(Introduction to Cellular Respiration)

Chapter 9: Cellular Respiration

This chapter covers in detail how organisms (aerobes and anaerobes) ***oxidize*** *the sugars produced in photosynthesis via the reduction of CO_2 and use this energy to convert ADP into ATP (the energy of cells).*

$$C_6H_{12}O_6 + \underline{6}O_2 \Rightarrow \underline{6}CO_2 + \underline{6}H_2O + \textit{36/38ATP}$$

(energy)

OBJECTIVES:

___ 1. Summarize the equation for cellular respiration.
___ 2. Define oxidation and reduction.
___ 3. Explain how redox reactions are involved in energy exchanges.
___ 4. Explain why organic molecules that have an abundance of hydrogen are excellent cellular fuels.
___ 5. Describe the role of NAD+ and the electron transport chain during respiration.
___ 6. Describe the regions where glycolysis, the Krebs cycle, and the electron transport chain occur.
___ 7. List the reactants, products and main events of glycolysis, the Krebs cycle, and the electron transport chain
___ 8. Describe the process of chemiosmosis.
___ 9. Explain how membrane structure is related to membrane function in chemiosmosis.
___ 10. Summarize the net ATP yield from the oxidation of a glucose molecule.
___ 11. Explain why fermentation is necessary.
___ 12. Compare the processes of fermentation and cellular respiration.
___ 13. Describe evidence that the first prokaryotes produced ATP by glycolysis.
___ 14. Describe how food molecules other than glucose can be oxidized to make ATP.

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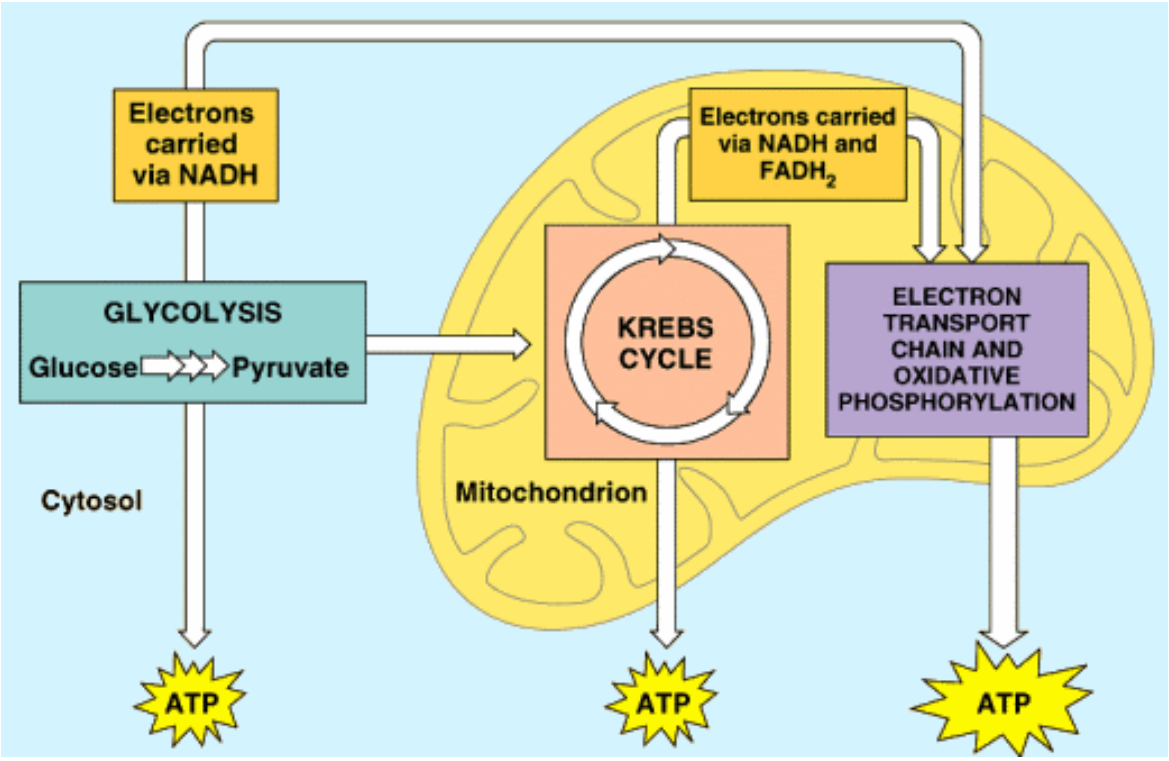
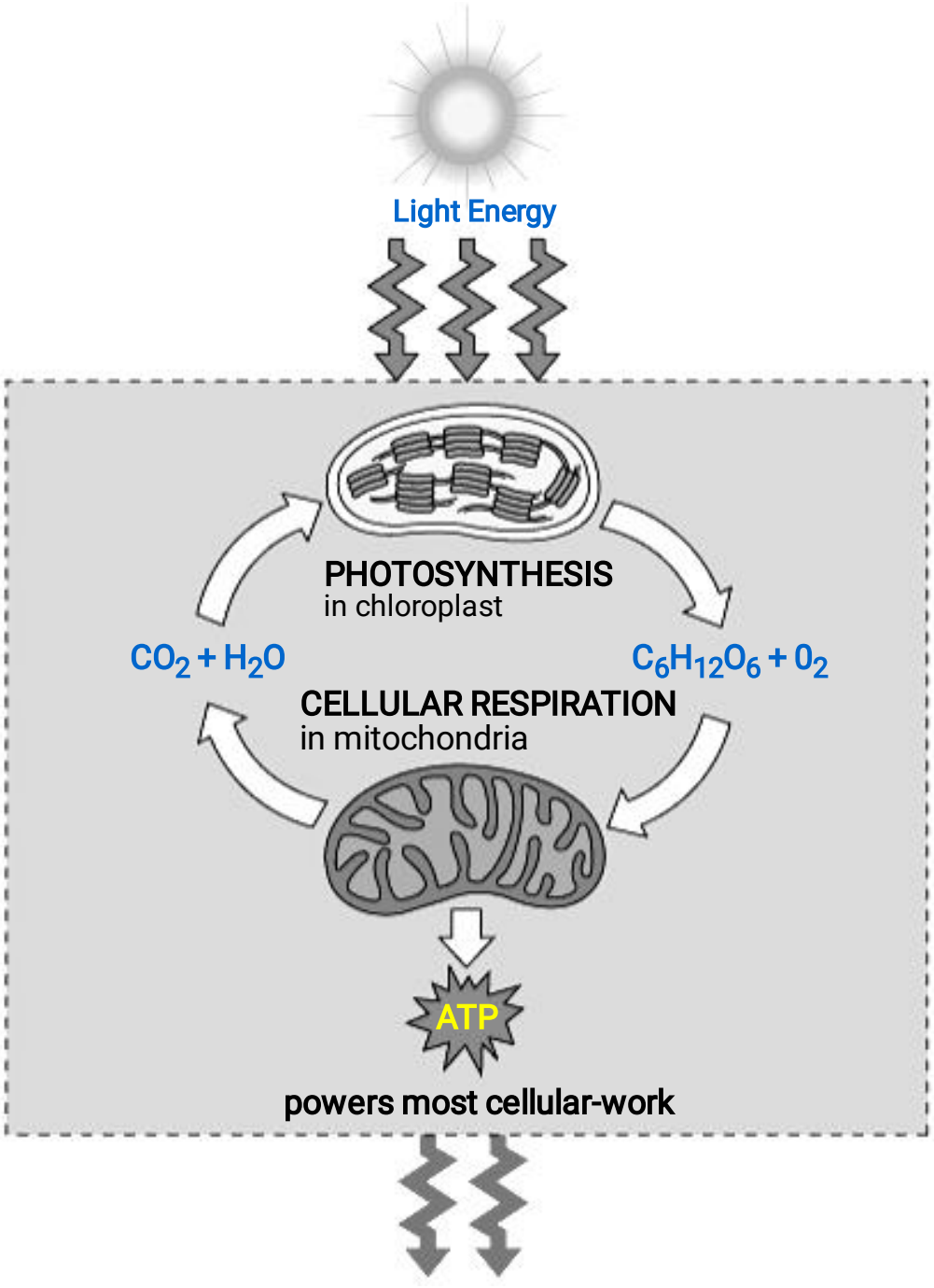


(p.157)

Overview: Before getting involved with the details of cellular respiration, take a second to look at the big picture. Photosynthesis and cellular respiration are key ecological concepts involved with energy flow. Label Figure 9.1 below and use it to help explain the flow of energy and chemical recycling that takes place in ecosystems.



(The first law of thermodynamics states that energy cannot be created or destroyed, but it can be transferred from one form to another.)

Principles of Energy Harvest

(p.157) **18.** Both cellular respiration and photosynthesis are *redox reactions*. In redox, reactions pay attention to the flow of electrons. What is the difference between oxidation and reduction?

Oxidation Is Loss (H^+/e^-) **OIL**

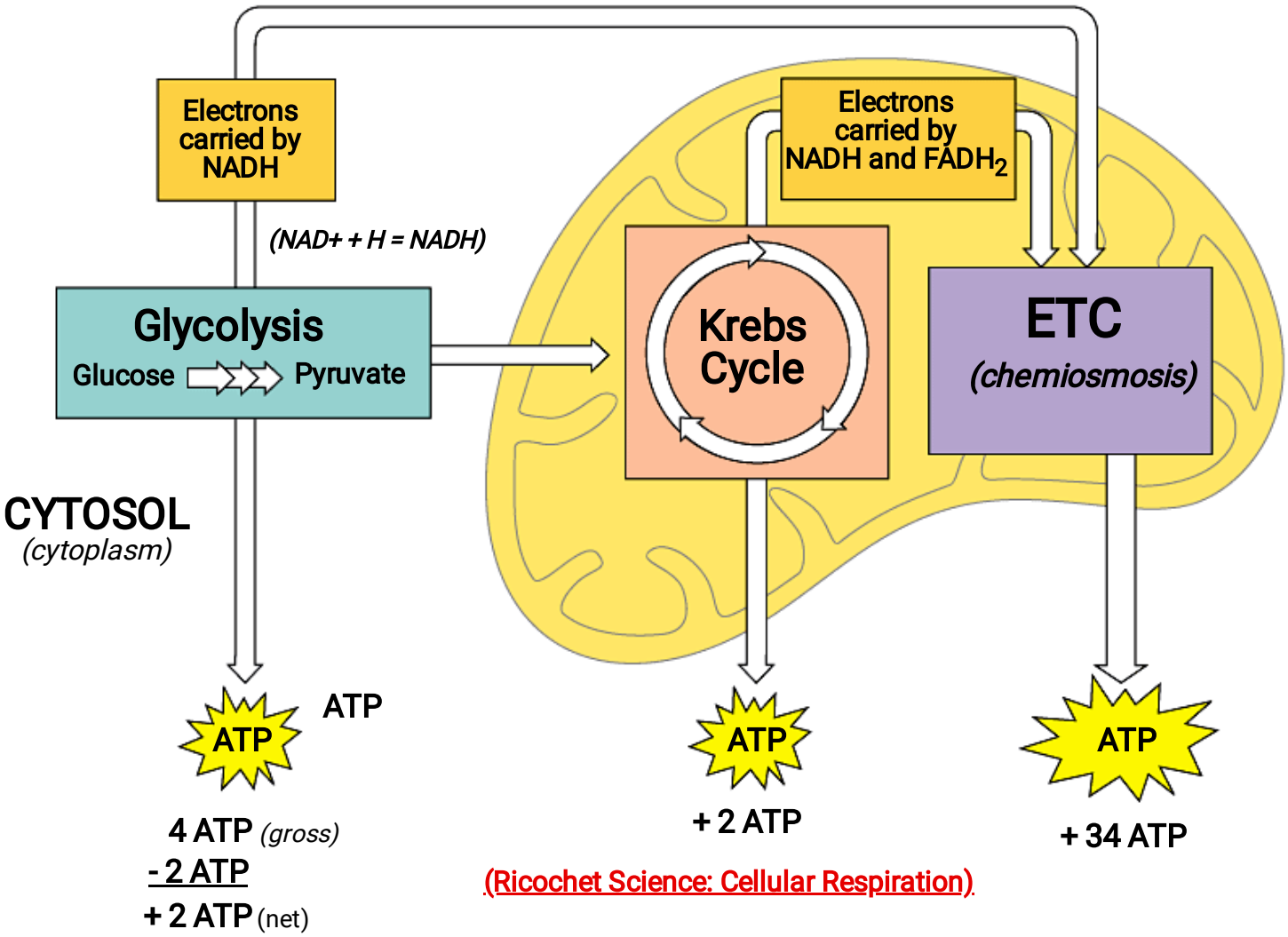
Reduction Is Gain (H^+/e^-) **RIG**

(p.158) **19.** In cellular respiration, electrons are not transferred directly from glucose to oxygen. Each electron is coupled with a proton to form a hydrogen atom. Following the movement of hydrogens allows you to follow the flow of electrons. The hydrogens are held in the cell temporarily by what electron carrier or "taxi cab"?

NAD^+

(p.160) **20.** Understanding the overall map of how cellular respiration works will make the details easier to learn. Use Figure 9.6 to label the missing information in the figure below.

(Animation: Cellular Respiration Overview)

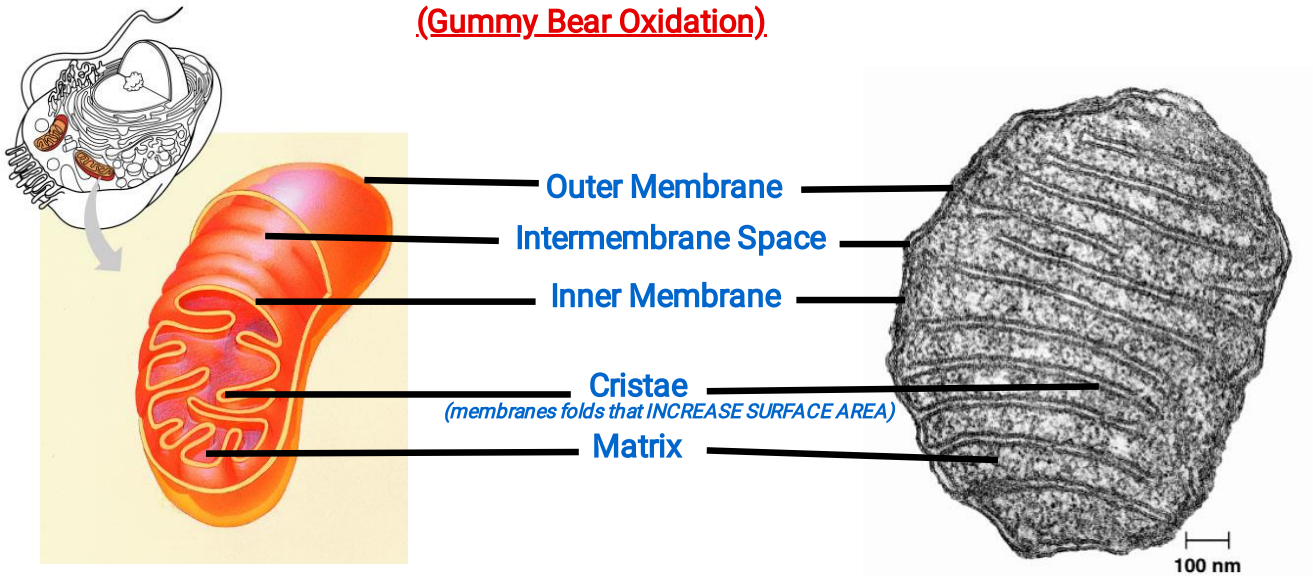


(Ricochet Science: Cellular Respiration)

(Animation: Structure of the Mitochondria)

(p.124) **21.** Label the diagrams of the mitochondria below from Ch. 7 - Figure 7.17.

(Gummy Bear Oxidation)



The Process of Cellular Respiration

(p.161) **22.** Why is glycolysis an appropriate term for this step of cellular respiration? (Animation: Glycolysis)

Glycolysis is an appropriate term because it means the *splitting* of *glucose.*

(p.161) **23.** The starting product of glycolysis is the six-carbon sugar glucose, and the ending product is two three carbon compounds termed pyruvate (*pyruvic acid*).

(p.160) **24.** Notice that glycolysis occurs in the cytoplasm of the cell.

(p.171) **25.** What is the relationship concerning glycolysis and oxygen and glycolysis and evolution?

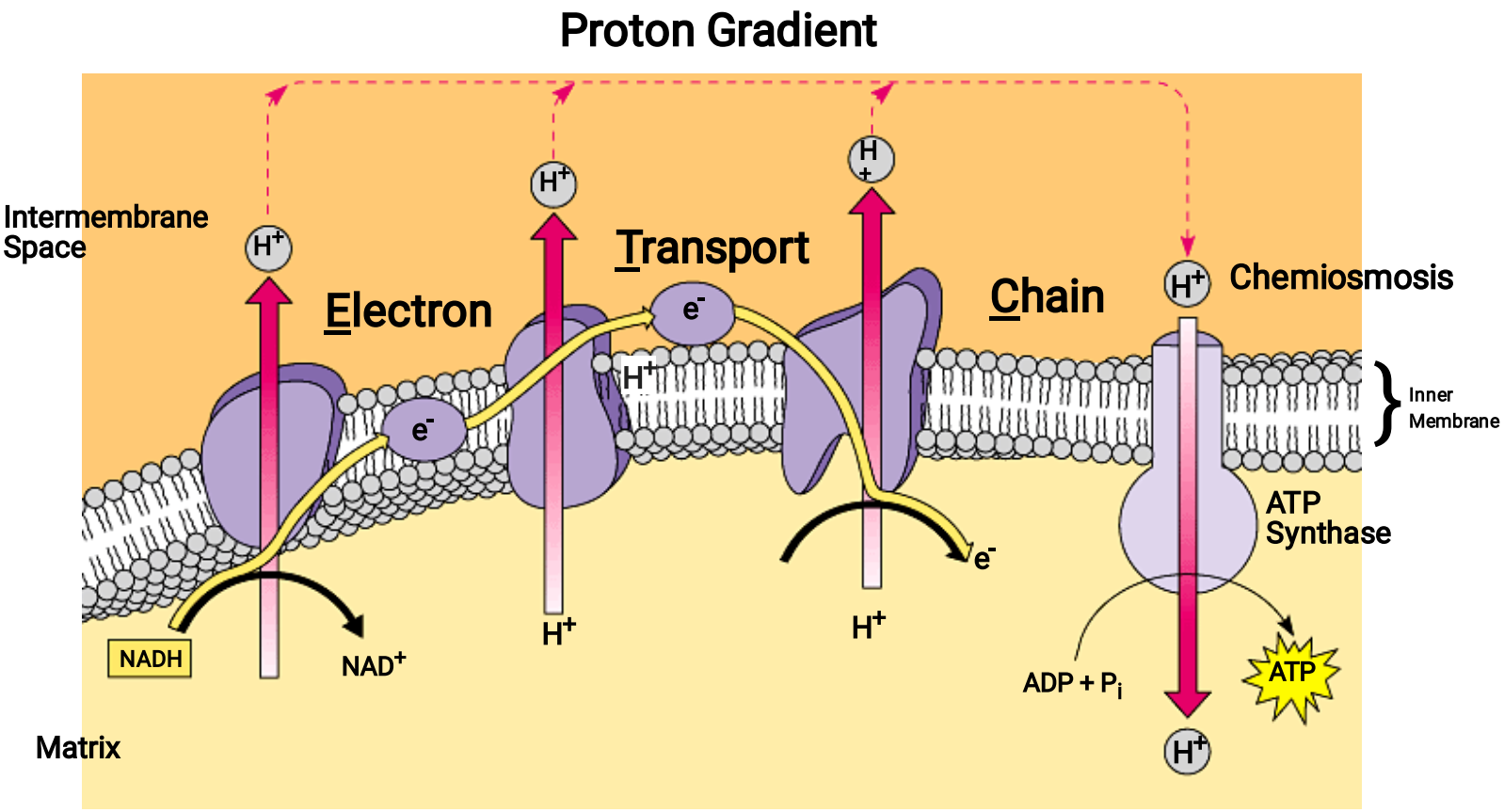
The relationship concerning glycolysis and oxygen and glycolysis and evolution is it is a form of energy production that existed long before oxygen was present in the Earth's atmosphere and the existence of complex, eukaryotic cell with the membrane-bound organelles needed for aerobic cellular respiration.

(p.161) **26.** What is the NET energy yield per glucose molecule from Glycolysis? 2 ATP

Phosphorylation (ADP ⟶ ATP) in cellular respiration involves two membrane components: the **electron transport chain** & **ATP synthase** (*just like in photosynthesis*). However, in photosynthesis the energy driving this reaction ultimately comes from the sun so it is termed photophosphorylation. In cellular respiration, this same ATP building process is called oxidative phosphorylation (*oxphos*) because the energy driving this process comes from the oxidation of glucose.

(Animation: How the Mitochondria Produce Energy)

(p.168) **27.** Figure 9.15 is a key to understanding the production of most of the ATP in the mitochondria. In the figure below, label all locations and molecules involved in the production of ATP via chemiosmosis.



(p.167) **28.** The 2 electron carriers that feed electrons into the ETC are NAD+ and FAD+.

(p.167) **29.** What is the role of the ETC in forming the H+ gradient across the inner mitochondrial membrane?

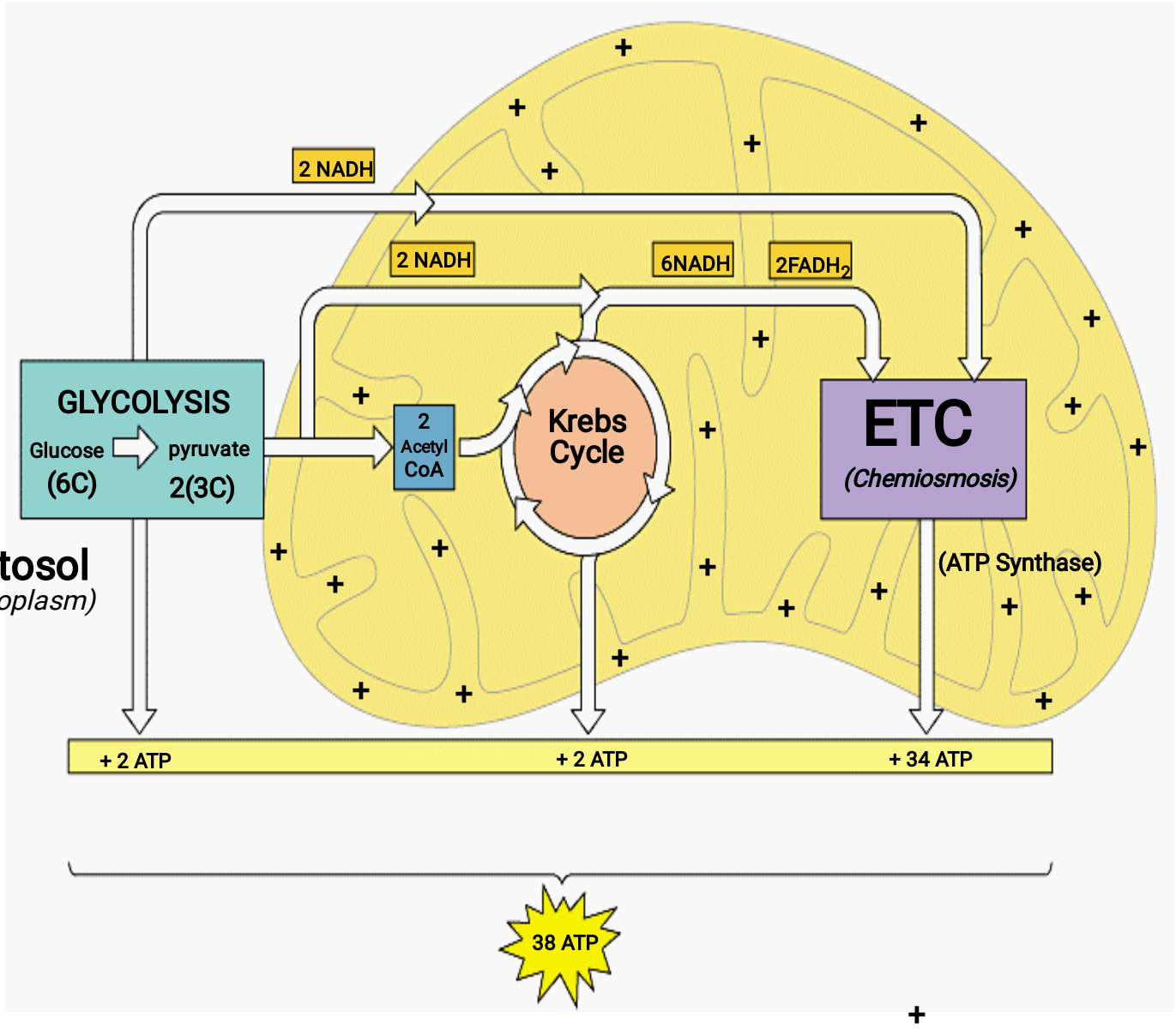
The role of the ETC is an energy converter that uses the flow of electrons to PUMP H+ across the inner membrane from the MATRIX and into the INTERMEMBRANE SPACE.

(p.167) **30.** What is the role of ATP synthase?

The role of ATP synthase is the same in photosynthesis and cellular respiration and it MAIN function is to utilize the potential energy of an existing H+ gradient established by the ETC to synthesize ATP from ADP.

(Ricochet Science: Cellular Respiration)

(p.176) **31.** Use figure 9.16 and the diagram below to help you account for the location, major events and total number ATP molecules formed during aerobic cellular respiration.



(p.169) **32.** Why is the total count about 36 or 38 ATP molecules rather than a specific number?

The total count is about 36 or 38 ATP molecules rather than a specific number because of many variables including the energy generated by the proton-motive force is often used for other work in the cell.

Related Metabolic Processes

(Fermentation – making ATP without oxygen)

(p.170) **33.** For aerobic respiration to continue, the cell must be supplied with oxygen - the ultimate electron acceptor. What is the electron acceptor in fermentation?)

The electron acceptor in fermentation in NAD+.

(p.170) **34.** Explain how alcohol fermentation starts with glucose and yields ethanol. Be sure to stress how NAD+ is recycled.

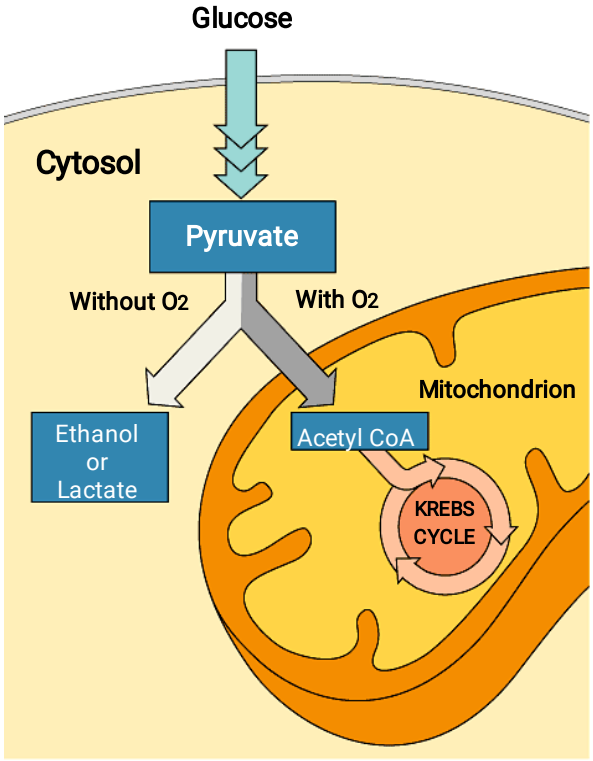
Alcohol fermentation consists of glycolysis (glucose —> pyruvate) followed by the conversion of pyruvate to ethanol along with the necessary reactions that regenerate NAD+ by transferring electrons from NADH to pyruvate.

(p.170) **35.** Explain how lactic acid fermentation starts with glucose and yields lactate. Be sure to stress how NAD+ is recycled.

Lactic acid fermentation consists of glycolysis (glucose —> pyruvate) followed by the conversion of pyruvate to lactate (lactic acid) along with the necessary reactions that regenerate NAD+ by transferring electrons from NADH to pyruvate.

(p.171) **36.** **THE FATE OF PYRUVATE.** Using Figure 9.19 as a guide to label the diagram to the right and explain why pyruvate is a key juncture in metabolism.

The Fate of Pyruvate



(Animation: Carbon / Oxygen Cycle) (Sumanas: Global Carbon Cycle)

The Carbon/Oxygen Cycle

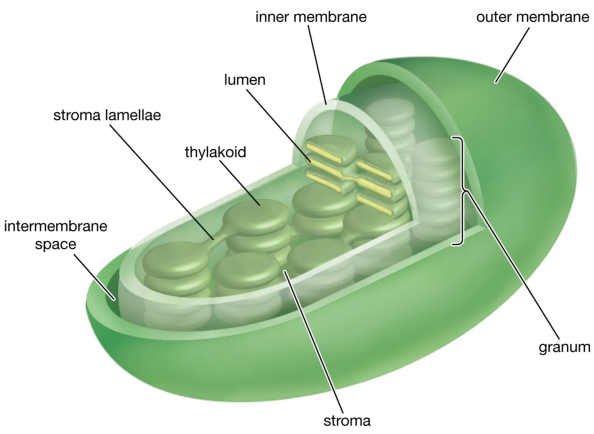
Photosynthesis

$6\ CO_2 + 6\ H_2O \xrightarrow{SUN} C_6H_{12}O_6 + 6\ O_2$

Aerobic Cellular

Respiration

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



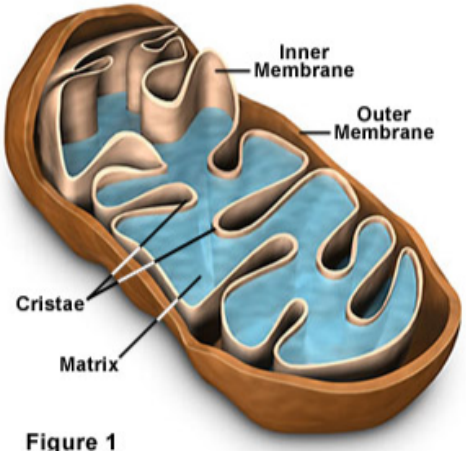


Figure 1

Chapter 9: Summary of Key Concepts

THE PRINCIPLES OF ENERGY HARVEST

- Chemical elements important to life are recycled by respiration and photosynthesis, but ENERGY IS NOT!!!
  Web/CD Activity9A: *Build a Chemical Cycling System*
- **Cellular respiration and fermentation are catabolic, energy-yielding pathways (pp. 155-156)** The breakdown of glucose and other organic fuels to simpler products is exergonic, yielding energy for ATP synthesis.
- **Cells recycle the ATP they use for work.** ATP transfers phosphate groups to various substrates, priming them to do work. To keep working, a cell must regenerate ATP. Starting with glucose or another organic fuel, and using O_2, cellular respiration yields H_2O, CO_2, and energy in the form of ATP and heat.
- **Redox reactions release energy when electrons move closer to electronegative atoms (pp. 156-158,** FIGURE 9.3) The cell taps the energy stored in food molecules through redox reactions, in which one substance partially or totally shifts electrons to another. The substance receiving electrons is reduced; the substance losing electrons is oxidized.
- **Electrons "fall" from organic molecules to oxygen during cellular respiration (p. 158)** Glucose ($C_6H_{12}O_6$) is oxidized to CO_2, and O_2 is reduced to H_2O. Electrons lose potential energy during their transfer from organic compounds to oxygen, and this energy drives ATP synthesis.
- **The "fall" of electrons during respiration is stepwise, via NAD^+ and an electron transport chain (pp. 158-159,** FIGURE 9.5) Electrons from food are usually passed to NAD +, reducing it to NADH. NADH passes the electrons to an electron transport chain, which conducts them to O_2 in energy-releasing steps. The energy released is used to make ATP by oxidative phosphorylation.

THE PROCESS OF CELLULAR RESPIRATION

- **Respiration involves glycolysis, the Krebs cycle, and electron transport: *an overview* (pp. 160-161,** FIGURE 9.6) Glycolysis and the Krebs cycle supply electrons (via NADH) to the transport chain, which drives oxidative phosphorylation. Glycolysis occurs in the cytosol, the Krebs cycle in the mitochondrial matrix. The electron transport chain is built into the inner mitochondrial membrane.
- **Glycolysis harvests chemical energy by oxidizing glucose to pyruvate: *a closer look* (p. 161,** FIGURES 9.8, 9.9) Glycolysis nets 2 ATP, produced by substrate-level phosphorylation, and 2 NADH.
- **The Krebs cycle completes the energy-yielding oxidation of organic molecules: *a closer look* (pp. 161-166,** FIGURES 9.11, 9.12) The conversion of pyruvate to acetyl CoA links glycolysis to the Krebs cycle. The two-carbon acetate of acetyl CoA joins the four-carbon oxaloacetate to form the six-carbon citrate, which is degraded back to oxaloacetate. The cycle releases CO_2, forms 1 ATP by substrate-level phosphorylation, and passes electrons to 3 NAD^+ and 1 FAD.
- **The inner mitochondrial membrane couples electron transport to ATP synthesis: *a closer look* (pp. 164-168,** FIGURE 9.15) Most of the ATP made in cellular respiration is produced by oxidative phosphorylation when NADH and $FADH_2$ donate electrons to the series of electron carriers in the electron transport chain. At the end of the chain, electrons are passed to O_2, reducing it to H_2O. Electron transport is coupled to ATP synthesis by chemiosmosis. At certain steps along the chain, electron transfer causes electron-carrying protein complexes to move H^+ from the matrix to the intermembrane space, storing energy as a proton-motive force (H^+ gradient). As H^+ diffuses back into the matrix through ATP synthase, its exergonic passage drives the endergonic phosphorylation of ADP.
- **Cellular respiration generates many ATP molecules for each sugar molecule it oxidizes: *a review* (pp. 169-170,** FIGURE 9.16) The oxidation of glucose to CO_2 produces a maximum of about 38 ATP.

RELATED METABOLIC PROCESSES

- **Fermentation enables some cells to produce ATP without the help of oxygen (pp. 170-172,** FIGURES 9.17, 9.18) Fermentation is anaerobic catabolism of organic nutrients. It yields ATP from glycolysis. The electrons from NADH made in glycolysis are passed to pyruvate, restoring the NAD^+required to sustain glycolysis. Yeasts and certain bacteria are facultative anaerobes, capable of making ATP by either aerobic respiration or fermentation. Of the two pathways, respiration is the more efficient in terms of ATP yield per glucose. Glycolysis occurs in nearly all organisms and probably evolved in ancient prokaryotes before there was O_2 in the atmosphere.

- **Glycolysis and the Krebs cycle connect to many other metabolic pathways (pp. 172-173,** FIGURE 9.19) These catabolic pathways combine to funnel electrons from all kinds of food molecules into cellular respiration. Carbon skeletons for anabolism (biosynthesis) come directly from digestion or from intermediates of glycolysis and the Krebs cycle.
- **Feedback mechanisms control cellular respiration (p. 173,** FIGURE 9.20) Cellular respiration is controlled by allosteric enzymes at key points in glycolysis and the Krebs cycle. This helps the cell strike a moment-to-moment balance between catabolism and anabolism.