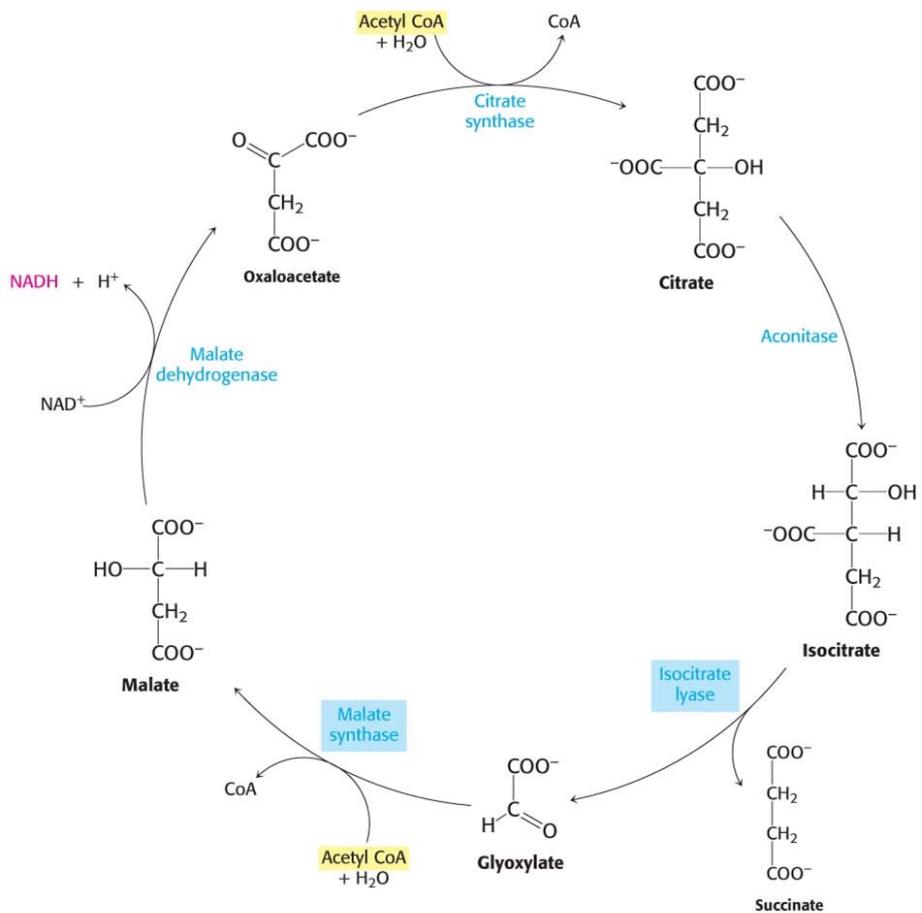
- The glyoxylate cycle is similar to the citric acid cycle but bypasses the two decarboxylation steps, allowing the synthesis of carbohydrates from fats.
- Succinate can be converted into oxaloacetate and then into glucose.
- The glyoxylate cycle is prominent in oil-rich seeds such as sunflower seeds.



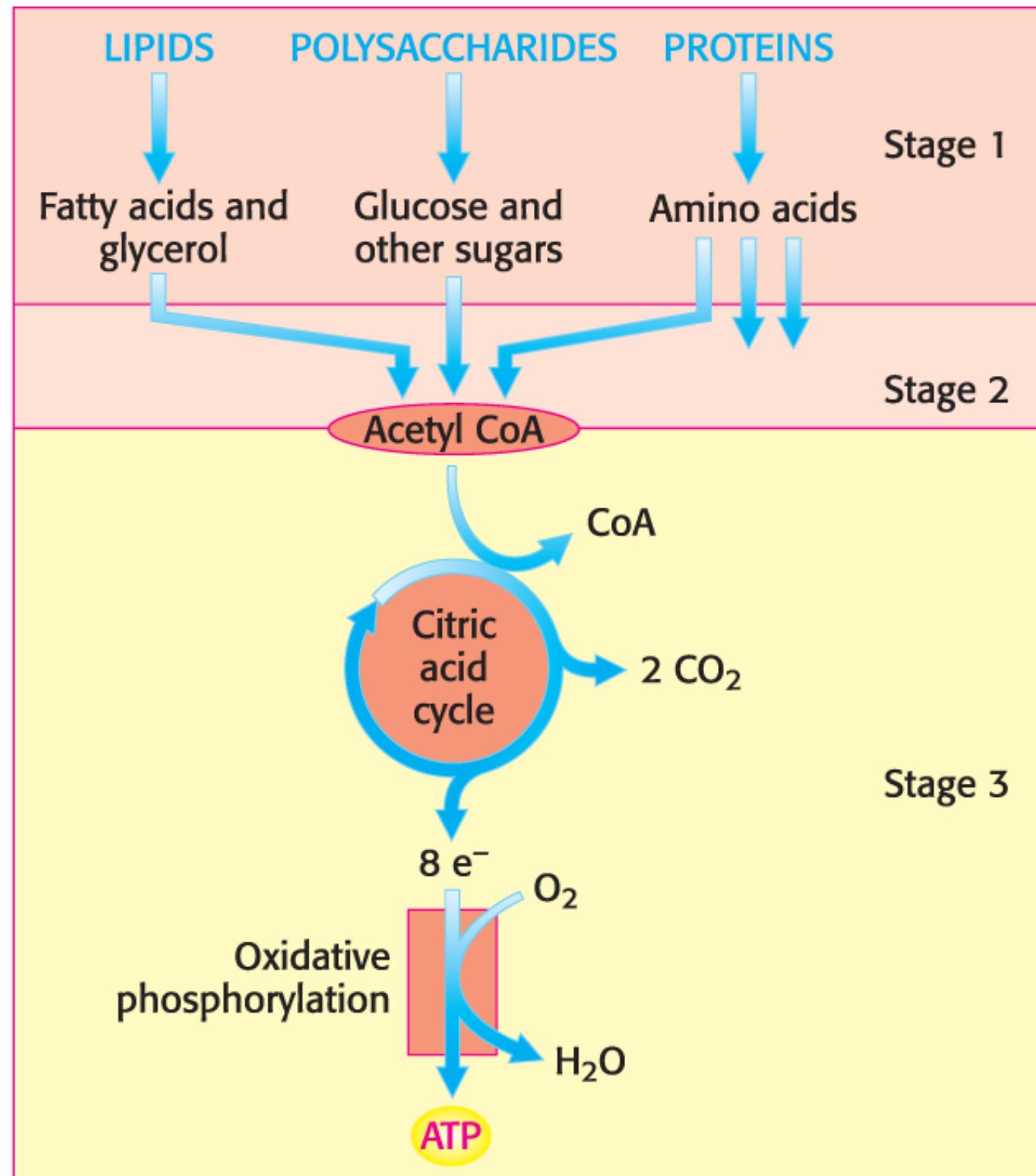
Quick Quiz 5

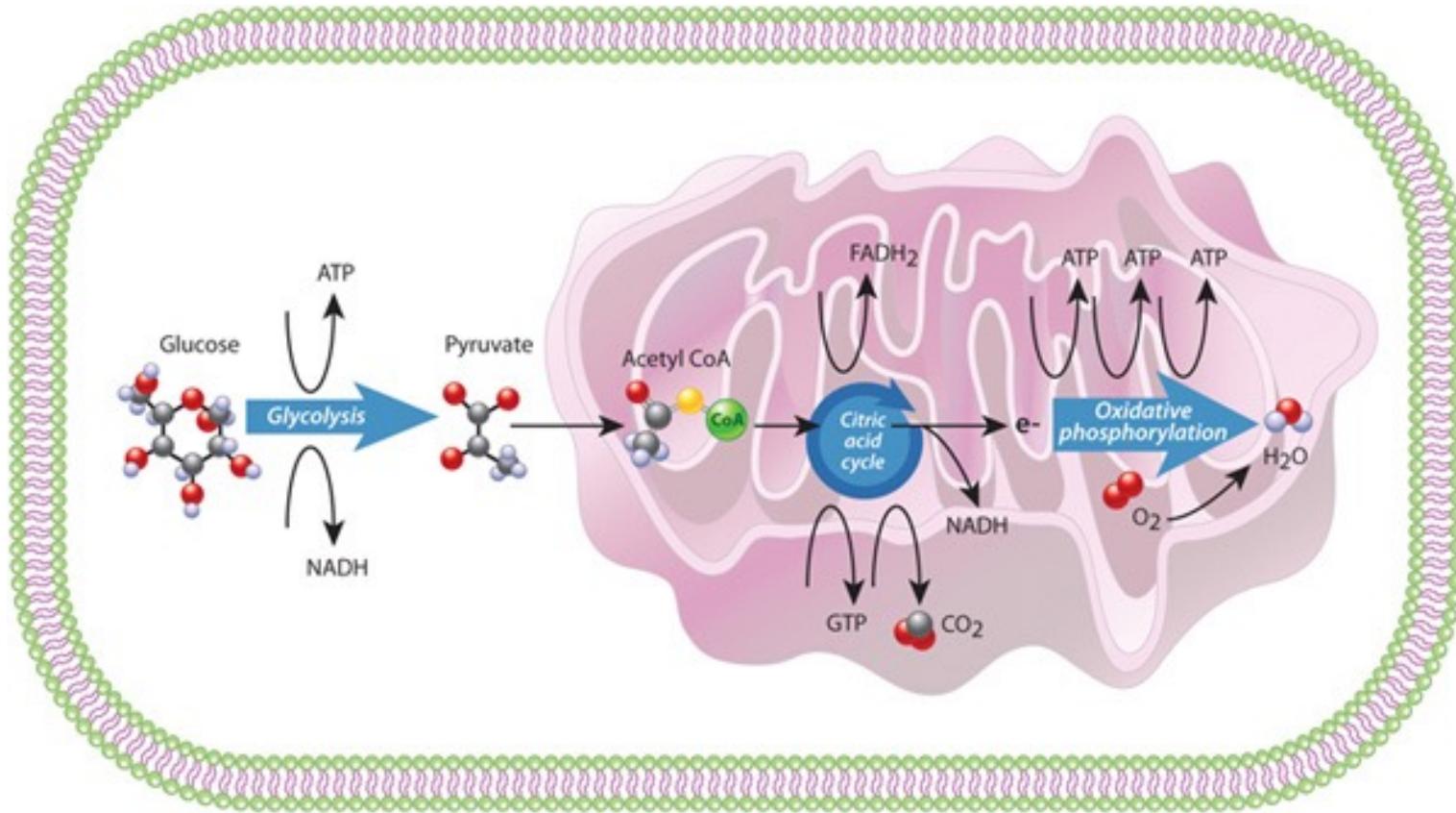
The sum reaction of the glyoxylate pathway shows that carbon enters the cycle from _____ and leaves as _____.

- A. acetyl CoA; succinate
- B. acetyl CoA; CO₂
- C. acetyl CoA; isocitrate
- D. succinate; acetyl CoA
- E. oxaloacetate; citrate.



Stages of Catabolism

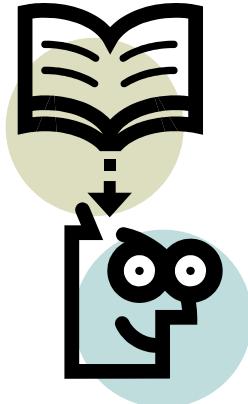




Lecture 11

Oxidative Phosphorylation

Oxidative Phosphorylation

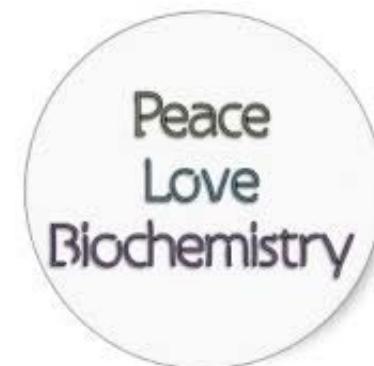


Lecture Outline:

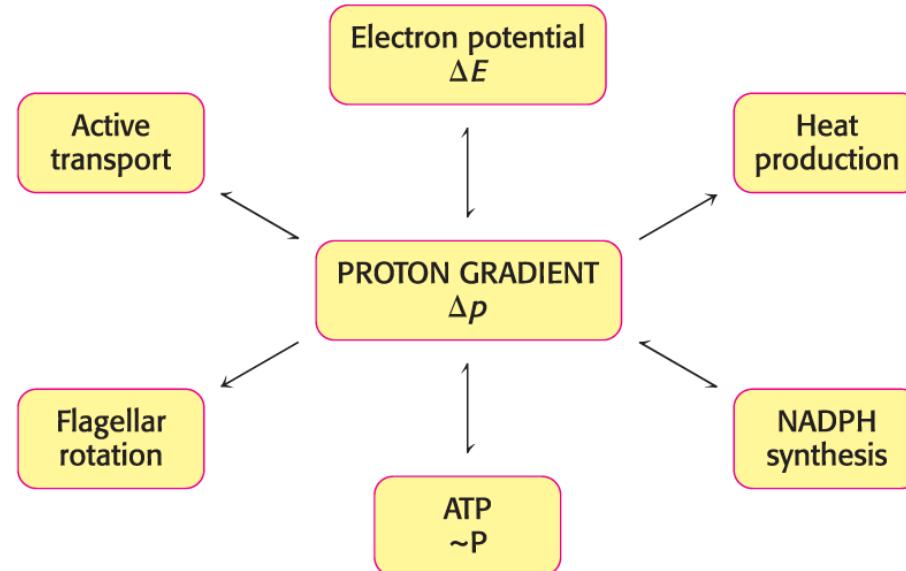
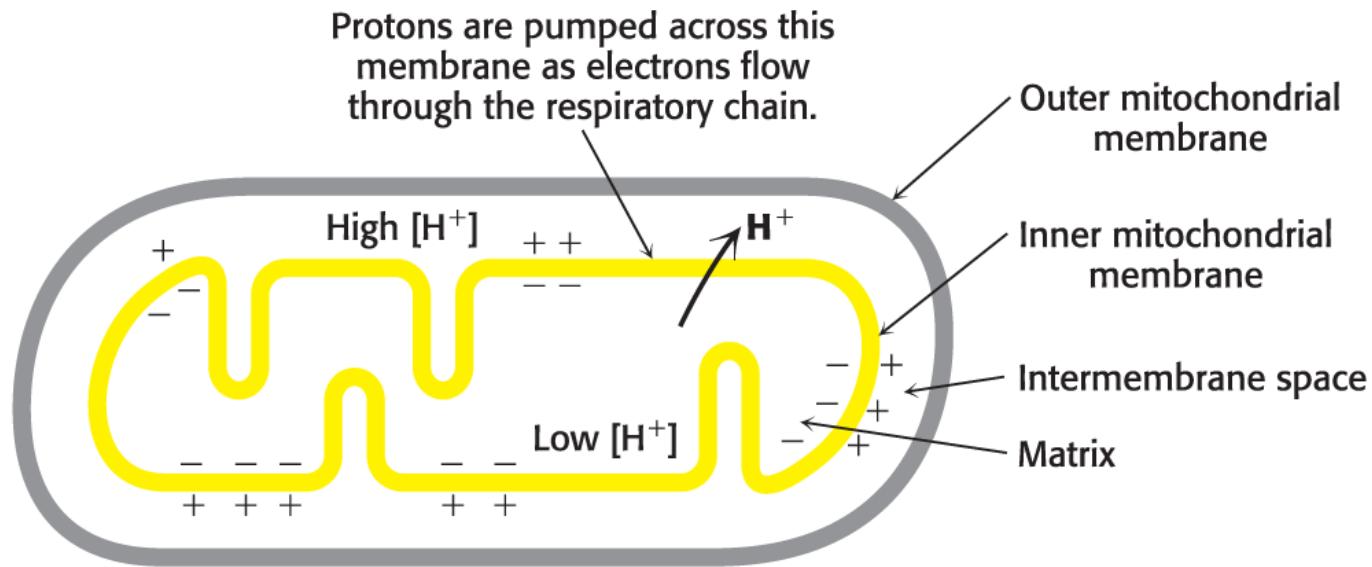
- Oxidative Phosphorylation in Eukaryotes Takes Place in Mitochondria
- Oxidative Phosphorylation Depends on Electron Transfer
- The Respiratory Chain Consists of Proton Pumps and a Physical Link to the Citric Acid Cycle
- Shuttles Allow Movement Across Mitochondrial Membranes
- Cellular Respiration is Regulated by the Need for ATP

Readings:

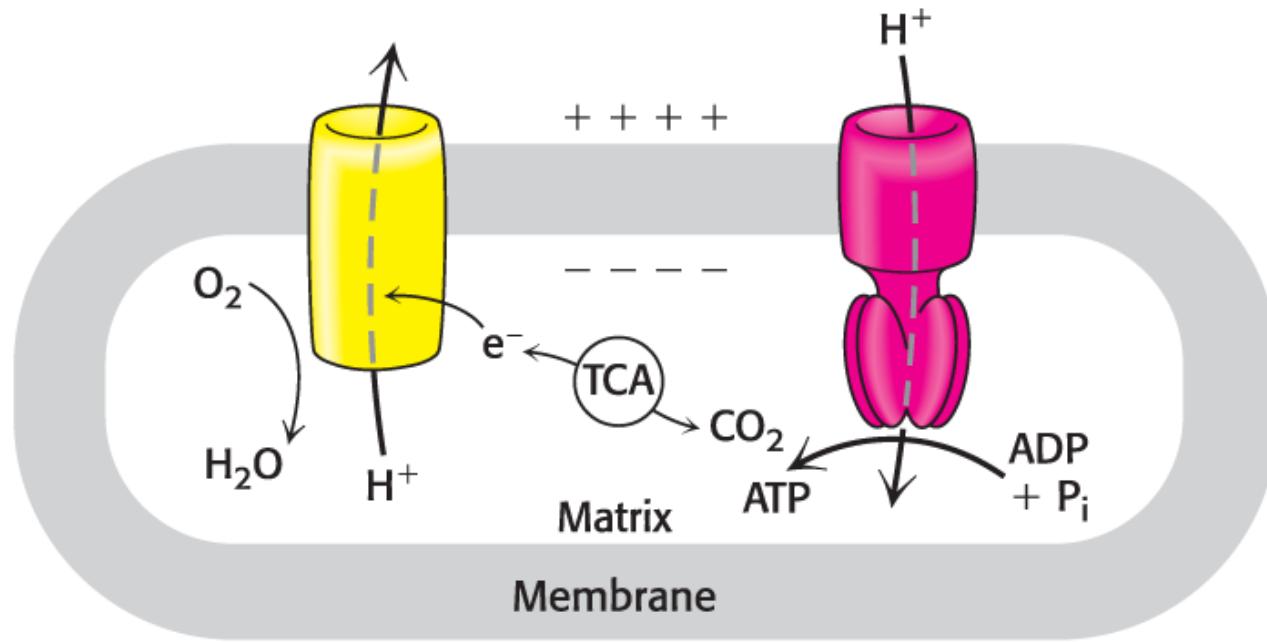
Tymochko, Berg, Stryer,
Biochemistry, 2nd Edition,
Ch. 20, 21, pp. 349 – 385
3rd Ed., Ch.20,21, pp. 361-393
4th Ed., Ch.20,21, pp. 399-437



The Cell's Microscopic Power Plant

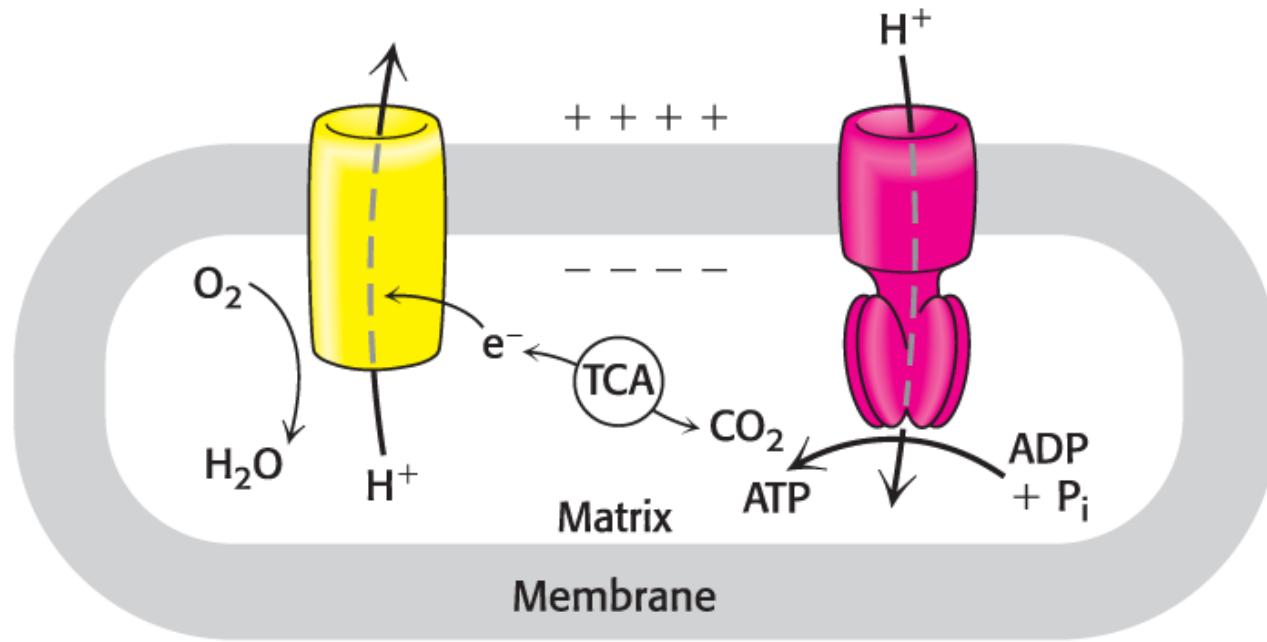


Powering the Cell One Electron at a Time



- Oxidative phosphorylation captures the energy of high-energy electrons to synthesize ATP.
- The flow of electrons from NADH and $FADH_2$ to O_2 occurs in the electron-transport chain or respiratory chain.
- This exergonic set of oxidation-reduction reactions generates a proton gradient.
- The proton gradient is used to power the synthesis of ATP.
- Collectively, the citric acid cycle and oxidative phosphorylation are called **cellular respiration** or simply **respiration**.

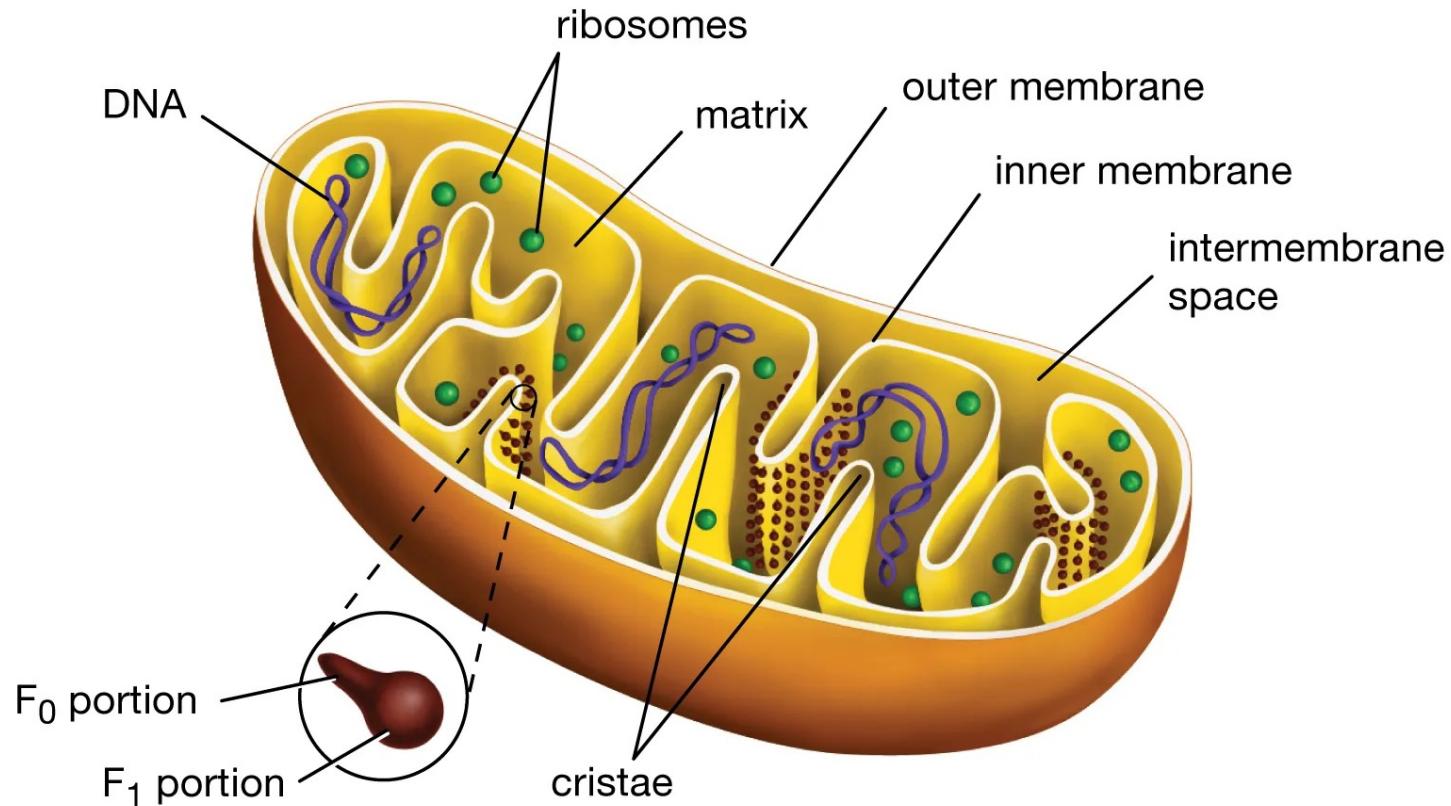
Powering the Cell One Electron at a Time



Where do electrons come from?

- NADH and FADH₂ carry high-energy electrons.
- These are produced in:
 - Glycolysis
 - Pyruvate oxidation
 - Citric acid cycle

The Cell's Microscopic Power Plant



© Encyclopædia Britannica, Inc.

- The electron-transport chain and ATP synthesis occur in the mitochondria.
- Recall that the citric acid cycle occurs in the mitochondrial matrix.
- Sequence data suggest that all mitochondria are descendants of an ancestor of *Rickettsia prowazekii*, which was engulfed by another cell.

Oxidative Phosphorylation Depends on Electron Transfer

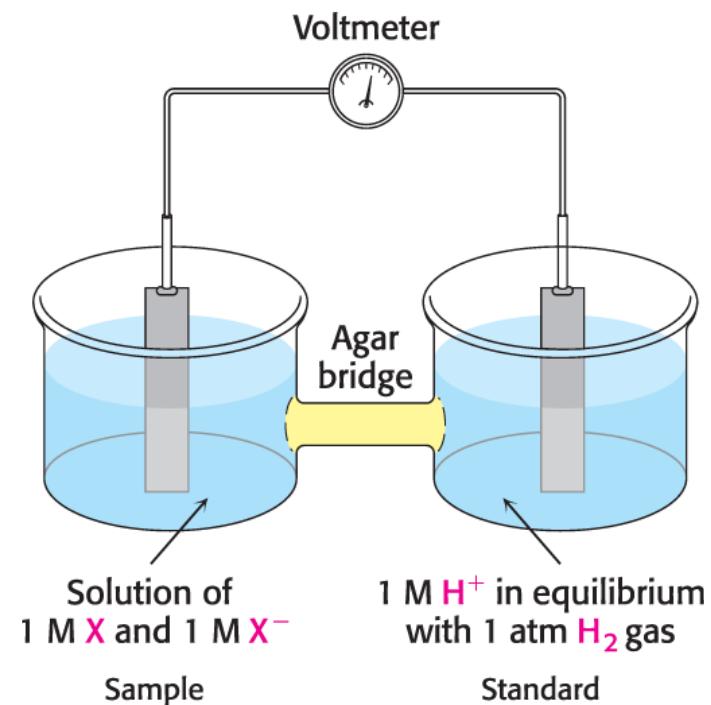
- The electron-transport chain is a series of coupled redox reactions that transfer electrons from NADH and FADH₂ to oxygen.
- The reduction potential E_0' , or redox potential, is a measure of a molecule's tendency to donate or accept electrons.
- A strong reducing agent readily donates electrons and has a negative E_0' .
- A strong oxidizing agent readily accepts electrons and has a positive E_0' .
- The standard free-energy change is related to the change in reduction potential.

$$\Delta G^{\circ '} = -nF\Delta E'_0$$

where n is the number of electrons transferred and F is the Faraday constant

(96.48 kJ mol⁻¹ V⁻¹, or 23.06 kcal mol⁻¹ V⁻¹)

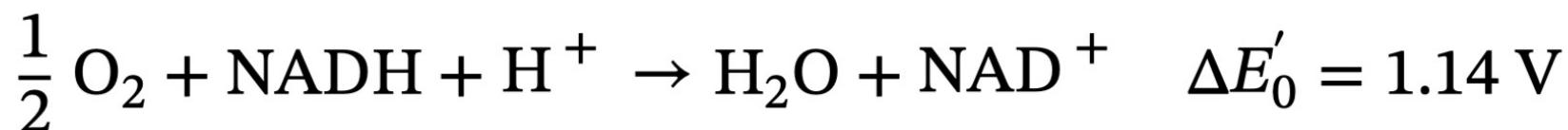
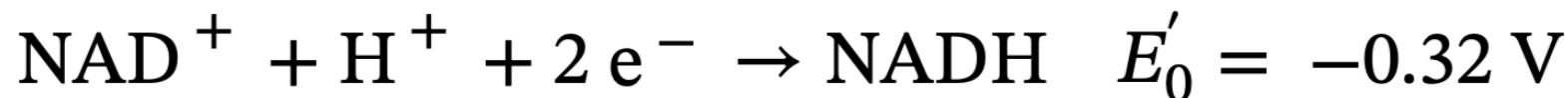
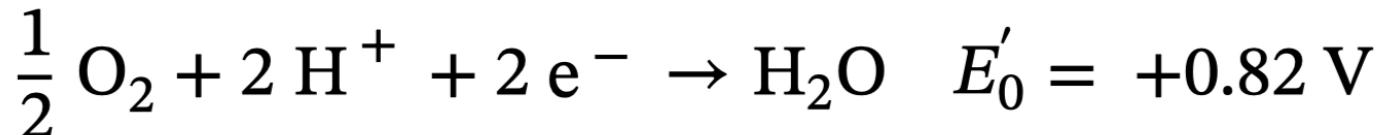
- Cellular Respiration (Electron Transport Chain)



Oxidative Phosphorylation Depends on Electron Transfer

Electron flow through the electron-transport chain creates a proton gradient.

- Energy is released when high-energy electrons are transferred to oxygen:



$$\Delta G^{\circ'} = -nF\Delta E'_0$$

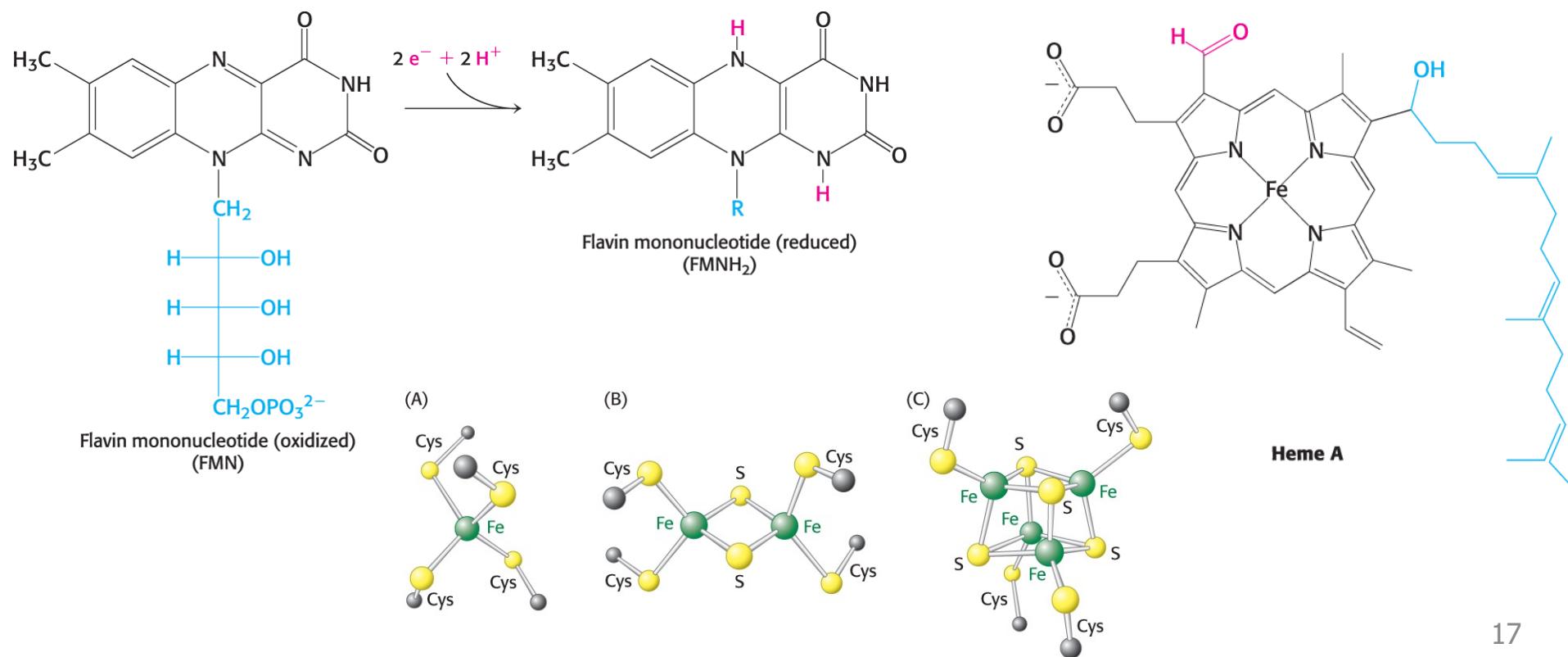
$$\begin{aligned}\Delta G^{\circ'} &= (-2 \times 96.48 \text{ kJ mol}^{-1} \text{ V}^{-1} \times 0.82 \text{ V}) + (-2 \times 96.48 \text{ kJ mol}^{-1} \text{ V}^{-1} \times 0.32 \text{ V}) \\ &= -158.2 \text{ kJ mol}^{-1} + (-61.7 \text{ kJ mol}^{-1}) \\ &= -220 \text{ kJ mol}^{-1}\end{aligned}$$

- The energy is used to establish a proton gradient!

Oxidative Phosphorylation Depends on Electron Transfer

The electron-transport chain is a series of coupled oxidation-reduction reactions.

- The electron-transport chain is composed of four large protein complexes.
- The electrons donated by NADH and FADH₂ are passed to **electron carriers** in the protein complexes.
- The carriers include flavin mononucleotide (FMN), iron associated with sulfur in proteins (iron-sulfur proteins), iron incorporated into hemes that are embedded in proteins called cytochromes, and a mobile electron carrier called coenzyme Q (Q).

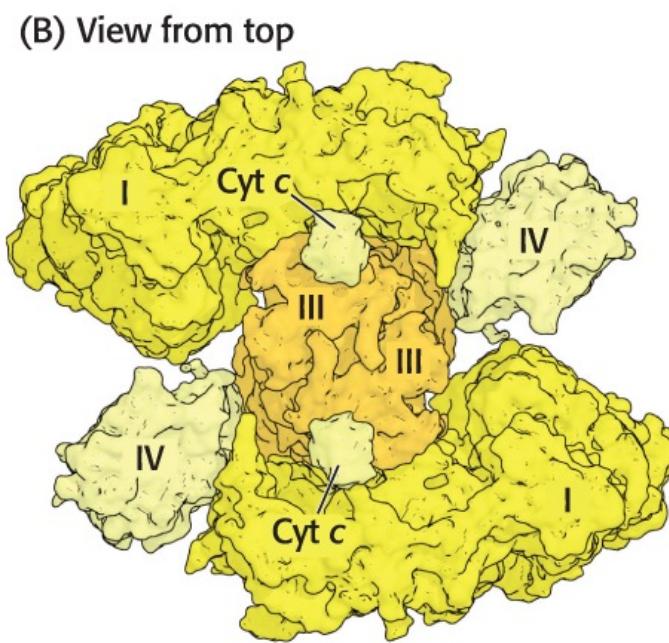
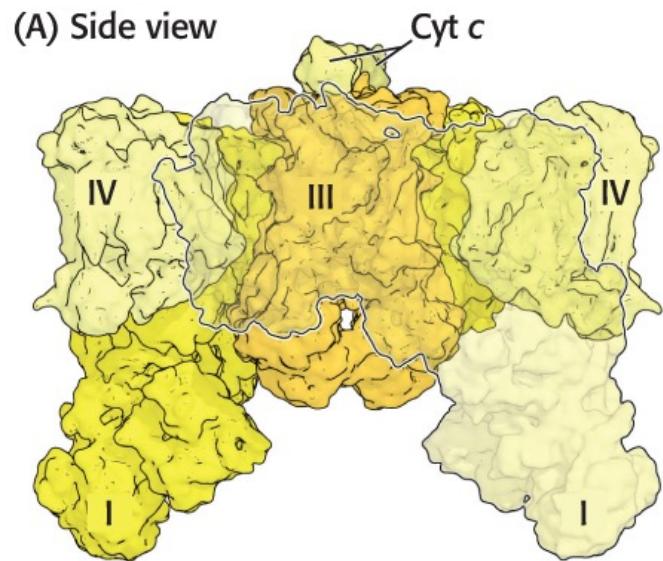


Components of the Electron-Transport Chain (ETC)

- Electrons flow down an energy gradient from NADH to O₂.
- The flow is catalyzed by four protein complexes.
- Iron is a component of all of the complexes as well as *Q*.

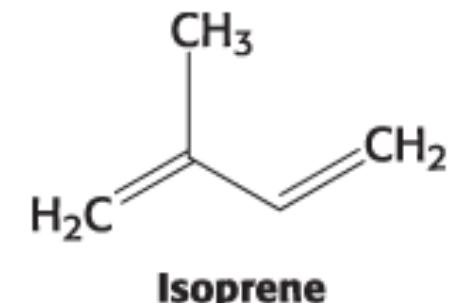
Why bother?

- "Without the electron transport chain, you wouldn't last more than a few minutes."
- The ETC is essential for aerobic life.
- This is where most of your ATP comes from!

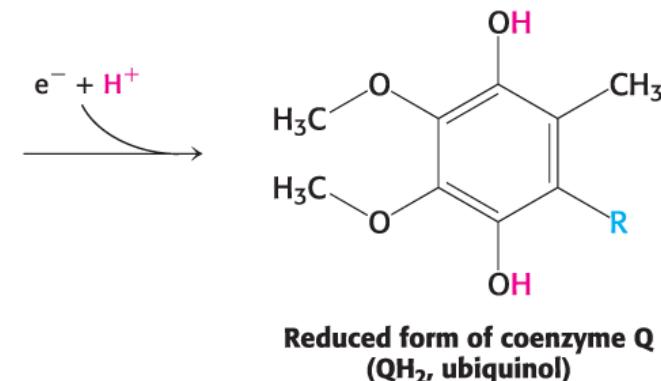
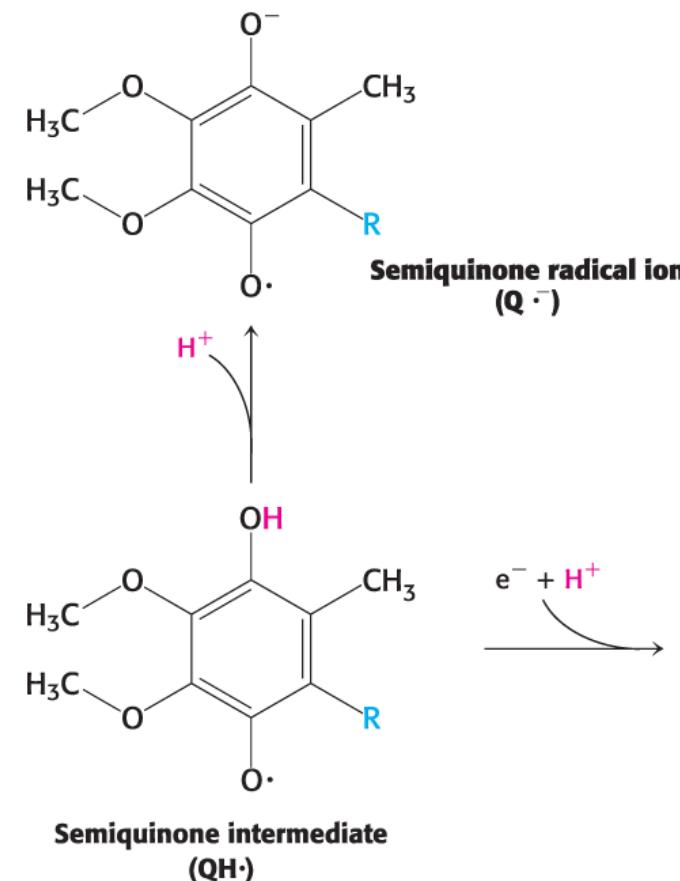
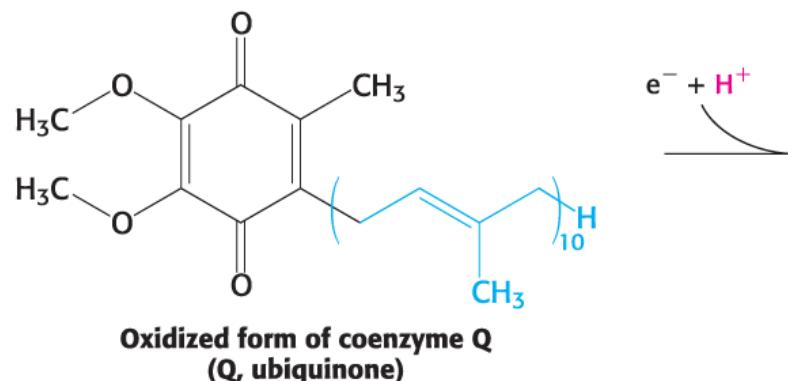


Oxidative Phosphorylation Depends on Electron Transfer

- Coenzyme Q is derived from isoprene.
- Coenzyme Q binds protons (QH_2) as well as electrons, and can exist in several oxidation states.
- Oxidized and reduced Q are present in the inner mitochondrial membrane in what is called the Q pool.



For quinones → electron transfer happens together with proton binding or release → combined action is important for moving protons across membranes

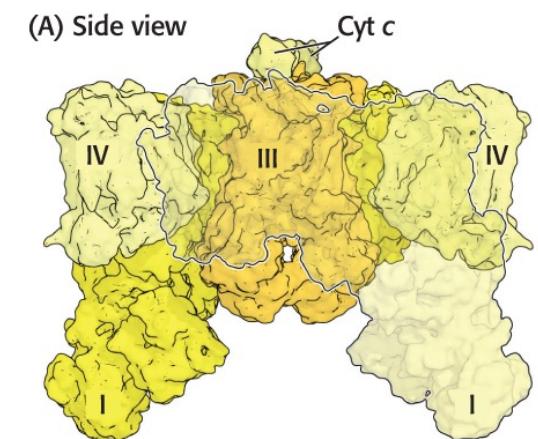
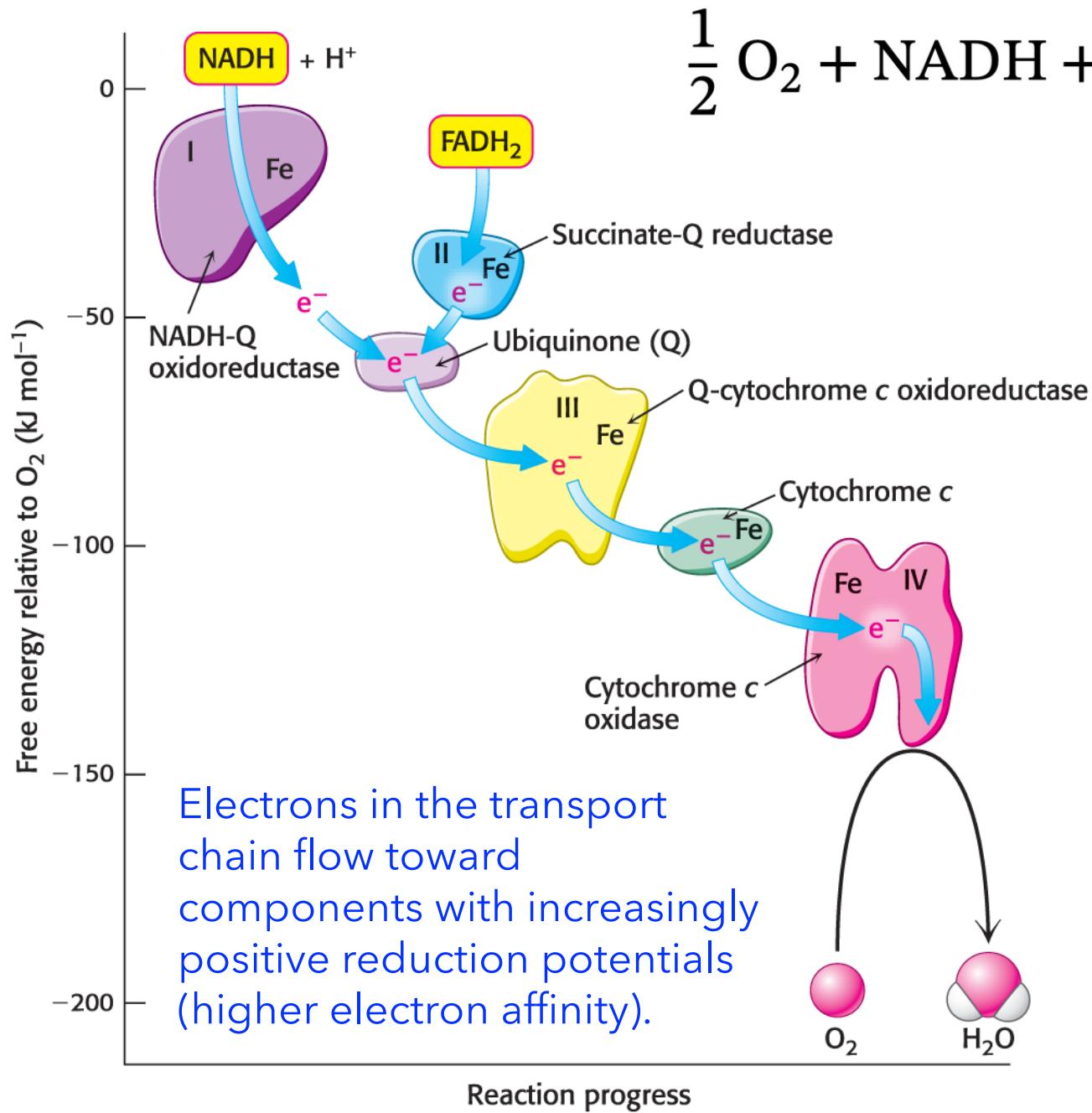


Quick Quiz 2

Consider a substance that can exist in an oxidized form X and a reduced form X⁻. Such a pair is called _____.

- A. a redox couple
- B. a reduction couple
- C. an X:X⁻ couple
- D. a half-cell
- E. an electron-transfer potential

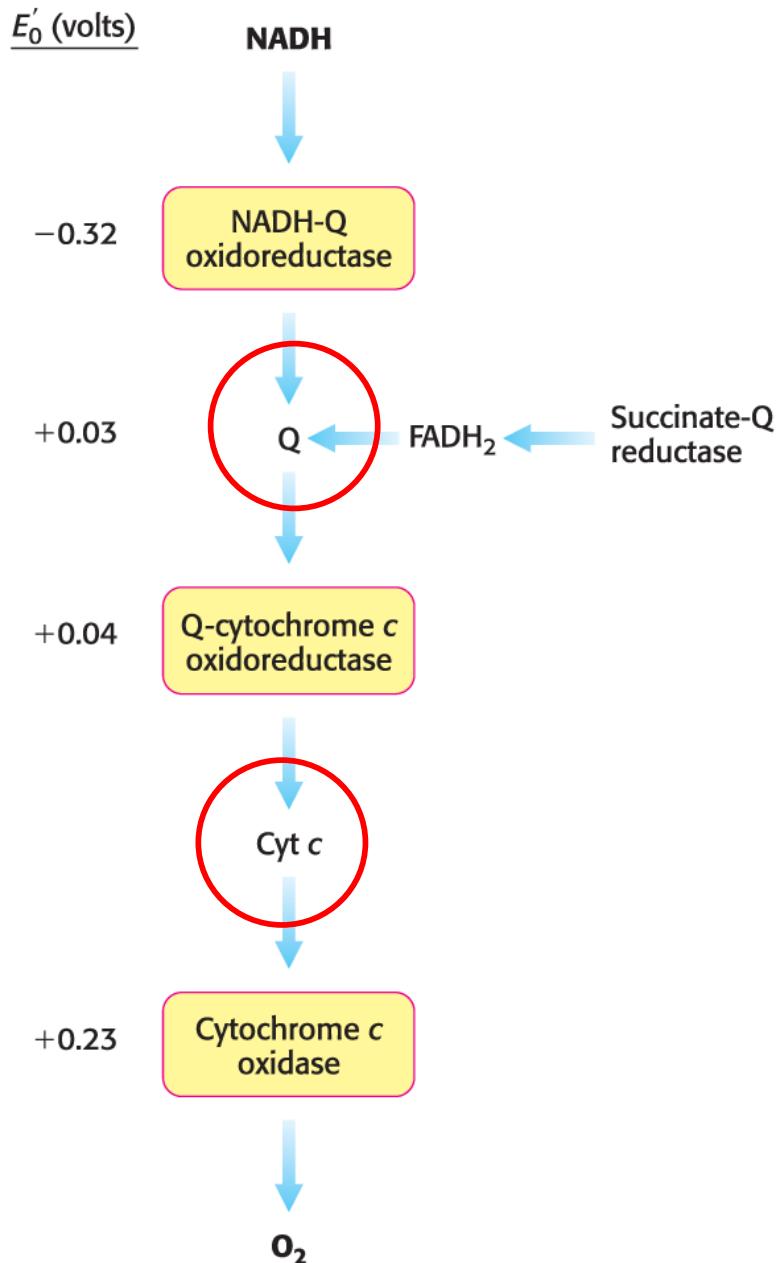
Components of the Electron-Transport Chain (ETC)



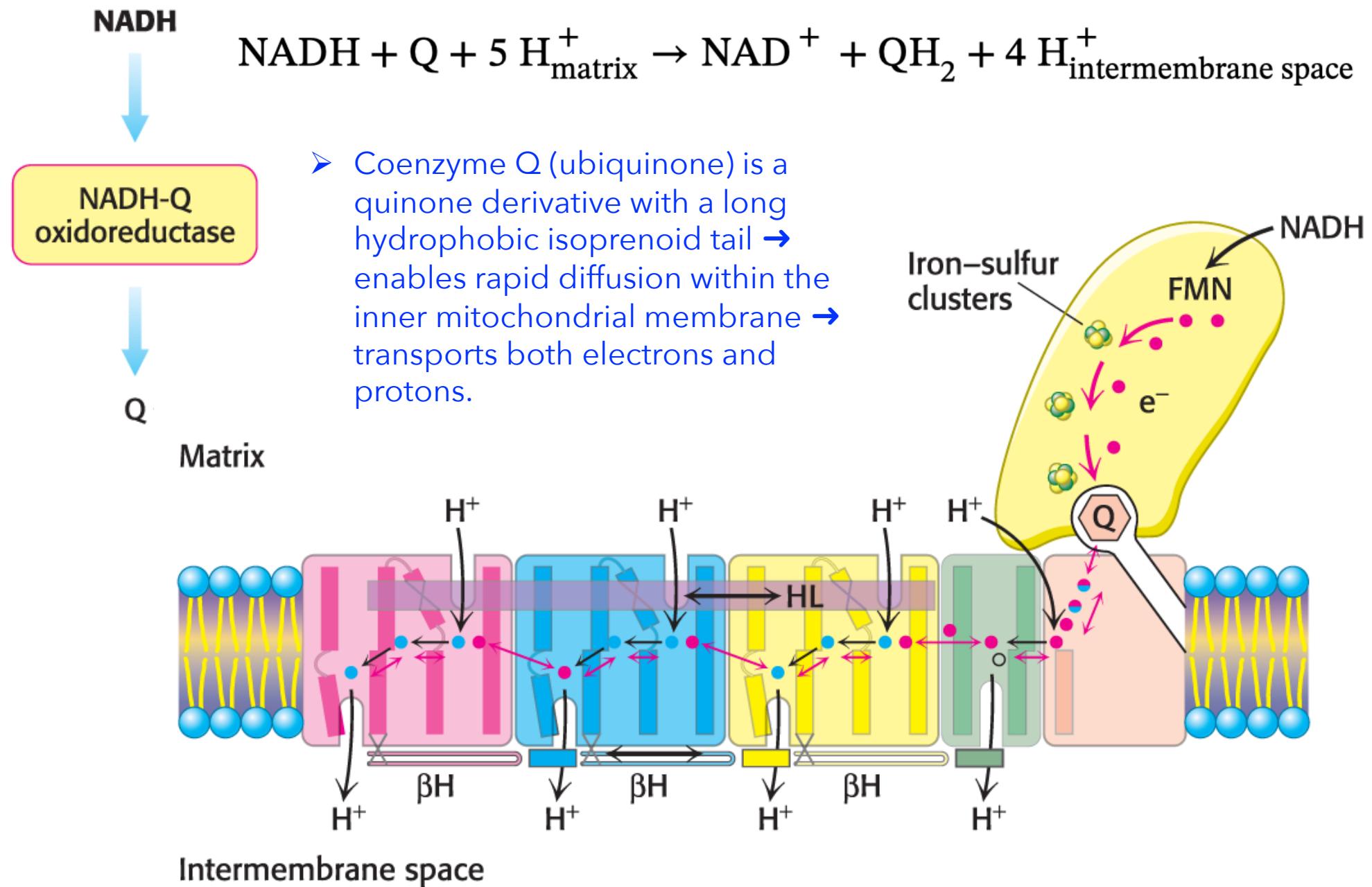
Respirasome (~1.7 MDa) 21

The Respiratory Chain Consists of Proton Pumps and a Physical Link to the Citric Acid Cycle

- Electrons flow from NADH to O_2 through three large protein complexes embedded in the inner mitochondria membrane.
 - **NADH-Q oxidoreductase (Complex I)**
 - **Q-cytochrome c oxidoreductase (Complex III)**
 - **Cytochrome c oxidase (Complex IV)**
- These complexes (i.e., yellow boxes) pump protons out of the mitochondria, generating a proton gradient.
- An additional complex, **succinate Q-reductase (Complex II)**, delivers electrons from $FADH_2$ to Complex III.
- Succinate-Q reductase is not a proton pump.

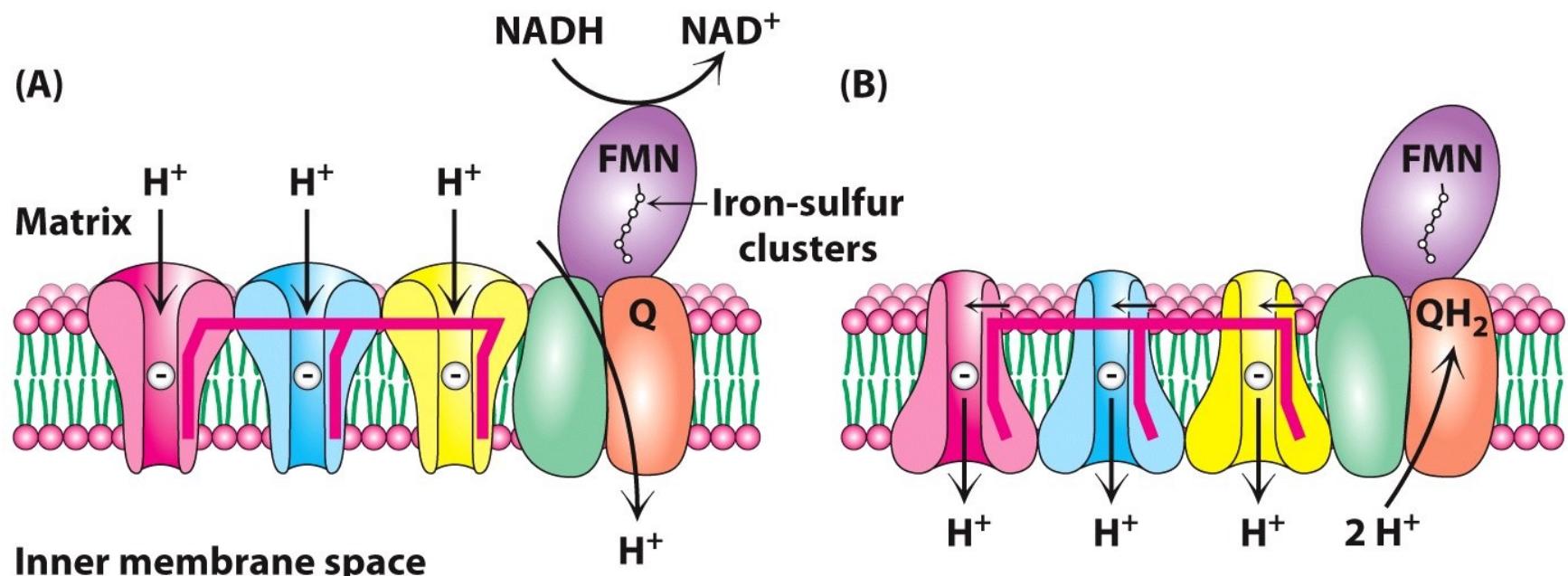


The Electron-Transport Chain (ETC) is a Series of Coupled Oxidation-Reduction Reactions

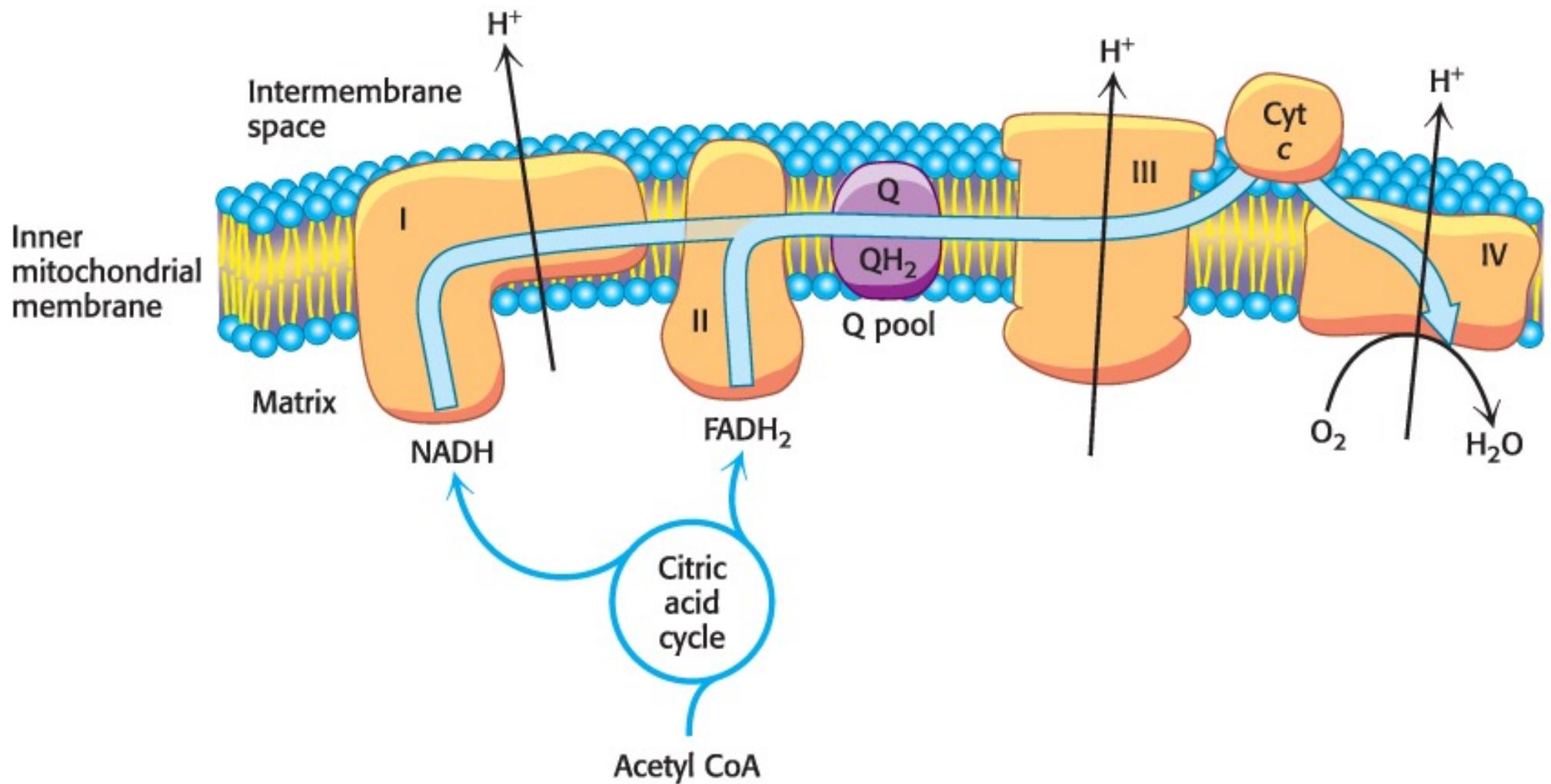


The Respiratory Chain Consists of Proton Pumps and a Physical Link to the Citric Acid Cycle

- Electron flow within the complexes in the inner-mitochondrial membrane generate a proton gradient.
- These complexes appear to be associated with one another in the respirasome.
- The electrons from NADH are passed along to Q to form QH_2 by Complex I. QH_2 leaves the enzyme for the Q pool in the hydrophobic interior of the inner-mitochondrial membrane.
- Four protons are simultaneously pumped out of the mitochondria by Complex I.



Electron Flow Through the Electron-Transport Chain Creates a Proton Gradient



Summary of the Electron Transport Chain

- **Complex I (NADH dehydrogenase)**
 - accepts electrons from NADH → passes electrons to coenzyme Q (Q)
 - pumps H⁺ into intermembrane

- **Complex III (Q-cytochrome c oxidoreductase)** → accepts electrons from QH₂ → passes them to cytochrome c → pumps H⁺ into

➤ ETC: inner mitochondrial membrane → convert energy from NADH and FADH₂ into a proton gradient → drive ATP synthesis via oxidative phosphorylation

- **Ubiquinone Q** → mobile carrier within membrane → transports electrons from Complexes I & II to III
- also carries protons (H⁺) across the membrane

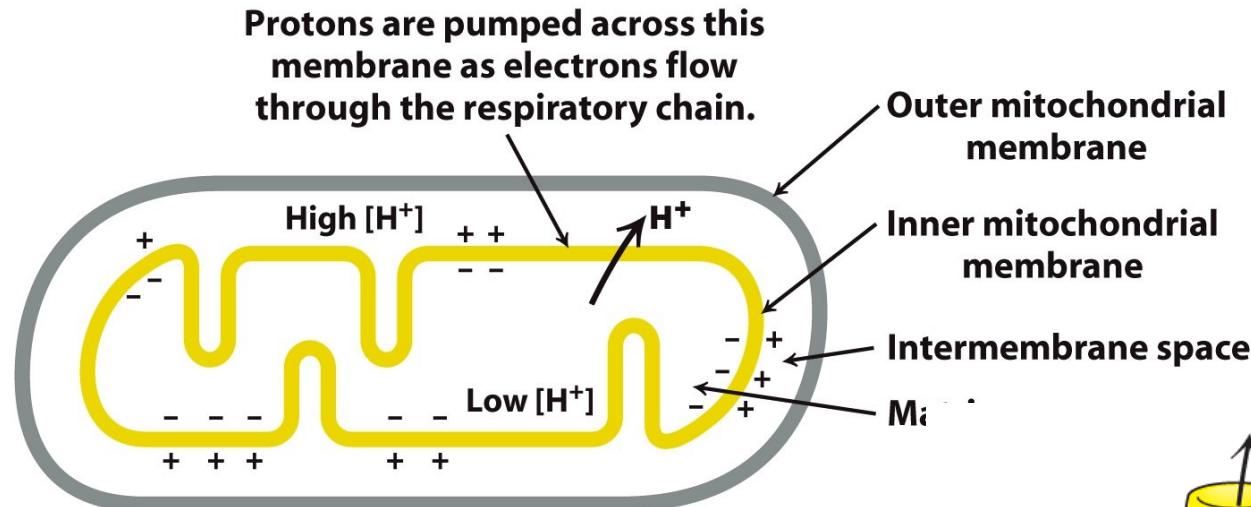
- **Complex IV (Cytochrome c oxidase)**
 - transfers electrons to O₂
- $\frac{1}{2} O_2 + 2e^- + 2H^+ \rightarrow H_2O$
- pumps H⁺ into intermembrane space

Quick Quiz 3

Electrons flow through the electron-transport chain in a specific order. Which of the following is a correct (but not necessarily complete) sequence of electron flow?

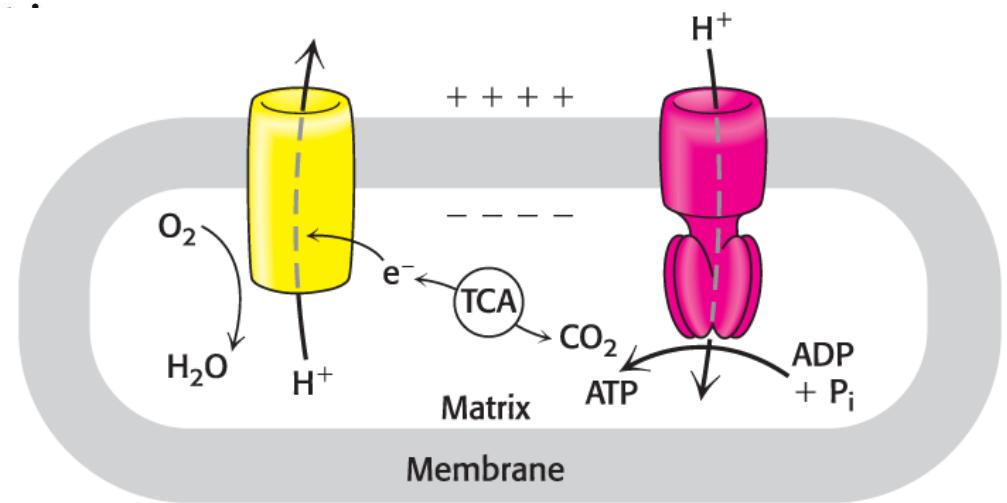
- A. NADH → Complex I → cytochrome c → Complex III
- B. NADH → Complex I → ubiquinone (coenzyme Q) → Complex II
- C. FADH₂ → Complex II → ubiquinone (coenzyme Q) → Complex III
- D. FADH₂ → Complex II → cytochrome c → Complex III
- E. A & C

A Proton Gradient Powers the Synthesis of ATP



...electron transport and ATP synthesis are coupled by a proton gradient across the inner mitochondrial membrane.

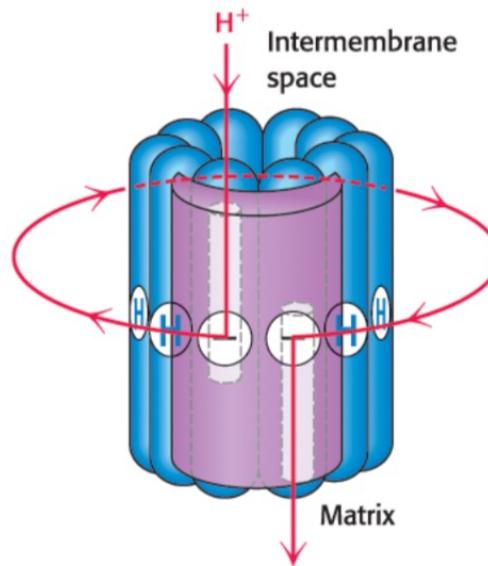
The Chemiosmotic Hypothesis
(Peter Mitchell, 1961)



- proton gradient generated by the oxidation of NADH and $FADH_2$ → **proton-motive force** → **powers the synthesis of ATP**

$$\text{Proton-motive force } (\Delta p) = \text{chemical gradient } (\Delta H) + \text{charge gradient } (\Delta \psi)$$

The Proton-Motive Force

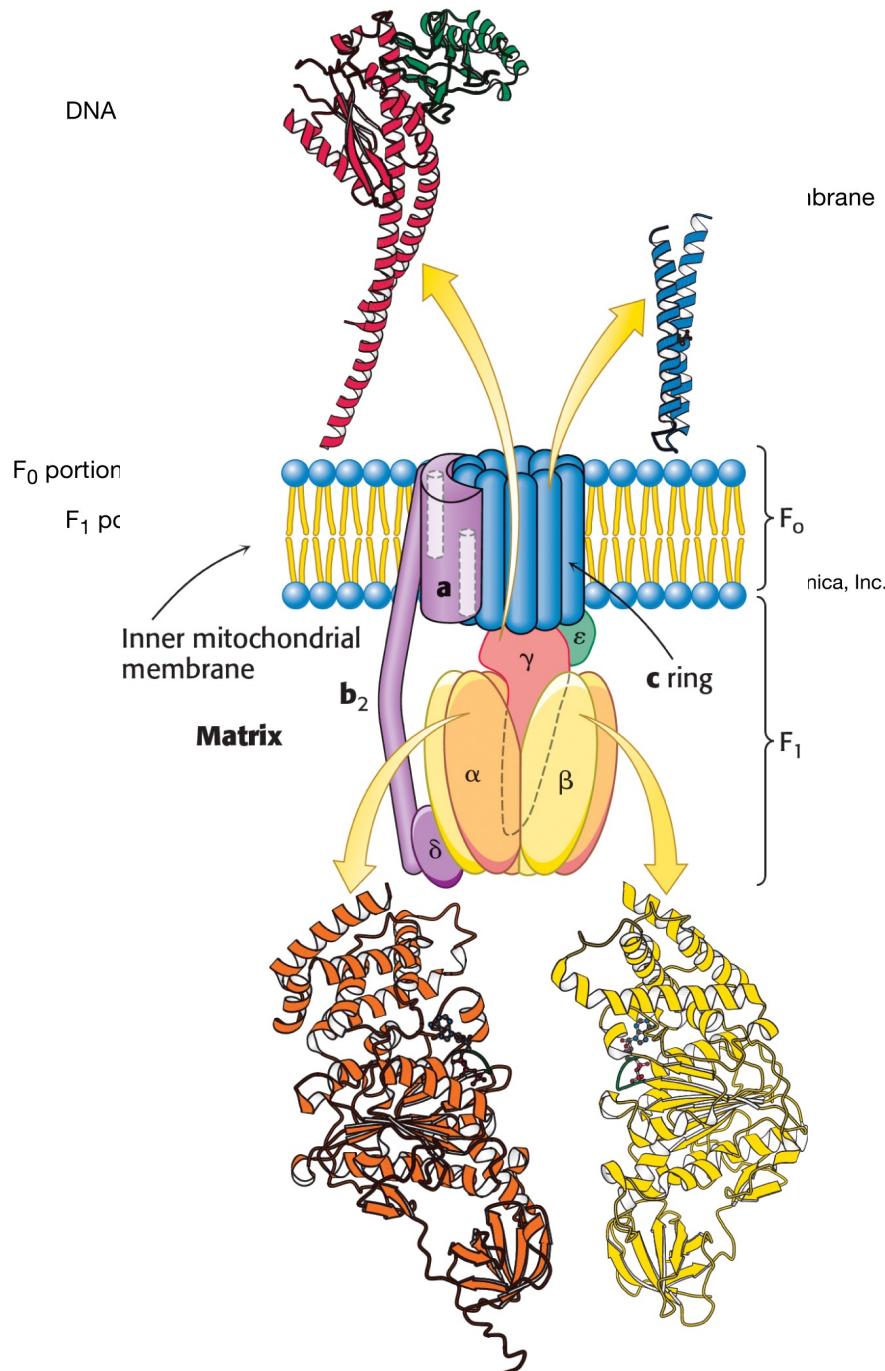


ATP Synthase



Photo: Melvyn Longhurst/Corbis Documentary/Getty Images
© Macmillan Learning

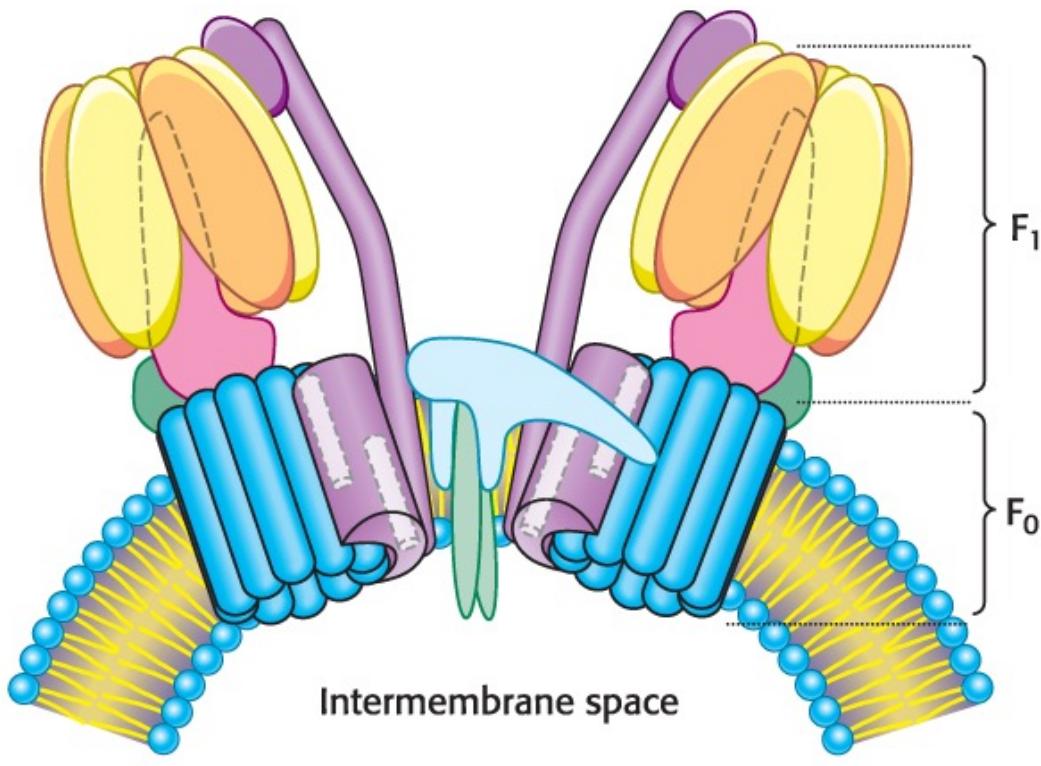
ATP Synthase: A Complex Molecular Rotational Motor



ATP synthase is composed of a **proton-conducting unit and a **catalytic unit**.**

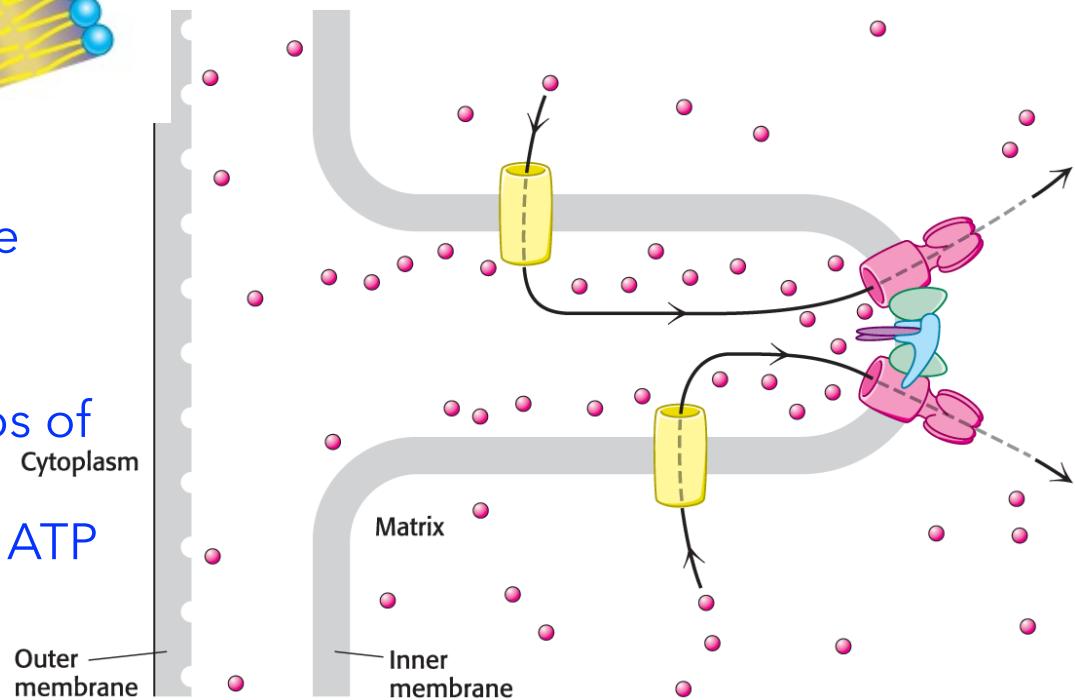
- ATP synthase is made-up of two components. The **F₁ component** contains the active sites and protrudes into the mitochondrial matrix.
- Each enzyme has three active sites located on the three **β subunits**.
- The **F₀ component** is embedded in the inner mitochondrial membrane and contains the proton channel.
- The **γ subunit** connects the F₁ and F₀ components.
- Each **β subunit** is distinct in that each subunit interacts differently with the **γ subunit**.

ATP Synthase forms dimers and assists in cristae formation

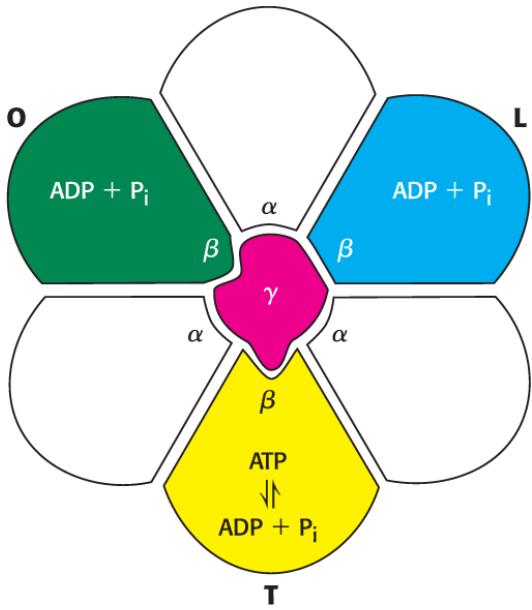


- Cristae formation helps concentrate the proton gradient near ATP synthases.
- ATP synthases are located at the tips of cristae.
- This spatial arrangement enhances ATP synthesis efficiency.

- Enzyme association stabilizes them against rotational forces during catalysis.
- Supports the curvature of the inner mitochondrial membrane into cristae.

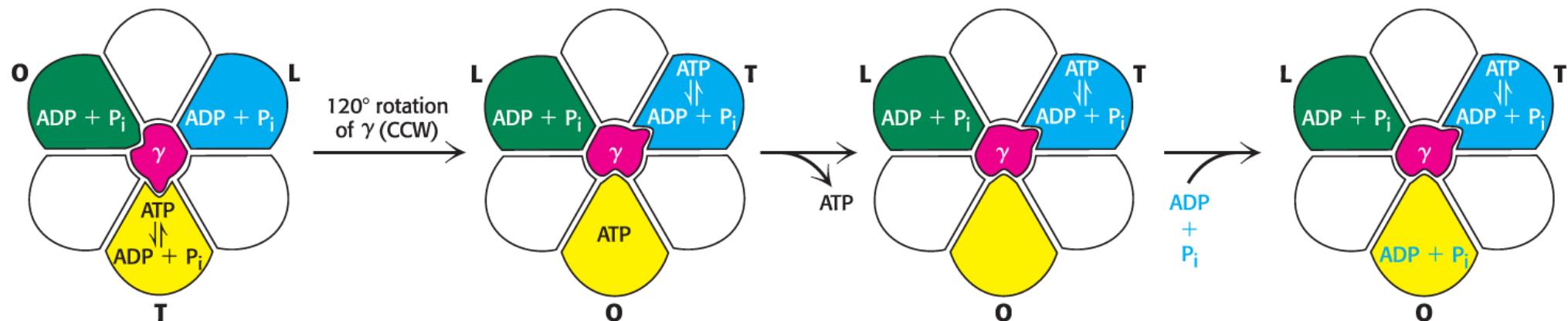


ATP Synthase binding sites cycle through distinct conformational states



The **binding change mechanism** accounts for the synthesis of ATP in response to proton flow.

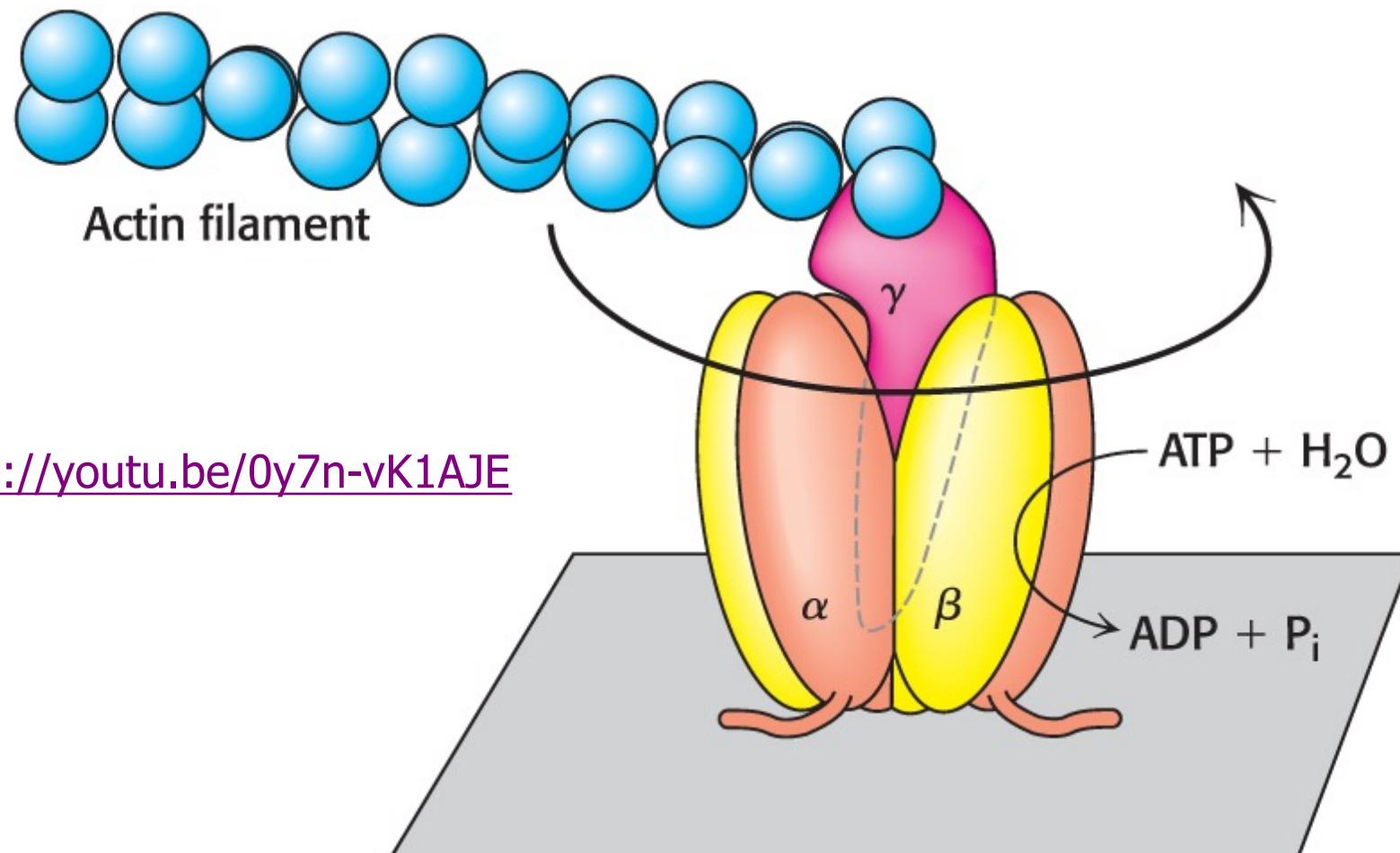
- The three catalytic β subunits of the F₁ component can exist in three conformations:
 - In the **L (loose) form**, ADP and Pi binds; nucleotides are trapped in the β subunit.
 - In the **T (tight) form**, ATP is synthesized from ADP and P_i.
 - In the **O (open) form**, nucleotides can bind to or be released from the β subunit.



- Rotation drives interconversion of the L, T, and O forms.

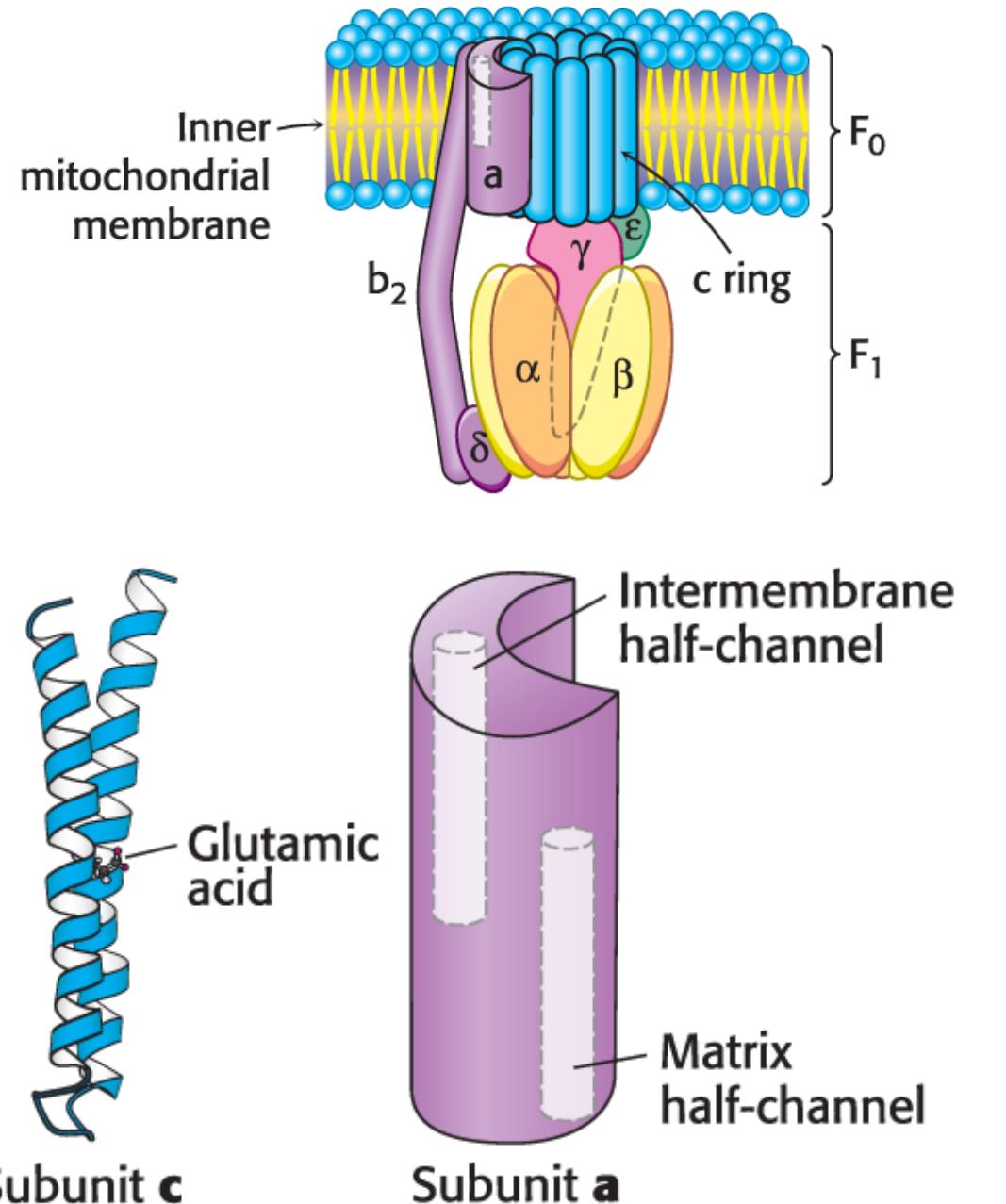
Rotational catalysis is the world's smallest molecular motor

- It is possible to observe the rotation of the γ subunit directly.
- Cloned $\alpha_3\beta_3\gamma$ subunits were attached to a glass slide that allowed the movement of the γ subunit to be visualized as a result of ATP hydrolysis.
- The hydrolysis of a single ATP powered the rotation of the γ subunit 120° .



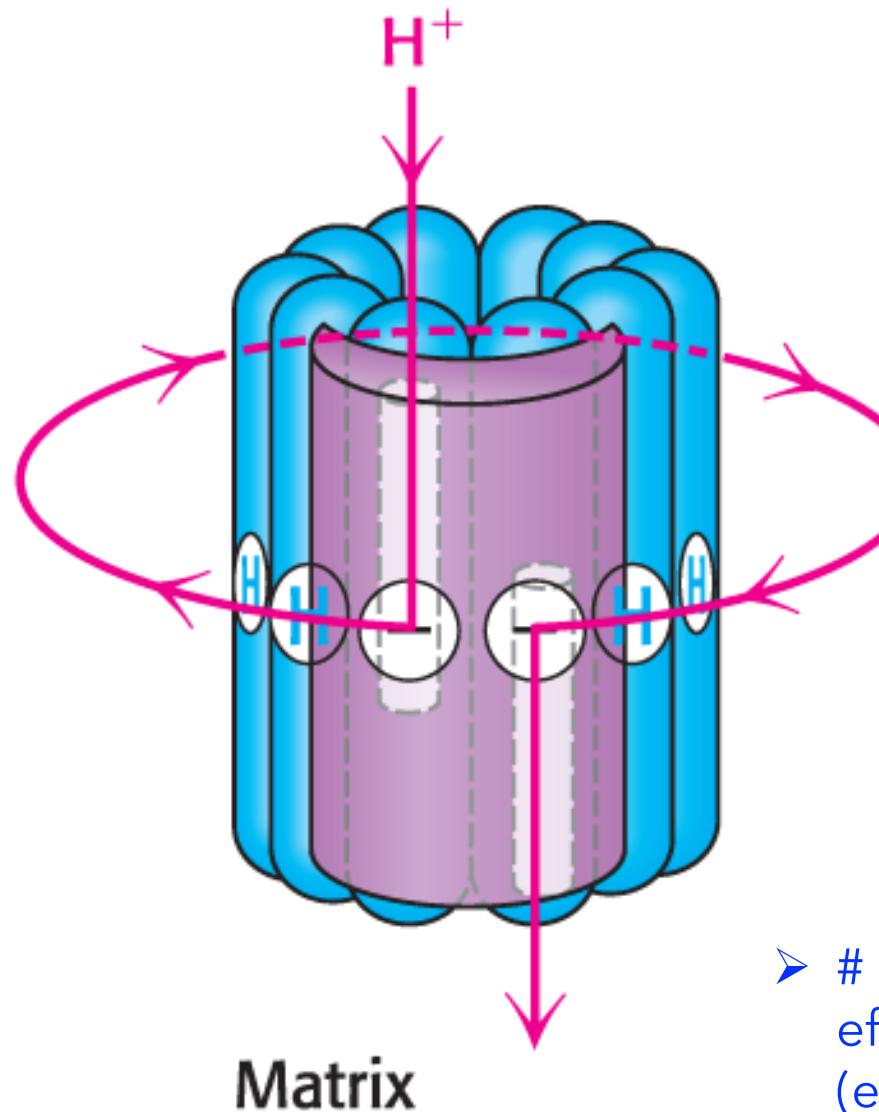
Proton flow around the c ring powers ATP synthesis

- Proton flow occurs through the F_0 component of the ATP synthase.
- Subunit a, next to the c ring, has two channels that reach halfway into the a subunit.
- The force of the proton gradient powers rotation of the c ring.
- The rotation of the c ring powers the movement of the γ subunit, which in turn alters the conformation of the β subunits.



Proton Motion Across the Membrane Drives the Rotation of the c Ring

Intermembrane
space



- Each 360°-rotation synthesizes and releases 3 ATP molecules.
- # of c subunits → efficiency of synthesis (e.g., 8, ~2.7 H⁺)

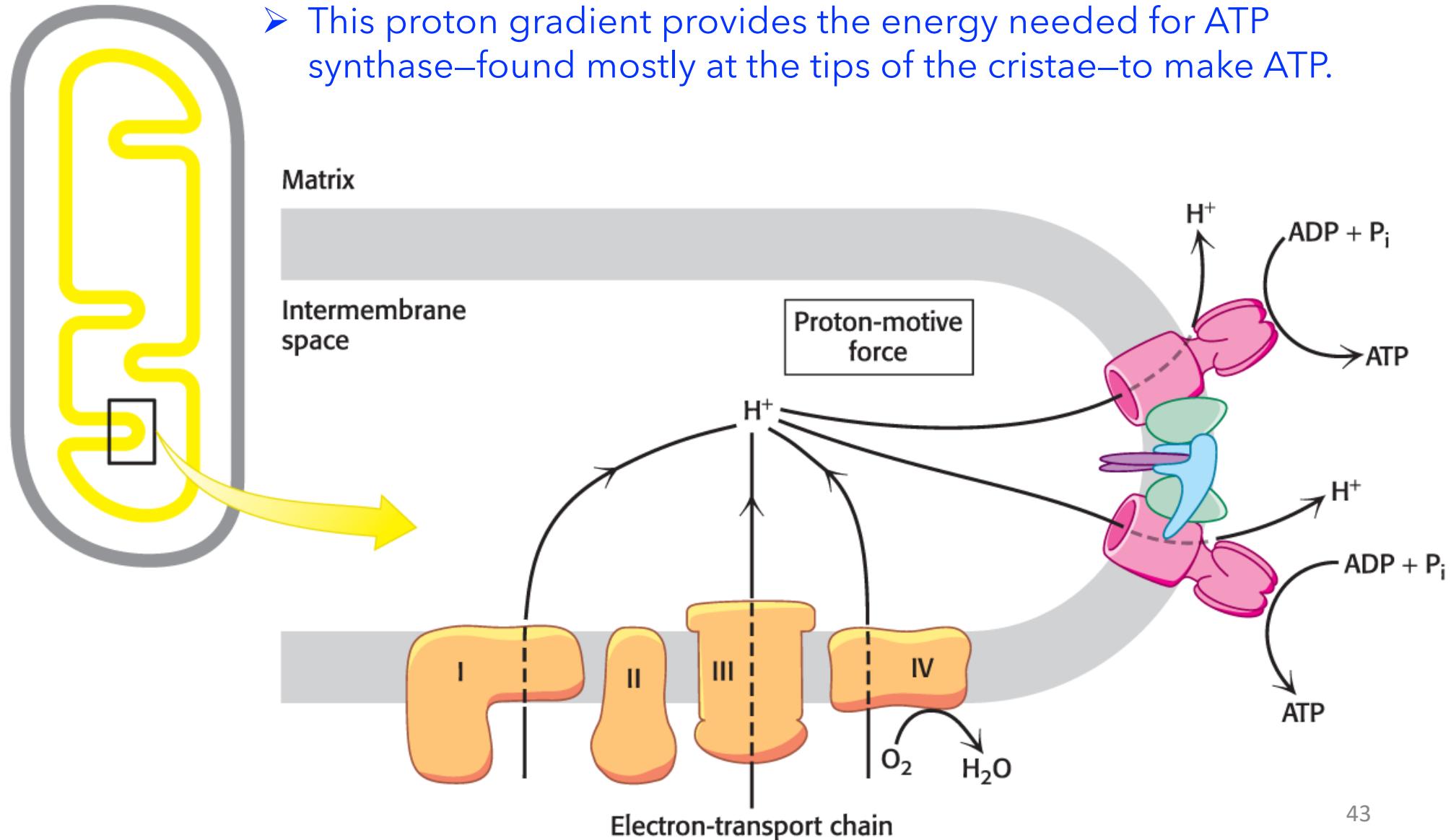
Quick Quiz 5

ATP synthase catalyzes the synthesis of ATP from _____.

- A. two molecules of ADP, with the concomitant formation of AMP along with the ATP
- B. ADP and AMP
- C. ADP and Pi
- D. ADP-CoA and Pi
- E. ADP-CoA and AMP

Oxidative Phosphorylation

- The electron transport chain creates a buildup of protons in the cristae by pumping them across the membrane.
- This proton gradient provides the energy needed for ATP synthase—found mostly at the tips of the cristae—to make ATP.

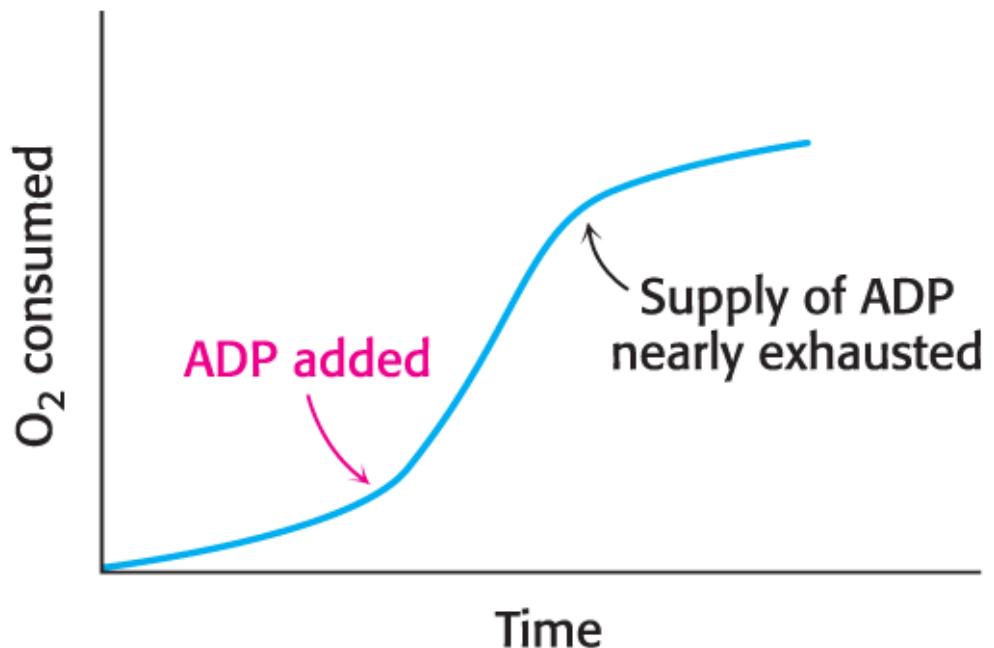


ATP yield from the complete oxidation of glucose

Reaction sequence	ATP yield per glucose molecule
Glycolysis: Conversion of glucose into pyruvate (in the cytoplasm)	
Phosphorylation of glucose	-1
Phosphorylation of fructose 6-phosphate	-1
Dephosphorylation of 2 molecules of 1,3-BPG	+2
Dephosphorylation of 2 molecules of phosphoenolpyruvate	+2
2 molecules of NADH are formed in the oxidation of 2 molecules of glyceraldehyde 3-phosphate	
Conversion of pyruvate into acetyl CoA (inside mitochondria)	
2 molecules of NADH are formed from 2 molecules of pyruvate	
Citric acid cycle (inside mitochondria)	
2 molecules of ATP are formed from 2 molecules of succinyl CoA	+2
6 molecules of NADH are formed in the oxidation of 2 molecules each of isocitrate, α -ketoglutarate, and malate	
2 molecules of FADH ₂ are formed in the oxidation of 2 molecules of succinate	
Oxidative phosphorylation (inside mitochondria)	
2 molecules of NADH are formed in glycolysis; each yields 1.5 molecules of ATP (assuming transport of NADH by the glycerol 3-phosphate shuttle)	+3
2 molecules of NADH are formed in the oxidative decarboxylation of 2 molecules of pyruvate; each yields 2.5 molecules of ATP	+5
2 molecules of FADH ₂ are formed in the citric acid cycle; each yields 1.5 molecules of ATP	+3
6 molecules of NADH are formed in the citric acid cycle; each yields 2.5 molecules of ATP	<u>+15</u>
Net yield per molecule of glucose	+30

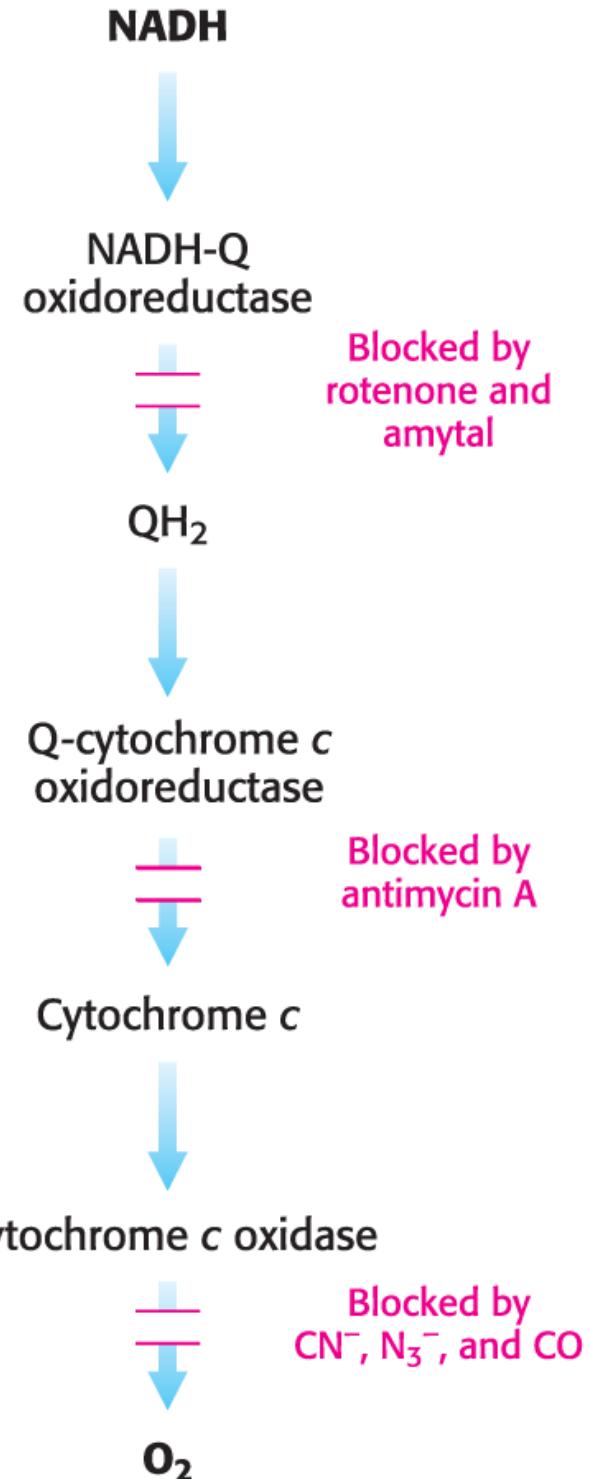
Cellular Respiration Is Regulated by the Need for ATP

- Of the **30** molecules of **ATP** formed by the complete combustion of glucose, **26 are formed in oxidative phosphorylation.**
- The metabolism of glucose to two molecules of pyruvate in glycolysis yields the remaining four ATP.
- *Electrons do not flow through the ETC unless ADP is available to be converted into ATP.*
- The regulation of oxidative phosphorylation by ADP is called **acceptor or respiratory control.**
- Acceptor control is an example of control of metabolism by energy charge.



Inhibition

- Inhibition of the electron-transport chain prevents oxidative phosphorylation by inhibiting the formation of the proton-motive force.
- Inhibition of ATP synthase (e.g., oligomycin) by inhibiting proton flow prevents electron transport.
- Uncouplers (e.g., xanthohumol and 2,4-dinitrophenol) carry protons across the inner mitochondrial membrane. The electron-transport chain functions, but ATP synthesis does not occur because the proton gradient can never form.



Quick Quiz 7

The current best estimate for the total number of ATP produced from the complete oxidation of a single glucose is about _____.

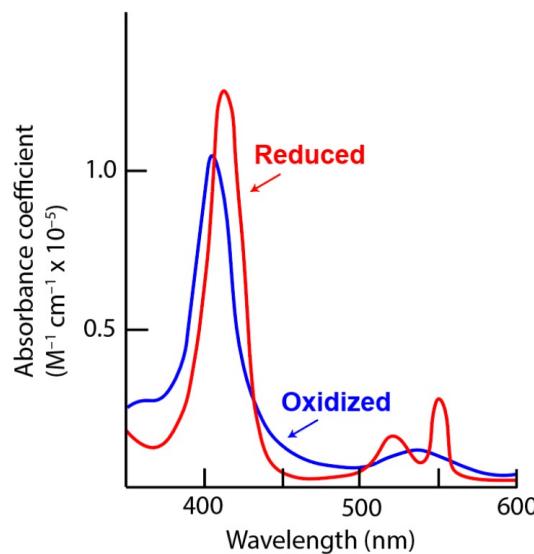
- A. 36
- B. 24
- C. 30
- D. 4
- E. 5

The *crossover technique* can reveal the precise site of action of a respiratory-chain inhibitor. Britton Chance devised elegant spectroscopic methods for determining the proportions of the oxidized and reduced form of each carrier. This determination is feasible because the forms have distinctive absorption spectra, as illustrated in the graph for cytochrome *c*.

Upon the addition of a new inhibitor to respiring mitochondria, the carriers between NADH and ubiquinol (QH_2) become more reduced, and those between cytochrome *c* and O_2 become more oxidized.

Where does your inhibitor act?

- Complex I
- Complex II
- Complex III
- Complex IV



The table shows standard reduction potentials (E'_0) for reactions with n transferred electrons.

Faraday's constant is 96.48 kJ mol⁻¹ V⁻¹.

Electrons from NADH pump more protons as a consequence of reaction with oxygen than do the electrons from FADH₂. Use the information provided to calculate the energy released by the reduction of O₂ with FADH₂.

Oxidant	Reducant	n	E'_0 (V)
$\frac{1}{2} \text{O}_2 + 2\text{H}^+$	H ₂ O	2	+0.82
FAD	FADH ₂	2	-0.22

Calculate and compare the $\Delta G^{\circ'}$ values for the oxidation of succinate by NAD^+ and FAD. Use the data given in the table to find the E'_0 of the $\text{NAD}^+ : \text{NADH}$ and fumarate : succinate couples, and assume that E'_0 for the enzyme-bound FAD : FADH_2 redox couple is nearly +0.05 V.

Oxidant	Reductant	<i>n</i>	E'_0 (V)
NAD^+	$\text{NADH} + \text{H}^+$	2	-0.32
Fumarate	Succinate	2	-0.03

Why is FAD rather than NAD^+ the electron acceptor in the reaction catalyzed by succinate dehydrogenase?

- The oxidation of succinate by NAD^+ is not thermodynamically feasible.
- The oxidation of succinate requires two NAD^+ molecules but only one FAD molecule.
- FAD is an oxidant, whereas NAD^+ is a reductant.
- The electron-transport chain can regenerate FAD, but not NAD^+ .

Hexokinase catalyzes the first step of glycolysis by phosphorylating glucose to glucose 6-phosphate. In red blood cells, hexokinase has a Michaelis constant (K_M) of approximately 50 μM , and the substrate concentration [S] is equal to the blood glucose concentration. Calculate the blood glucose concentration that would yield a hexokinase reaction velocity (V_0) equal to 90% of its maximum reaction velocity (V_{\max}).

What does this result tell you about how hexokinase functions at a normal blood glucose concentration of 3.6 mM to 6.1 mM?

- It functions at close to its V_{\max} because nearly all the active sites are saturated with substrate.
- It functions at about half its V_{\max} because about half the active sites are saturated with substrate.
- It functions above its V_{\max} because the active sites are supersaturated with substrate.
- It functions at a minimal level because very few active sites are saturated with substrate.

The pyruvate dehydrogenase (PDH) complex catalyzes the oxidative decarboxylation of pyruvate to acetyl-CoA and CO₂. Multiple copies of pyruvate dehydrogenase (E₁), dihydrolipoyl transacetylase (E₂), and dihydrolipoyl dehydrogenase (E₃) along with five cofactors form the PDH complex. Biochemists have studied the PDH complex for decades, in part due to its interesting use of substrate channeling during catalysis.

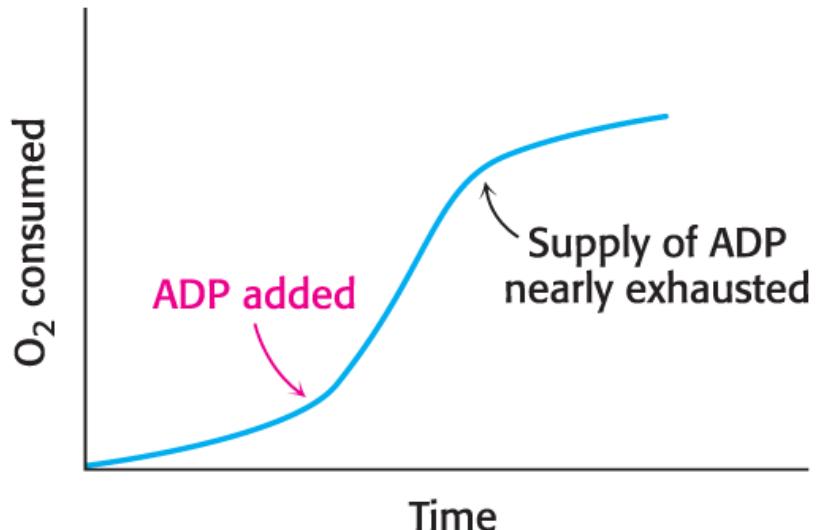
What is the benefit of substrate channeling?

- Intermediates of a multistep reaction sequence do not dissociate from the enzyme complex.
- Reaction intermediates move to sequential active sites faster than the diffusion constant.
- The PDH complex sequesters excess substrate to use at later time.
- Every intermediate or product made by the PDH complex enters the citric acid cycle as a substrate.
- The PDH active site forms in the hydrophobic core of the complex instead of a surface-exposed region.

What is the molecular mechanism of substrate channeling in the PDH complex?

- The swinging lipoyllysyl arm of E₂ carries electrons and an acetyl group from E₁ to E₂.
- Electrons and an acetyl group travel between E₁ and E₂ through a tunnel in E₂.
- Metal ions coordinated with thiamine pyrophosphate (TPP) in E₁ shield the electrons and acetyl group from scavenging by other enzymes until they reach E₃.
- The active sites of E₁, E₂, and E₃ undergo conformational changes that move products of one reaction to their next position without solvent exposure.

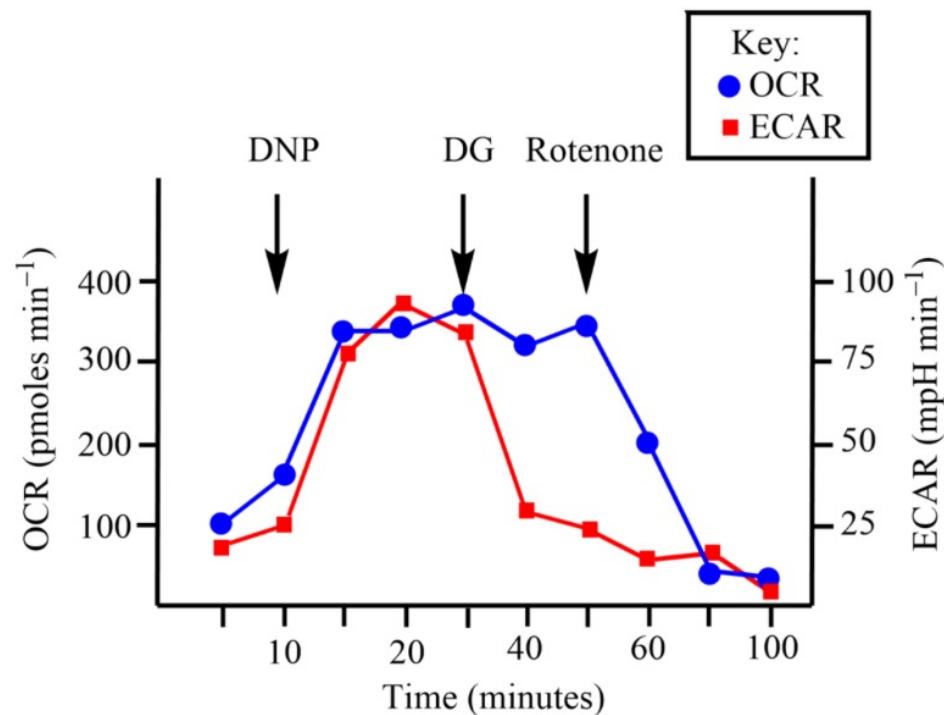
In the presence of phosphate, the rate of oxygen consumption by mitochondria increases markedly when ADP is added and then decreases to its initial value when the added ADP has been converted into ATP.



Why does the rate of oxygen consumption decrease when all of the available ADP has been converted into ATP?

- ATP synthase can no longer function, and the proton gradient eventually becomes so large that the electron-transport chain cannot pump protons against it.
- ATP synthase can no longer function, and the proton gradient rapidly dissipates, removing the driving force for electron transfer to O_2 in the electron-transport chain.
- Complex IV of the electron-transport chain cannot reduce O_2 to H_2O when its substrate ADP is absent.
- The buildup of ATP in the mitochondrial matrix inhibits the reduction of O_2 to H_2O by Complex IV of the electron-transport chain.

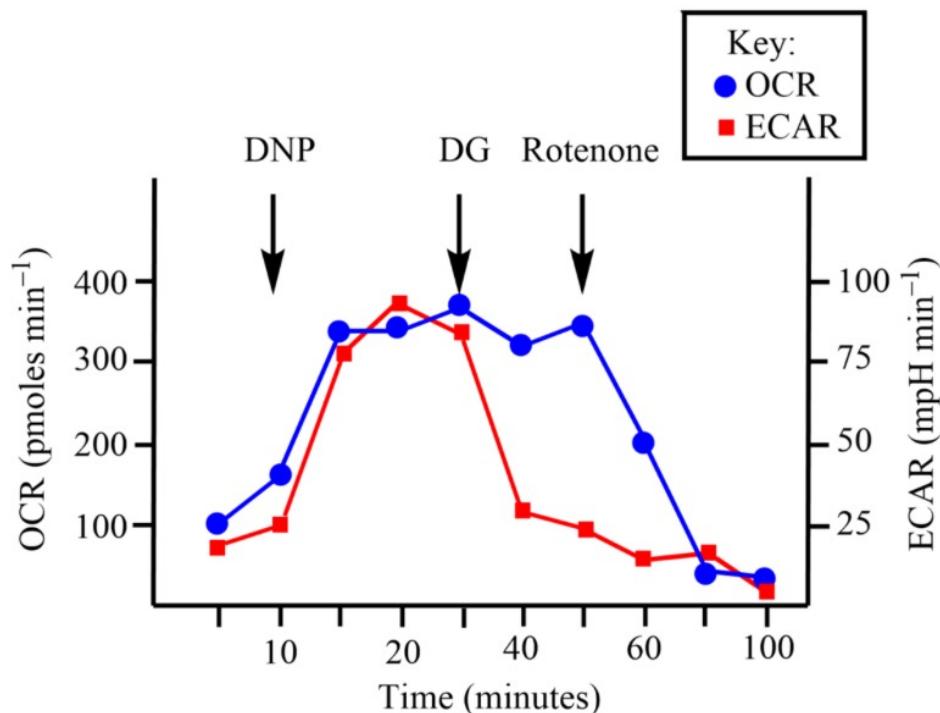
XF technology (Seahorse Bioscience) now allows the measurements of the rate of aerobic respiration and lactic acid fermentation simultaneously in real time in cultured cells. The extent of aerobic respiration is determined by measuring the oxygen consumption rate (OCR, measured in picomoles of oxygen consumed per minute) while the rate of glycolysis correlates with the extracellular acidification rate [ECAR-milli pH per minute (the changes in pH that occur over time)]. The graph shows the result of an experiment using this technology. 2,4-Dinitrophenol (DNP), the glycolysis inhibitor 2-deoxyglucose (DG), and rotenone were added sequentially to cell cultures.



What is the effect on OCR and ECAR of adding DNP to the cell culture?

- DNP increases OCR by uncoupling respiration from ATP synthesis, driving an increase in ECAR by activating glycolysis.
- DNP causes a decrease in OCR by inhibiting Complex I and an increase in ECAR by driving glycolysis.
- DNP causes an increase in OCR by activating ATP synthase, which reduces ECAR by inhibiting glycolysis.
- DNP decreases OCR by inhibiting Complex III, which increases ECAR from glycolysis to compensate.

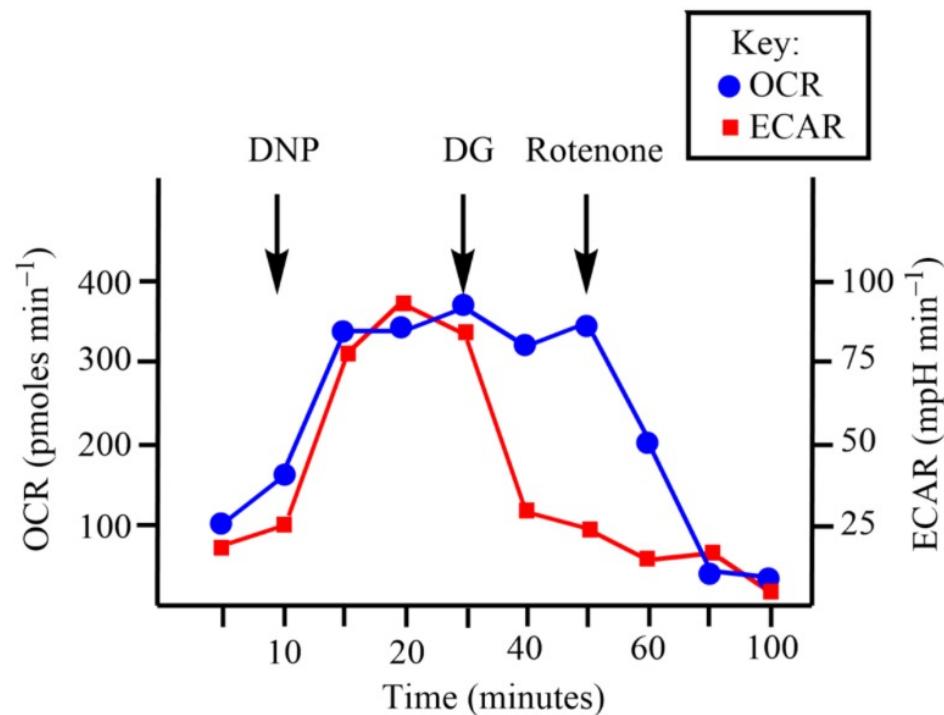
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What is the effect of rotenone?

- Rotenone blunts OCR by inhibiting Complex I.
- Rotenone decreases OCR by blocking Complex IV activity.
- Rotenone decreases OCR by preventing pyruvate from entering the mitochondrial matrix.
- Rotenone decreases OCR by stopping citrate synthase activity, blocking the citric acid cycle.

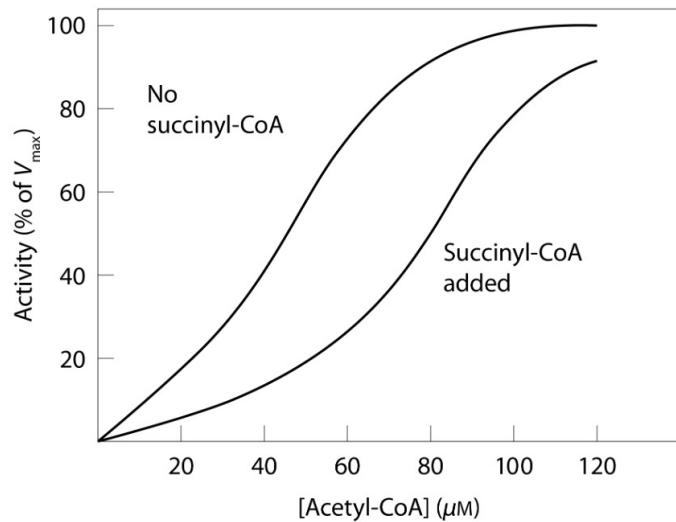
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What is the effect on OCR and ECAR of adding 2-deoxyglucose?

- 2-Deoxyglucose does not affect OCR because DNP is still present, and ECAR decreases because glycolysis is inhibited.
- 2-Deoxyglucose does not affect OCR because glycolysis does not use oxygen, and ECAR increases when glycolysis is inhibited.
- 2-Deoxyglucose increases OCR because respiration must compensate for the inhibition of glycolysis, which causes a decrease in ECAR
- 2-Deoxyglucose increases OCR because it reverses the effect of DNP, which increases ECAR by activating glycolysis.

In the presence of saturating amounts of oxaloacetate, the activity of citrate synthase from pig heart tissue shows a sigmoid dependence on the concentration of acetyl-CoA, as shown in the graph. Adding succinyl-CoA shifts the curve to the right and makes the sigmoid dependence more pronounced.



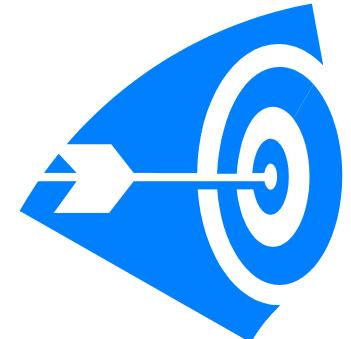
On the basis of these observations, how might succinyl-CoA regulate the activity of citrate synthase?

- Succinyl-CoA inhibits citrate synthase.
- Succinyl-CoA activates citrate synthase.
- Succinyl-CoA decreases the V_{max} of the citrate synthase reaction.
- Succinyl-CoA serves as a substrate for the citrate synthase reaction.

Why is succinyl-CoA an appropriate signal for regulation of the citric acid cycle?

- By regulating citrate synthase, succinyl-CoA controls entry of acetyl-CoA into the citric acid cycle.
- Succinyl-CoA is the source of activated two-carbon units oxidized by the citric acid cycle.
- Succinyl-CoA is the primary product of the citric acid cycle.
- The depletion of succinyl-CoA occurs in response to inhibition of oxidative phosphorylation.

Assigned Problems



Chapter	Tymochko, Berg, Stryer, Biochemistry, 2 nd Edition,	Chapter	Tymochko, Berg, Stryer, Biochemistry, 2 nd Edition,
20	1, 2, 4, 6, 9, 10, 11, 12, 13, 15, 16, 20.	21	1, 2, 5, 6, 8, 13, 14, 16, 19, 21, 25, 28, 30.
Chapter	Tymochko, Berg, Stryer, Biochemistry, 3 rd Edition, 4 th Edition (bottom line)	Chapter	Tymochko, Berg, Stryer, Biochemistry, 3 rd Edition, 4 th Edition (bottom line)
20	1, 2, 4, 6, 9, 10, 11, 12, 13, 15, 16, 20. 1, 2, 4, 6, 9, 10, 11, 12, 13, 15, 16, 20.	21	1, 2, 5, 6, 8, 13, 14, 16, 19, 21, 26, 29, 31 . 1, 2, 5, 6, 8, 13, 14, 16, 19, 21, 27, 30, 32.