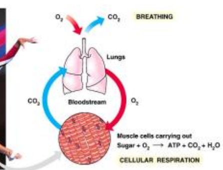
Chapter 5 Cellular Respiration

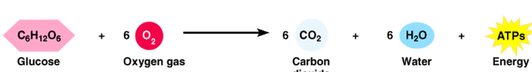


Releasing Stored Energy

- 1. **Aerobic Cellular Respiration**- Carried out by organisms in oxic (oxygen containing) environment.
- 2. **Anaerobic Cellular Respiration-** Anoxic (no-oxygen containing) environment.
- 3. **Fermentation-** Modified process- anaerobic respiration.

5.3 Cellular Respiration

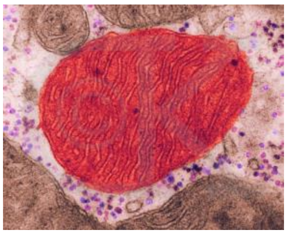
- A series of chemical reactions that <u>break down glucose</u> to release energy
- The energy is then stored in the form of **ATP**
- Formula is:

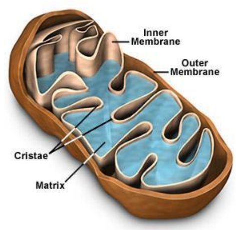


Cellular respiration banks energy as ATP

- <u>1 molecule of glucose</u> has a <u>LOT</u> of <u>energy</u> (too much at once!)
- Cells <u>change it</u> into a more <u>useable</u> form = <u>ATP</u>
- It's like changing a $100 bill for 100 loonies (easier to spend loonies)
- **<u>64%</u>** of energy is released as **<u>HEAT-</u>** (keeps you **<u>warm</u>**!)
  - (Exam Question)

Mitochondria structure



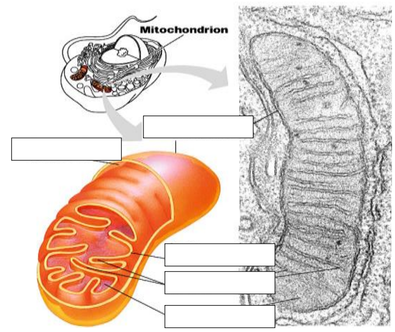


Practice: Mitochondria Structure

Mitochondria Anatomy

Label the diagram choosing from the following words or phrases:

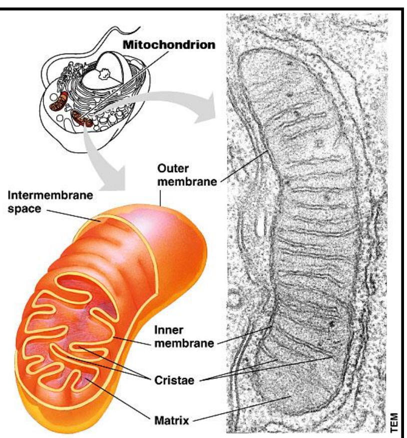
- Inner membrane
- Mitochondrion
- Outer membrane
- Cristae
- Intermembrane space
- Matrix



Mitochondria Anatomy

Label the diagram choosing from the following words or phrases:

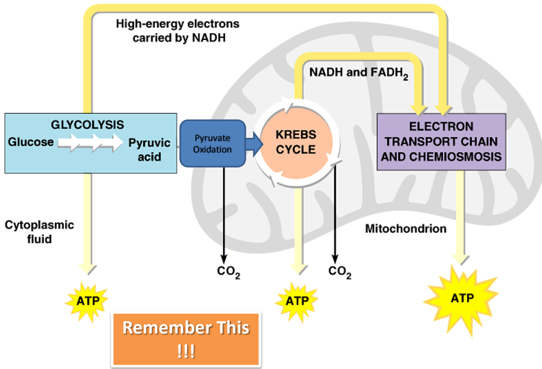
- Inner membrane
- Mitochondrion
- Outer membrane
- Cristae
- Intermembrane space
- Matrix



Cellular Respiration Takes Place in Four Stages

1. **Glycolysis**– Anaerobic
   - Cytoplasm
2. **Pyruvate Oxidation**- Aerobic
   - Mitochondria
3. **Kreb's cycle**- Aerobic
   - Matrix of mitochondria
4. **Electron Transport Chain and Chemiosmosis-** Aerobic
   - Inner membrane of mitochondria

Overview of cellular respiration



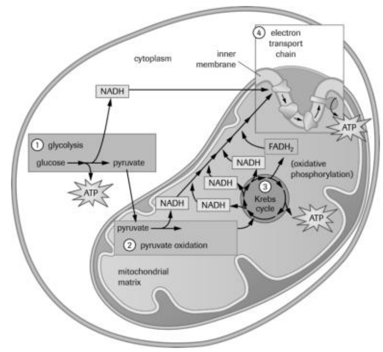
Cellular Respiration

Stage 1: Glycolysis—cytoplasm

Stage 2: Pyruvate oxidation—matrix

Stage 3: The Krebs cycle—mitochondrial matrix

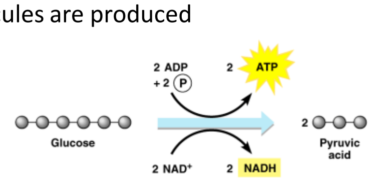
Stage 4: Electron transport and chemiosmosis—inner mitochondrial membrane



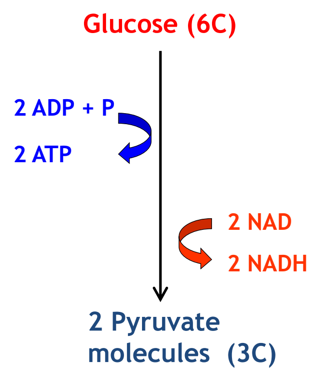
GLYCOLYSIS

Glycolysis

- Takes place in the cytoplasm of cell
- A 6-carbon **glucose** molecule is **split** into **two** molecules of **pyruvate** (a 3 carbon molecule)
- **Anaerobic** process (does not require oxygen)
  - Anna- Crazy Ex.
- **2 ATP** molecules are produced

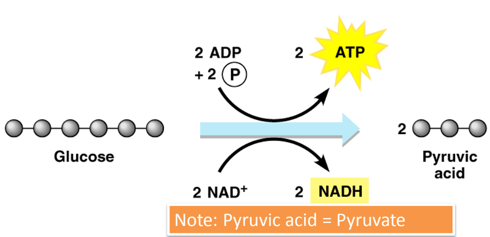


Draw:



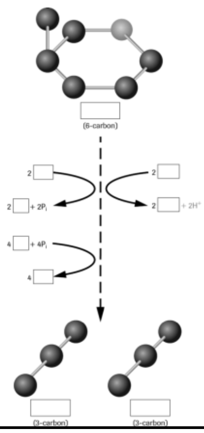
Other products of glycolysis

- Glucose is oxidized
- NAD+ is reduced
- NADH molecules are also produced



What happens to the products of Glycolysis?

- Pyruvate enters the next phase of cellular respiration (pyruvate oxidation)
- **NADH** is used in **chemiosmosis** and **electron transport**
- ATP is used by the cell



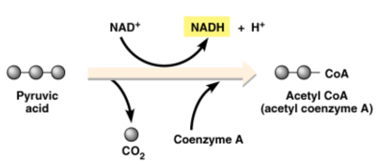
Glycolysis -

- Pyruvate
- ADP
- ATP
- Glucose
- NAD+
- NADH

AEROBIC CELLULAR RESPIRATION

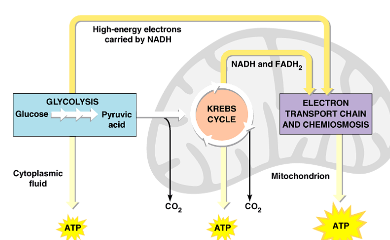
Aerobic Cellular Respiration – Pyruvate Oxidation

- Before Kreb's cycle begins- pyruvate is modified
- This takes place in the mitochondria
- One carbon is lost (in the form of CO_2) to form an **acetyl molecule**
- Acetyl joins to a carrier called coenzyme A to form **acetyl Co-A**
- NADH forms



Energy Tally

- **Glycolysis**
  - 2 ATP
  - 2 NADH

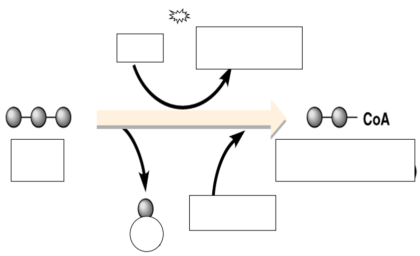


- **Pyruvate Oxidation**
  - 2 NADH

Pyruvate Oxidation – Label Diagram

Label the diagram choosing from the following words or phrases:

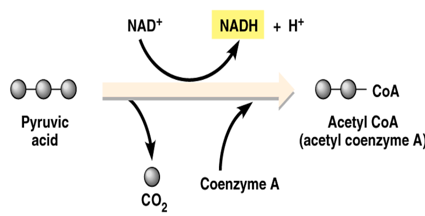
- Acetyl CoA (acetyl coenzyme A)
- Pyruvic acid
- NADH + H^+
- Coenzyme A
- CO_2
- NAD^+



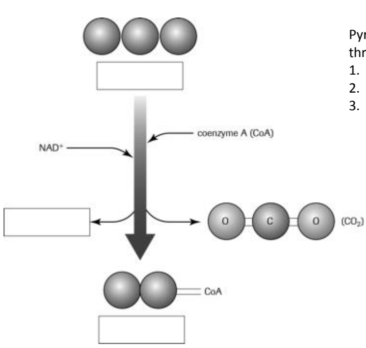
Pyruvate Oxidation – Label Diagram

Label the diagram choosing from the following words or phrases:

- Acetyl CoA (acetyl coenzyme A)
- Pyruvic acid
- NADH + H^+
- Coenzyme A
- CO_2
- NAD^+

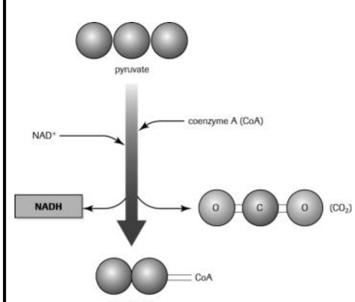


Practice - Pyruvate Oxidation



Pyruvate oxidation results in three changes to pyruvate:
1.
2.
3.

Practice - Stage 2—Pyruvate Oxidation



Pyruvate oxidation results in three changes to pyruvate:

1. A CO_2 portion is removed.
2. NAD+ is reduced to NADH
3. Coenzyme A is attached to the remaining two-carbon portion (acetyl group).

Questions

Section 7.1 Questions

1. What are the characteristics of glucose that make it well suited as an energy supply molecule within our bodies?
2. The conversion of glucose energy to ATP energy is less than 50 % efficient. In what way do birds and mammals take advantage of this inefficiency?
3. Briefly describe one cellular process that involves the use of active transport. How is ATP involved in this process?
4. Why is cellular respiration necessary?
5. What are the four stages of aerobic respiration?

- 1. Glucose has a high energy content, is relatively small, and is highly soluble.
- 2. Both animals use the waste energy (heat) to keep their bodies warm. Both organisms are warm-blooded.
- 3. Two processes that require the use of ATP are the movement of material up the concentration gradient (low to high concentration) and the movement of specific molecules through proteins in the cell membrane. Both of these processes require ATP to change the nature of the cell membrane or activate the membrane proteins.
- 4. Cellular respiration is required to convert stored food energy into the usable form of ATP.
- 5. Pyruvate Oxidation, Krebs cycle, and Oxidative Phosphorylation.

KEY

Section 7.2 Questions

1. Write an overall chemical equation for glycolysis.
2. (a) What does *glycolysis* mean?
   (b) List the final products of glycolysis.
3. As a result of glycolysis, only a small portion of the energy of glucose has been converted to ATP. In what form is the rest of the usable energy found at this stage of the process?

1. $C6H12O6 \rightarrow 2\ C3H6O3$
   (glucose) (pyruvate)

2. (a) Glycolysis refers to the breaking of the glucose molecule into two pyruvate molecules.
   (b) 2 pyruvate, 2 NADH, 2 ATP

3. NADH and the 2 pyruvate molecules

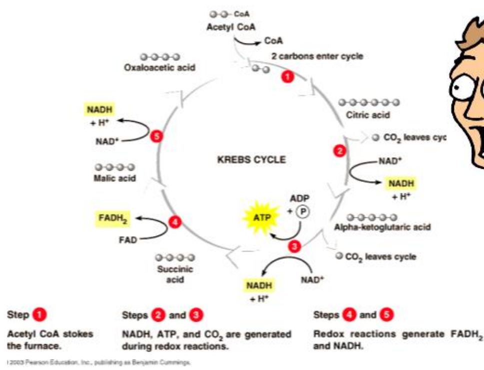
3. Kreb's Cycle

- Takes place in the **matrix** of the mitochondria
- Starts with Acetyl-CoA
- Acetyl-CoA is oxidized, NAD+ and FAD are reduced

3. Kreb's Cycle

- 2 carbons enter as **acetyl – CoA**
- Binding to **Oxaloacetate (4 carbon)**
- Forming **6** carbon molecule
- 2 Carbons leave as **CO_2**
- **2 NAD^+** are reduced to form 2 **NADH**
- **ATP** is formed
- **FAD** is reduced to form **$FADH_2$**
- Additional **NAD^+** are reduced to form **NADH**
  - **Note:** 2 pyruvate enter cycle- per glucose molecule

Kreb's Cycle



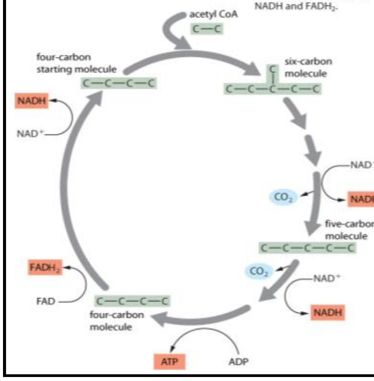


Figure 5.19 The role of the Krebs cycle is to transfer the energy that was originally stored in glucose to the reducing power of NADH and $FADH_2$.

Another Look

Practice-A-Time. Find diagram 6 and Complete the questions from workbook

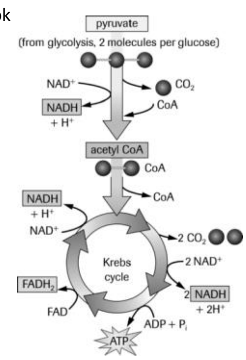
The diagram is a simplified view of stage 2 and stage 3 of aerobic respiration.

1. Circle the part of the diagram that shows <u>pyruvate oxidation</u>.

2. What happens to the carbon atoms in acetyl CoA?

3. Identify the product(s) of the Krebs cycle that provides energy for cell processes. How many molecules of this(these) are produced for every turn of the Krebs cycle?

4. Identify the product(s) that provides reducing energy for cell processes. How many molecules of this(these) are produced for every turn of the Krebs cycle?



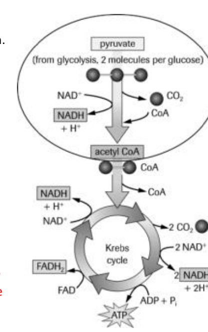
KEY

The diagram is a simplified view of stage 2 and stage 3 of aerobic respiration.

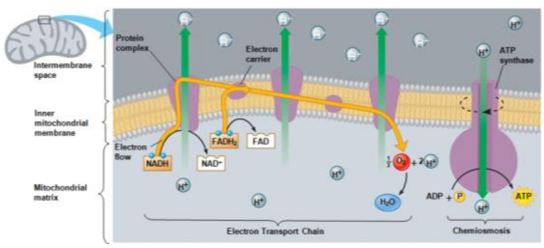
1. Circle the part of the diagram that shows pyruvate oxidation.
2. What happens to the carbon atoms in acetyl CoA?
The carbon atoms in acetyl CoA are used in the formation of CO2.

3. Identify the product(s) of the Krebs cycle that provides energy for cell processes. How many molecules of this(these) are produced for every turn of the Krebs cycle?
The product of the Krebs cycle that provides energy for cell processes is ATP. Each turn of the Krebs cycle produced 2 ATP, 6 NADH, and 2 FADH- per glucose molecule.

4. Identify the product(s) that provides reducing energy for cell processes. How many molecules of this(these) are produced for every turn of the Krebs cycle?
The products of the Krebs cycle that provide reducing energy for cell processes are NADH and FADH2. Each turn of the Krebs cycle produces 6 NADH molecules and 2 FADH2 molecules

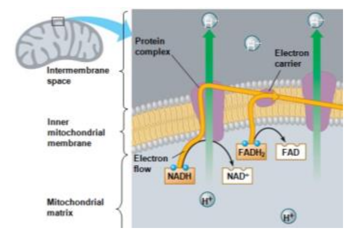


Electron Transport Chain and Chemiosmosis Overview



4. Electron Transport Chain

- The inner membrane of the mitochondria contain proteins that carry electrons
- They take electrons from **NADH** and **$FADH_2$** that are produced in glycolysis and the Kreb's cycle
- NAD+ and FAD are recycled and can be used in glycolysis and Kreb's cycle

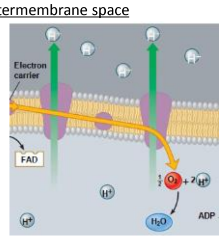


As the electrons move…

- A small amount of energy is released as they are passed from protein to protein
- This energy is used to move H+ into the intermembrane space

OXYGEN

- Is the final electron acceptor
- It is reduced to form water
- 2 H^+ + ½ O_2 + 2e^- ⟶ H_20



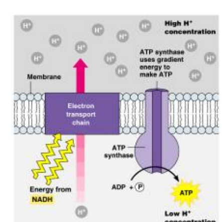
- What happens to the ETC if there is no O_2?
- A lack of oxygen causes the system to back up all the way to glycolysis because the NADH and $FADH_2$ can't be recycled. Hence why if we don't take in O_2, no ATP = cells die = you die!

Chemiosmosis

- A process that produces most of the ATP for cellular respiration
- **32 ATP** are produced per glucose in chemiosmosis

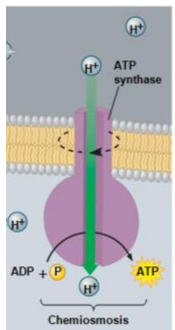
Chemiosmosis requires…

- A concentration gradient of H^+ ions

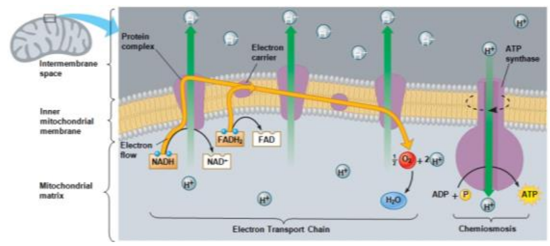


  - An ATP synthase channel which is found in the inner membrane of the mitochondria
  - Remember that electron transport causes H^+ to build up in the intermembrane space

- H⁺ ions are not allowed to diffuse back into the matrix
- The **ATP synthase channel** is the only place permeable to H⁺
- As hydrogen flow back into the matrix from the intermembrane space energy is released
- This energy is used to make ATP
- 32 per glucose



Electron Transport Chain and Chemiosmosis



Products- Cellular Respiration

- http://www.warrencountyschools.org/userfiles/2623/Classes/10683/Cell%20Respiration%20Chart.pdf

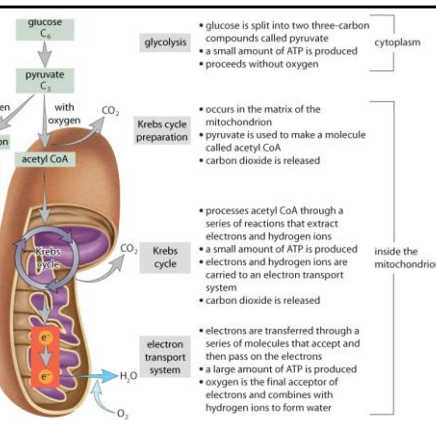


Figure 5.17 Aerobic cellular respiration includes four main stages: glycolysis, Krebs cycle preparation, Krebs cycle, and an electron transport system.

Crash course Biology Review

Practice –A- Time!

Diagram 8: Stage 4—Electron Transport

Directions. Fill in the missing labels in this outline of the mitochondrial ECT and then complete the blanks.

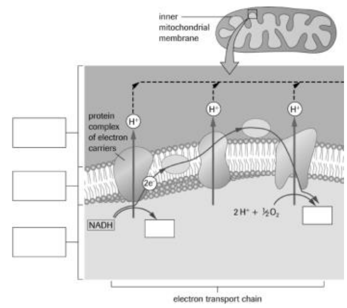
The NADH carries the electrons gained from food to the _______________________.

As these electrons are passed along carrier molecules, the energy released is used to pump

______________________________across the membrane.

The electrons are finally accepted by ______________molecules.

_____________________ is the byproduct of the electron transport chain.



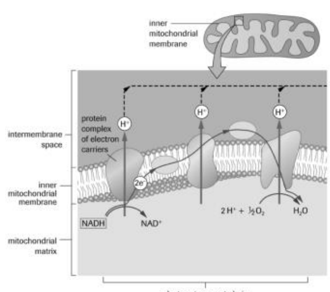
Practice –A- Time! - KEY

The NADH carries the electrons gained from food to the **electron transport chain**.

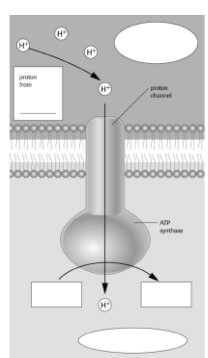
As these electrons are passed along carrier molecules, the energy released is used to pump **hydrogen ions** across the membrane.

The electrons are finally accepted by **oxygen** molecules.

Water is the byproduct of the electron transport chain.



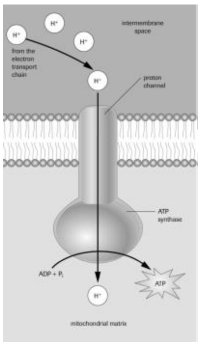
Label Diagram 9: Chemiosmosis



Fill in the missing labels in this outline of chemiosmosis.

One molecule of ATP is synthesized from ____________ and ____________as an H^+ ion passes through _________________________ into the mitochondrial matrix from the H+ reservoir in the intermembrane space.

Label Diagram 9: Chemiosmosis

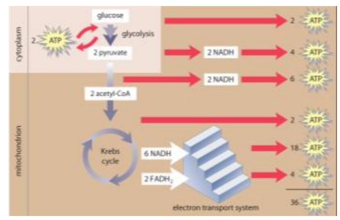


Fill in the missing labels in this outline of chemiosmosis.

One molecule of ATP is synthesized from **ADP** and **P** as an H^+ ion passes through **the ATP Synthase Channel (complex)** into the mitochondrial matrix from the H+ reservoir in the intermembrane space.

Total ATP produced:

- 2 ATP from glycolysis
- 2 ATP from Kreb's
- 32 ATP from the electron transport and chemiosmosis
- Total = **36 ATP per glucose**



Section 7.3 Questions (Page 220) #1-10 Key

1. Arrange the following types of cells in order of increasing number of mitochondria in the cytoplasm: nerve cell, skin cell, fat cell, heart muscle cell. Provide a rationale for your sequence.

2. (a) In eukaryotic cells, where does glycolysis occur?
(b) What two products of glycolysis may be transported into mitochondria for further processing?

- 1. Heart muscle cells have the most mitochondria as they require the most energy to contract (approximately 70 times per minute). Nerve cells have the second most mitochondria as they need to maintain the membrane potential necessary to conduct a nerve impulse. Skin cells are next as their functions require little energy, followed by fat cells, which provide insulation and nutrient storage for the body and therefore contain few mitochondria.

2. (a) Glycolysis occurs in the cytoplasm of eukaryotic organisms.

(b) The two products of glycolysis that enter the mitochondria are pyruvate and NADH.

Page 220 #3

3. Describe two functions that mitochondrial membranes serve in energy metabolism.

3. Mitochondrial membranes perform several vital roles in energy metabolism. The outer membrane of the mitochondria acts as a cell membrane and houses transport proteins that allow substances in and out of the mitochondria. For instance, the outer membrane houses transport proteins, which move the two pyruvate molecules formed during glycolysis from the cytoplasm into the mitochondria, where they undergo pyruvate oxidation before entering the Krebs cycle. The inner membrane of mitochondria serves several functions. It divides the mitochondrion into two compartments: the matrix and the intermembrane space. Both of these areas play important roles in energy metabolism. For instance, the matrix is where most of the Krebs cycle reactions take place and the intermembrane space is where protons are pumped as they are produced by the electron transport chain. These protons are used to create the electrochemical gradient that stores free energy, which is necessary to create ATP. The inner membrane of mitochondria also houses the numerous proteins and cofactors required ultimately to generate ATP. NADH hydrogenase, cytochrome b-c1 complex, cytochrome oxidase complex, and ATP synthase are all found in the inner mitochondrial membrane.

4. Why is aerobic cellular respiration a more efficient energy-extracting process than glycolysis alone?

- 4. Glycolysis is not considered a highly effective energy-harnessing mechanism because it transfers only about 2.1 % of the free energy available in one molecule of glucose into ATP. Most of the energy is still trapped in two pyruvate molecules and 2 NADH molecules. Aerobic respiration further processes the pyruvate and NADH during pyruvate oxidation, the Krebs cycle, chemiosmosis, and electron transport. During pyruvate oxidation, the pyruvate and NADH are transformed into two molecules each of acetyl-CoA, hydrogen, carbon dioxide, and NADH. Acetyl-CoA enters the Krebs cycle and increases ATP production. By the end of the Krebs cycle, the entire original glucose molecule is consumed. It has been transformed into 6 CO2 molecules, which are released as waste, and energy, which is stored as 4 ATP molecules and 12 reduced coenzymes (NADH and FADH2). Most of the free energy stored in NADH and FADH2 will be transformed to ATP in the final stage of aerobic respiration, chemiosmosis, and electron transport. By the end of aerobic respiration, all the energy available in glucose has been harnessed.

5. (a) What part of a glucose molecule provides electrons in cellular respiration?
(b) Describe how electron transport complexes set up a proton gradient in response to electron flow.
(c) How is the energy used to drive the synthesis of ATP?
(d) What is the name of this process?
(e) Who discovered this mechanism?

5. (a) The hydrogens

(b) The electron transport chain creates a proton gradient by pumping electrons from the matrix to the inner membrane. The membrane becomes impermeable to protons due to their high concentration and forces the protons to move through proton channels to form ATP.

(c) The potential energy stored in this gradient causes the protons to move through special protein channels, and the energy released is used to form ATP.

(d) This process is termed chemiosmosis or oxidative phosphorylation.

(e) Chemiosmosis was discovered by Peter Mitchell in 1961.

6. (a) Distinguish between an electron carrier and a terminal electron acceptor.
(b) What is the final electron acceptor in aerobic respiration?

7. Explain how the following overall equation for cellular respiration is misleading:

$$C_6H_{12}O_6 + 6\,O_2 \longrightarrow 6\,CO_2 + 6\,H_2O$$

6. (a) An electron carrier is a molecule that can accept and donate electrons from and to various enzymes. A terminal electron acceptor is the final substance that receives electrons in an oxidation-reduction reaction.

(b) The final electron acceptor in aerobic respiration is oxygen.

7. The equation does not show the formation of energy. It also does not include the fact that water is required on the reactant side of the equation.

8. Explain why CO_2 does not serve as a source of free energy in living systems.

9. (a) Explain the role of $FADH_2$ in the electron transport chain.
(b) Explain why $FADH_2$ does not generate as many ATP molecules as NADH does.

10. Aerobic cellular respiration stops if no oxygen is present. Explain why.

8. CO2 cannot serve as a source of free energy because the carbon atoms are fully oxidized; there are no H atoms bonded to any of the C valence electron positions. Thus, its chemical potential energy is 0 kJ/mole. The bond in ATP is easy to break and releases abundant energy.

9. (a) FADH2 is an electron carrier. In the electron transport chain, FADH2 donates electrons.

(b) FADH2 does not generate as many ATP molecules as NADH because it has a lower energy content and it enters the electron transport chain later in the process.

10. Oxygen is necessary for aerobic cellular respiration because it is the final acceptor of electrons in the electron transport chain.

ANAEROBIC RESPIRATION

Anaerobic Respiration

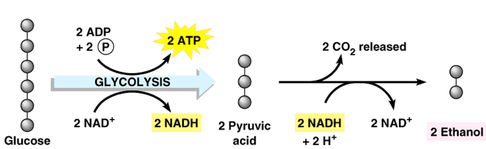
- Refers to respiration without oxygen
- Without oxygen NADH and $FADH_2$ cannot get rid of their electrons
- This means there is no NAD^+ for glycolysis or Kreb's cycle

When oxygen levels decrease…

- NADH and $FADH_2$ give their electrons to another acceptor instead of oxygen
- This allows NAD^+ and FAD to be available for glycolysis (which produces a small amount of ATP

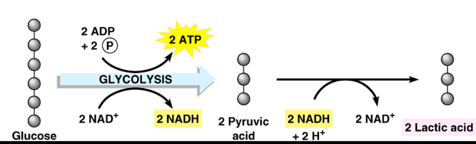
In Yeast Cells

- Anaerobic respiration produces ethanol, and is called **fermentation**
- Fermentation has commercial uses: breweries, bread making, wine making



In animal cells

- Anaerobic respiration produces **lactic acid**
- When cells are not receiving enough oxygen, muscles become cramped due to a build of lactic acid
- When oxygen becomes available, lactic acid is converted back into <u>pyruvate</u>
- Pyruvate then continues to Kreb's cycle
- Anaerobic respiration is useful because it provides a short burst of energy when oxygen is not available
- However, it can only produce a small amount of ATP compared with aerobic respiration (2 ATP)



Lactic acid threshold

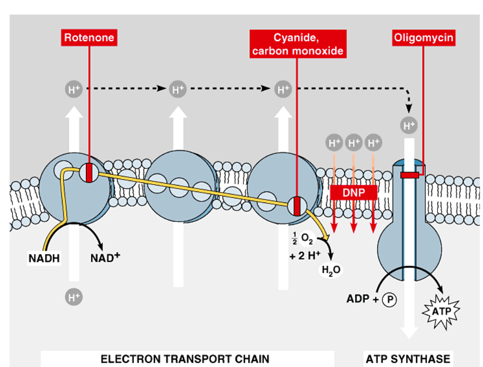
- Value of exercise intensity at which blood lactic acid concentration begins to increase sharply
  - Exercising beyond threshold may limit duration of exercise
    - Due to pain, muscle stiffness, and fatigue
- Athletic training improves blood circulation and efficiency of O_2 delivery to body cells
  - Result:
    - Decrease in lactic acid production
    - Increase in lactic acid threshold

Supplements and toxins

- Creatine phosphate
  - May serve as an E source by donating its phosphate to ADP
  - Occurs naturally in body and many foods
  - Athletes consume compound to produce more ATP in muscles
  - Compound may also buffer muscle cells and delay onset of lactic acid fermentation
  - Potential harmful side – effects are possible

Metabolic Poisons

- Some poisons interfere with the electron transport chain
- Causes death quickly because electron flow stops, which stops all stages of cellular respiration
- Examples:
  - Cyanide
  - Hydrogen sulfide



Section 7.4 Review Questions - Key

1. List two differences between aerobic respiration and fermentation.

2. A student regularly runs 3 km each afternoon at a slow, leisurely pace. One day, she runs 1 km as fast as she can. Afterward, she is winded and feels pain in her chest and leg muscles. What is responsible for her symptoms?

1. Two differences in aerobic respiration and fermentation are as follows:
- Aerobic respiration yields 36 ATP molecules per glucose molecule, whereas fermentation yields 2 ATP molecules per glucose molecule.
- Aerobic respiration produces water and carbon dioxide, whereas fermentation produces ethanol or lactic acid.

2. The student will feel soreness in her chest and legs due to the buildup of lactic acid in her muscle tissues.

3. What role does alcohol fermentation play in the food industry?

4. Compare and contrast the use of anaerobic and aerobic microbes in waste treatment.

5. Define *maximum oxygen consumption, VO_2 max.*

3. Fermentation is used to produce alcoholic beverages, bread, and certain types of cheese.
4. Both types of respiration can be used in waste treatment. Aerobic respiration is quick but expensive. Anaerobic respiration takes longer but is inexpensive and capable of removing toxic properties from the waste that aerobic respiration cannot.
5. Maximum oxygen consumption, VO2 max, is a measure of a body's capacity to generate the energy required for physical activity. It is the maximum volume of oxygen that the cells of the body can remove from the bloodstream in 1 min per kilogram of body mass while the body experiences maximal exertion.

6. (a) Determine the value of the lactic acid threshold from **Figure 10**.
(b) What does this value mean?

9. Lactic acid fermentation is used in the food industry. Use Internet and print sources to answer the following questions.
(a) What foods depend on lactic acid fermentation?
(b) What microbes are used in each food in (a).

www.science.nelson.com GO

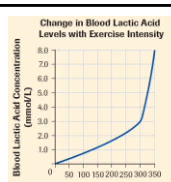


Figure 10

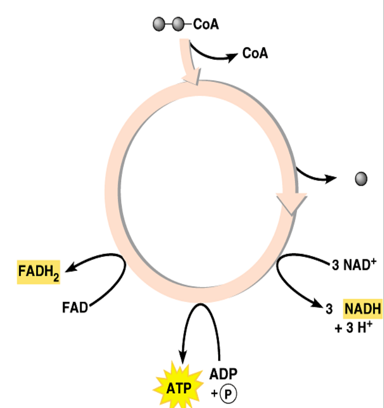
6. (a) The lactate threshold is 3.0 mmol/L.
(b) This value refers to a threshold. Below this level, an individual can sustain exercise for long periods; above the threshold, an individual cannot sustain exercise for long periods. Once the lactate threshold is passed in the body, the lactate concentration in the blood increases sharply, which causes pain, muscle stiffness, and fatigue.

9. (a) The production of wine, cheese, bread, yogurt, pickles, and some meats depends on lactic acid fermentation.
(b) Different species of bacteria are used to produce yogurt, fungus produces cheeses, yeasts and moulds produce meats such as salami and chorizo, bacteria make pickles and wine, and bacteria and yeasts produce breads.

Simplistic View of Krebs Cycle

Label the diagram choosing from the following words or phrases:

- CoA
- NADH
- ATP
- $FADH_2$

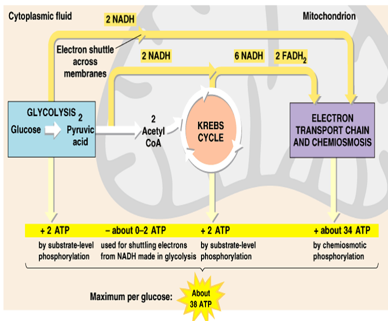


Aerobic Respiration Energy Balance Sheet

Use Nelson page 219

Label the diagram choosing from the following words or phrases:

- •Cytoplasmic fluid
- •Glycolysis: glucose → pyruvic acid
- •2NADH X 2
- •6 NADH
- •2 $FADH_2$
- •+ 2 ATP X 2
- •+ about 34 ATP
- •By chemisosmotic phosphorylation
- •About 38 ATP
- •Krebs Cycle
- •Electron Transport Chain and Chemiosmosis
- •Mitochondrion
- •Electron shuttle across membranes
- •2 Acetyl CoA

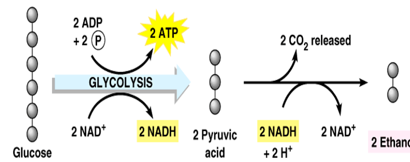


Alcohol Fermentation

Use Nelson page 221

Label the diagram choosing from the following words or phrases:

- •Glycolysis
- •Glucose
- •2 ATP
- •2 NADH X 2
- •2 pyruvic acid
- •2 ethanol
- •2 CO_2 released
- •2 ADP + 2 P

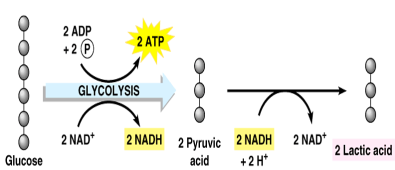


Lactic Acid Fermentation

Use Nelson page 224

Label the diagram choosing from the following words or phrases:

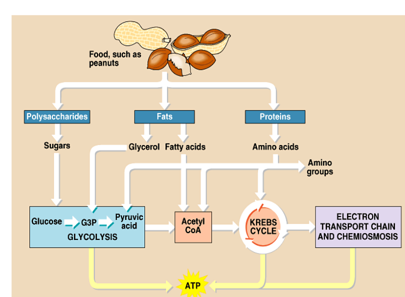
- •Glycolysis
- •Glucose
- •2 ATP
- •2 NADH X 2
- •2 pyruvic acid
- •2 lactic acid
- •2 ADP + 2 P



Cellular Respiration and Other Sources of Energy

Label the diagram choosing from the following words or phrases:

- •Krebs cycle
- •ATP
- •Electron Transport Chain and Chemiosmosis



Cellular Respiration and Biosynthesis

Label the diagram choosing from the following words or phrases:

- Krebs cycle
- ATP
- Cells, tissues, organisms