How Cells Harvest Chemical Energy 6

You need to eat and breathe because your cells need food and oxygen for energy. In every cell in your body, organic molecules and oxygen interact in a complex process called cellular respiration. In this process, food molecules such as glucose are broken down and the energy contained in their chemical bonds is used to make ATP. The ATP made in cellular respiration is then used to drive cellular activities. Right now, ATP produced in cellular respiration is being used to generate the nerve impulses from your eyes to your brain, to move your muscles, and to drive your heartbeat. This chapter explains how your cells harvest the energy that keeps you alive.

Organizing Your Knowledge

Exercise 1 (Introduction – Module 6.3)

Review the basic terms and concepts of cellular respiration by filling in the blanks below.

Right now, you are breathing at a steady rate of 12 to 20 breaths per minute. Breathing, or [1] ________________, is necessary for life, but why? Breathing allows the body to take in [2] ________________ gas and expel waste [3] ________________. Your breathing is closely related to [4] ________________, the aerobic harvest of the energy in food molecules by cells. Most of the time, most cells acquire energy by taking in both [5] ________________ and [6] ________________ from the blood. These two substances interact, the sugar is broken apart, and [7] ________________ and [8] ________________ are produced. In the process, some of the energy is stored in molecules of ________________, which provide the energy for body activities. To make enough ATP for their needs, average human beings must take in food that provides about ________________ kilocalories (kcal) of energy per day.

When using oxygen, cells are said to function [11] ________________. Cells making ATP this way capture about [12] ________________ of the energy in glucose. For short bursts, cells can make ATP [13] ________________ — that is, without using oxygen. This process is much less efficient; it only banks about [14] ________________ % of the energy in glucose. But it is useful during intense bursts of activity, such as sprinting or heavy lifting.

Muscles contain a mixture of two kinds of cells, or fibers, specialized either for aerobic or anaerobic ATP production. [15] ________________ fibers can sustain repeated, long contractions, by continuously producing ATP via [16] ________________ cellular respiration. Slow fibers are long and [17] ________________, maximizing their surface area and contact with nearby [18] ________________ that deliver oxygen. They have many ________________, the structures where aerobic ATP breakdown occurs. And they are rich in [20] ________________, a red protein related to hemoglobin that supplies O_2

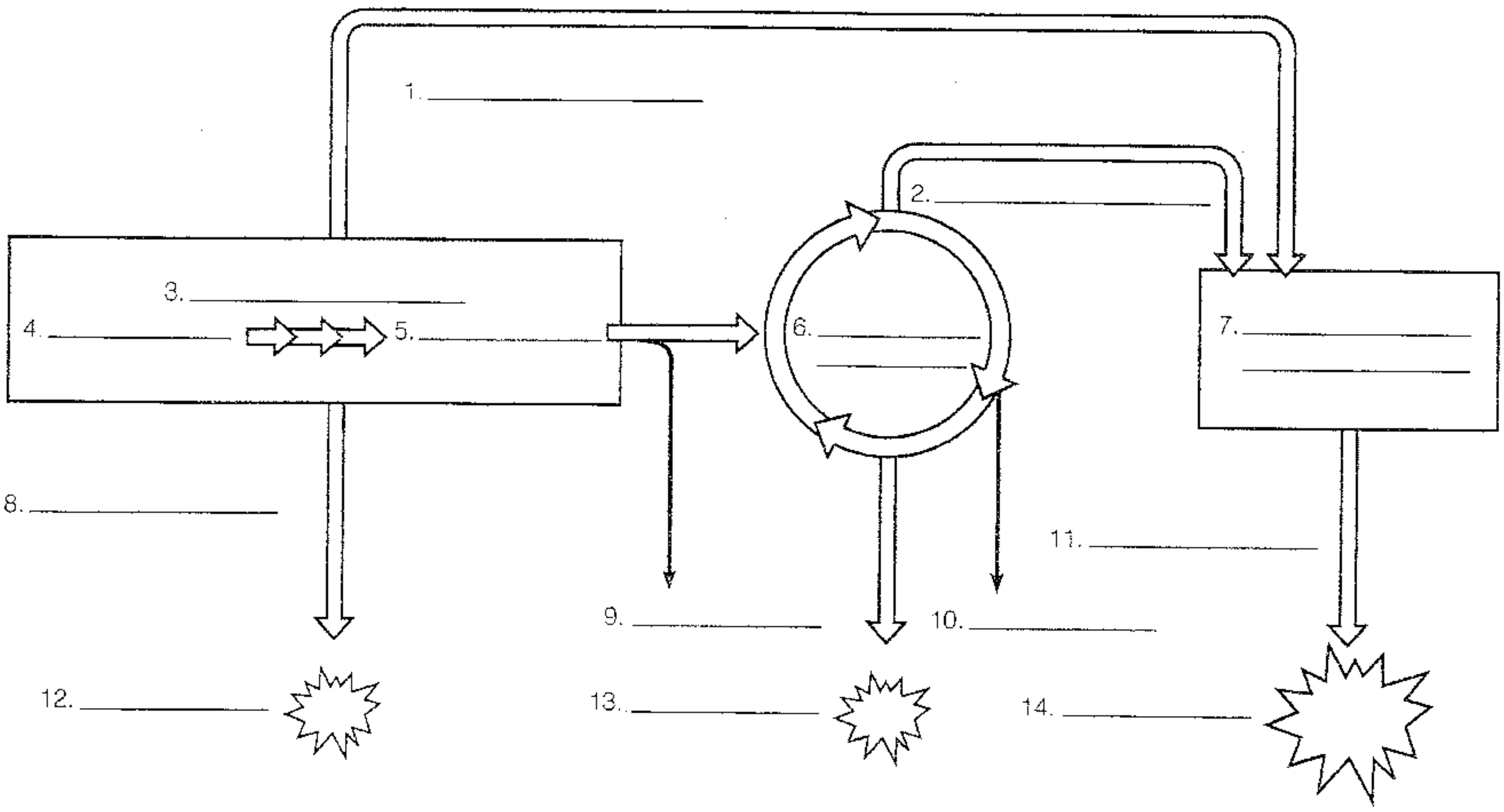
molecules. The [21]________________ meat of a turkey leg consists mostly of myoglobin-rich slow muscle fibers. The white meat of a turkey breast, on the other hand, consists mostly of [22]________________ muscle fibers, which are specialized for quick, powerful bursts of flight. These fibers are [23]________________ and are more powerful than slow fibers, having [24]________________ mitochondria and [25]________________myoglobin than slow fibers. During intense activity, when the blood cannot deliver O_2 fast enough for aerobic cellular respiration, fast fibers can function anaerobically, making small amounts of ATP without oxygen. They don't completely break down [26]________________, and therefore do not capture all its energy, and instead of producing CO_2 they make [27]________________, which makes muscles [28]________________ and fatigue. This is why [29]________________ fibers are best at producing short bursts of power.

Human muscles contain both kinds of fibers. Their proportions vary from muscle to muscle, and person to person. A runner whose leg muscles are primarily composed of [30]________________ fibers would be more likely to excel in distance events, while an individual with an abundance of [31]________________ fibers might make a better sprinter.

Exercise 3 (Module 6.8)

Web/CD Activity 6A *Overview of Cellular Respiration*

The illustration in Module 6.8 introduces the three stages of cellular respiration. After studying it, see if you can label the diagram below without referring to the text. Include **electron transport chain and chemiosmosis, pyruvic acid, mitochondrion, CO_2, high-energy electrons carried by NADH, Krebs cycle, glycolysis, cytoplasmic fluid, ATP, glucose,** and **NADH and $FADH_2$**. (Note: 3, 6, and 7 are processes, 8 and 11 are places, and the rest are inputs and outputs.)



Exercise 4 (Module 6.9)

Web/CD Activity 6B *Glycolysis*

Glycolysis is the first of three steps in cellular respiration. Review glycolysis by matching each phrase on the right with a term on the left. Some terms are used twice.

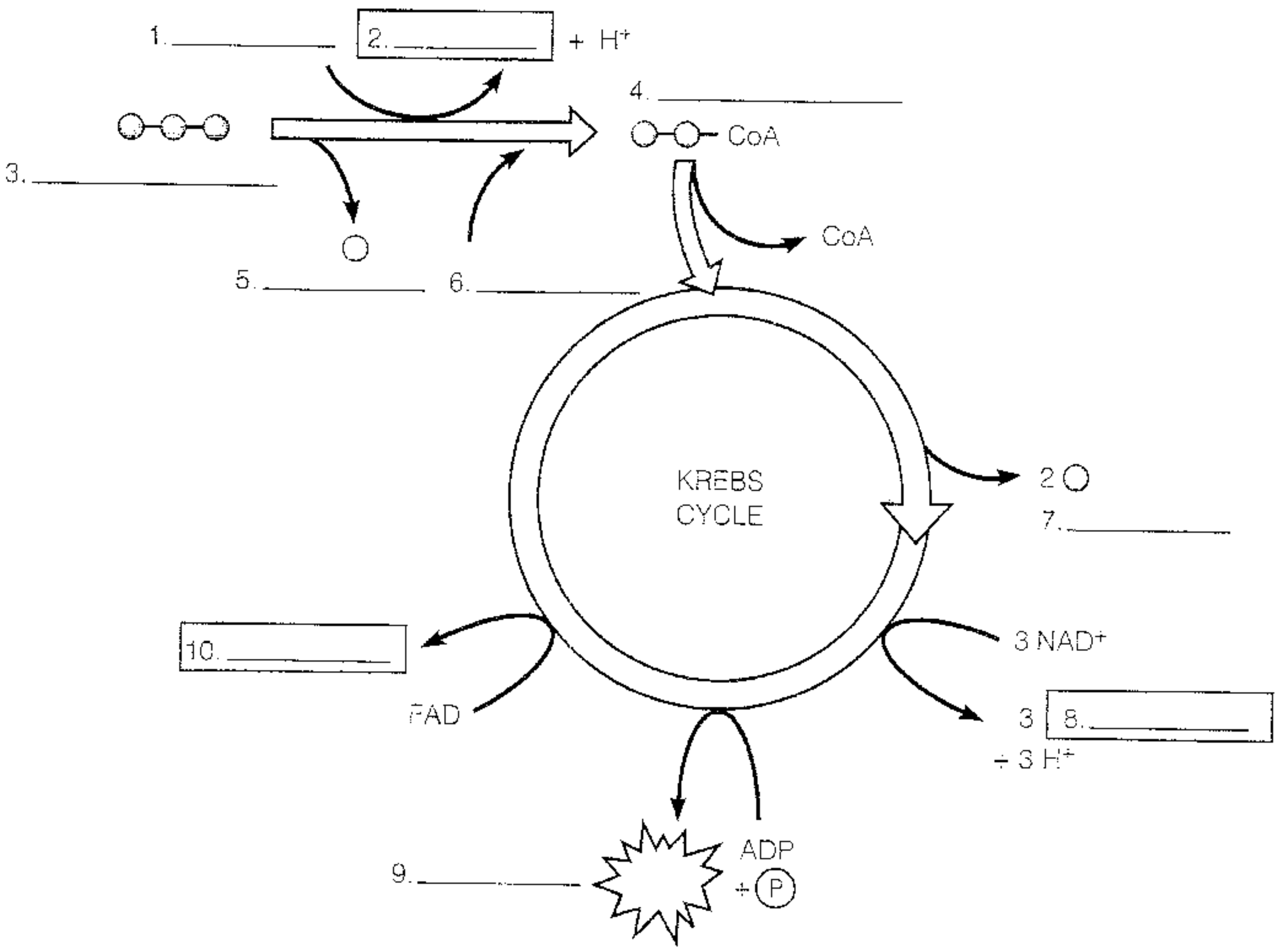
A. NADH
B. Pyruvic acid
C. ATP
D. NAD^+
E. Glucose
F. Glycolysis
G. ADP and P
H. Oxygen
I. Intermediate

_____ 1. Compound formed between glucose and pyruvic acid
_____ 2. Not involved in glycolysis
_____ 3. Fuel molecule broken down in glycolysis
_____ 4. Produced by substrate-level phosphorylation
_____ 5. Invested to energize glucose molecule at start of process
_____ 6. Reduced as glucose is oxidized
_____ 7. Glucose converted to two molecules of this
_____ 8. Assembled to make ATP
_____ 9. "Splitting of sugar"
_____ 10. Carries hydrogen and electrons from oxidation of glucose

Exercise 5 (Modules 6.10 – 6.11)

Web/CD Activity 6C *The Krebs Cycle*

Pyruvic acid from glycolysis is chemically altered and then enters the Krebs cycle, a series of steps that completes the oxidation of glucose. The energy of pyruvic acid is stored in NADH and $FADH_2$. To review these processes, fill in the blanks in the diagram below. (Try to do as many as you can without referring to the text.) Include the following: NAD^+, **pyruvic acid**, CO_2, $FADH_2$, **NADH**, **coenzyme A**, **ATP**, and **acetyl CoA**.



Exercise 6 (Module 6.12)

Web/CD Activity 6D *Electron Transport and Chemiosmosis*

Circle the correct words or phrases in parentheses to complete each sentence.

The [1] *(final, second)* stage of cellular respiration is the electron transport chain and synthesis of [2] *(glucose, ATP)* by [3] *(chemiosmosis, active transport)*. The electron transport chain is a sequence of [4] *(electron, proton)* carriers built into the [5] *(outer, inner)* membrane of the mitochondrion. Molecules of [6] *(ADP, NADH)* bring hydrogens and electrons to the chain from glycolysis and [7] *(the Krebs cycle, chemiosmosis)*. The electrons move along the chain from carrier to carrier in a series of redox reactions, finally joining with [8] *(H_2O, CO_2, O_2)* and H^+ from the surrounding solution to form [9] *(H_2O, CO_2, O_2)*. Energy released by the electrons is used to move protons—[10] *(H^+ ions, ADP molecules)*—by [11] *(active transport, passive transport)* into the space between the inner and outer mitochondrial membranes.

The buildup of protons in the intermembrane space—a proton gradient—constitutes [12] *(kinetic, potential)* energy that the cell can tap to make [13] *(ATP, glucose)*. The concentration of protons tends to drive them back through the membrane into the [14] *(inner* *compartment of the mitochondrion, cytoplasm of the cell)*, but protons can cross the membrane only by passing through special protein complexes, called [15] *(coenzyme As, ATP synthases)*. As these complexes allow protons back through the membrane, their enzymes harness the energy of the moving protons to phosphorylate [16] *(NAD, ADP)* and make [17] *(NADH, ATP)*. Thus, electron transport and chemiosmosis transform [18] *(most, some, a small portion)* of the energy extracted from glucose into the phosphate bonds of ATP.

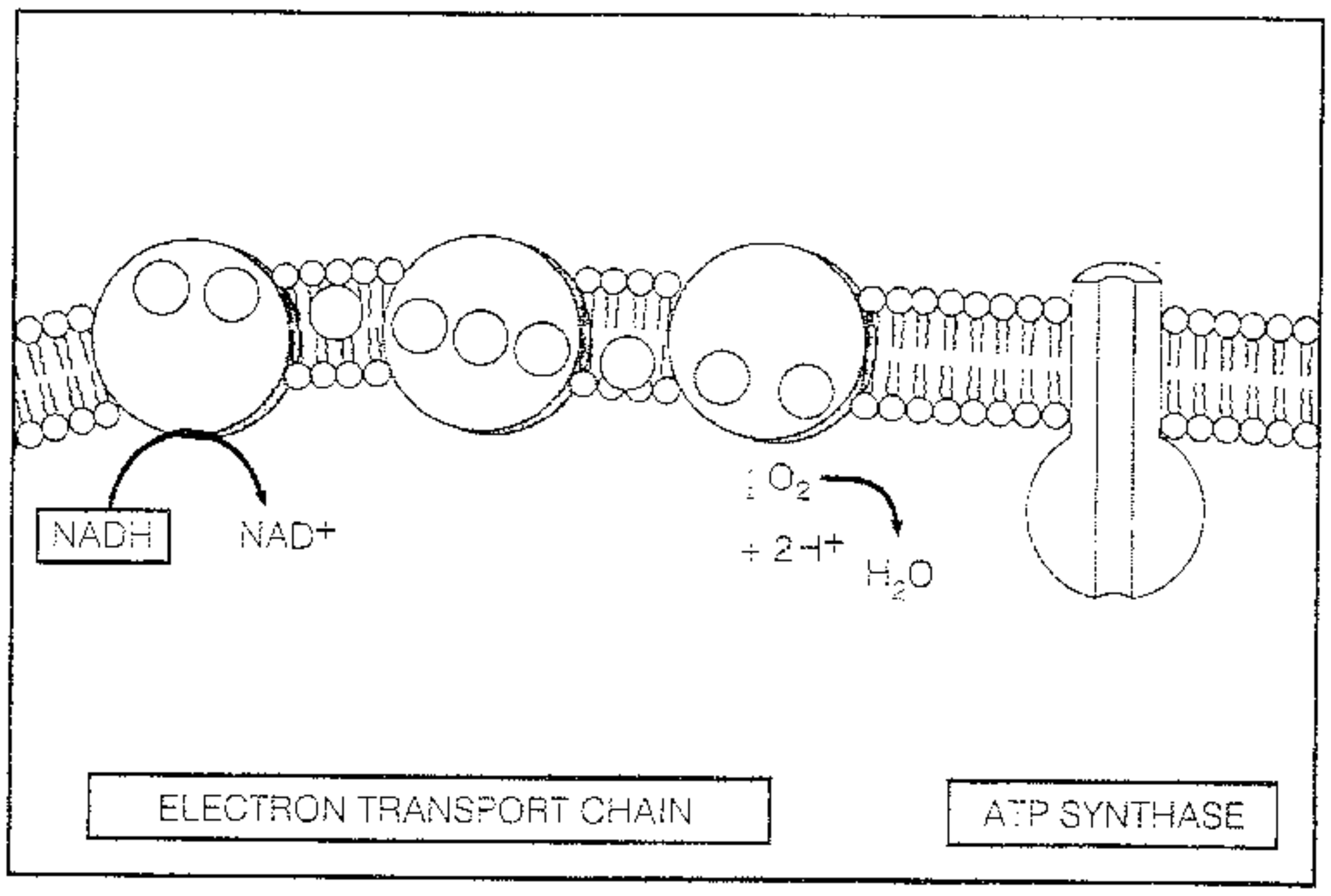
Exercise 7 (Modules 6.12 – 6.13)

Web/CD Activity 6D *Electron Transport and Chemiosmosis*

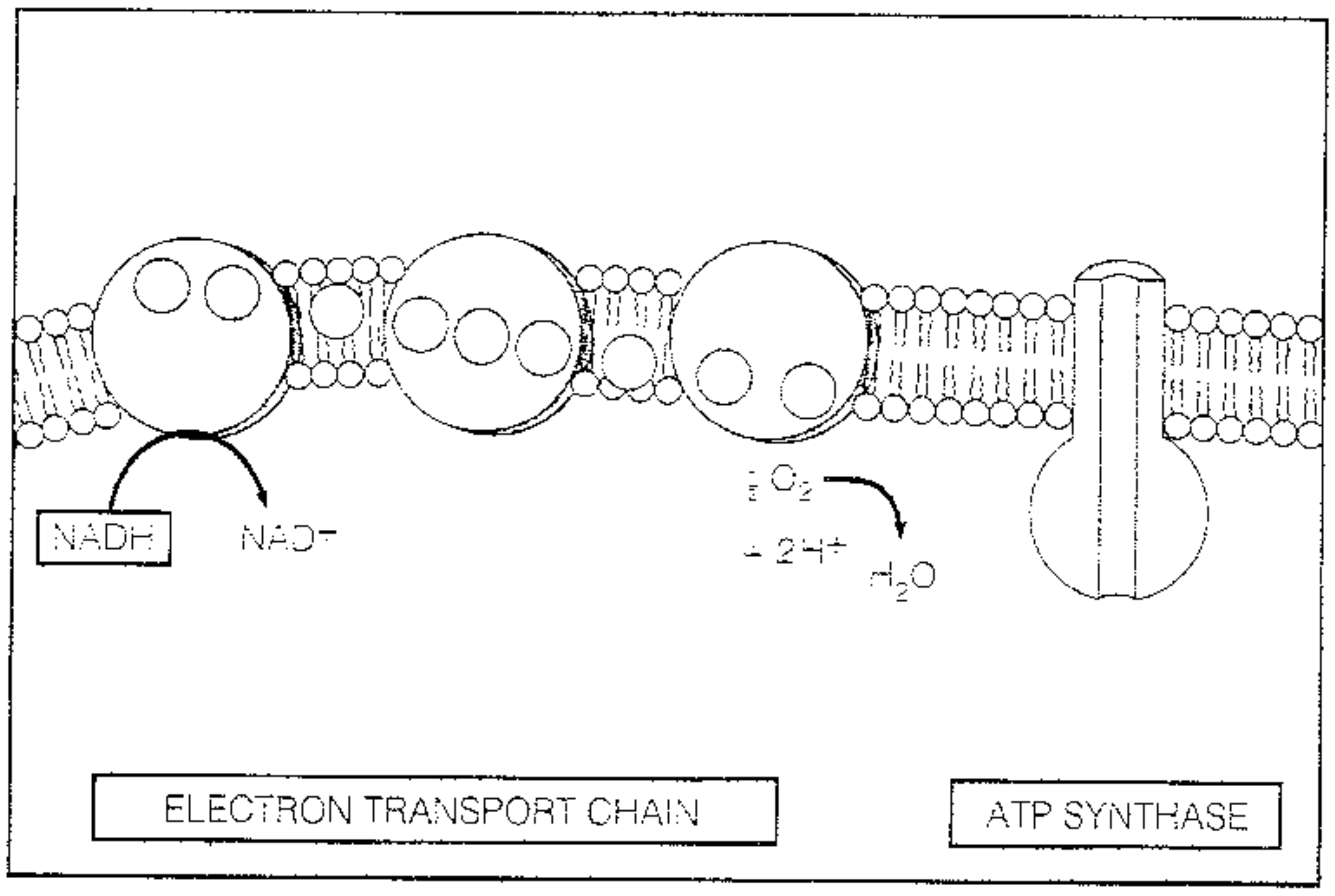
These diagrams will help you review electron transport, chemiosmosis, and how poisons disrupt them. In the first diagram, show how the processes work normally. Trace movement of an electron with an orange arrow, movement of H^+ ions (active transport and chemiosmosis) with black arrows, and formation of ATP with a pink arrow.

In the second diagram, draw arrows showing the movement of electrons and H^+ and the formation of ATP, as in the first diagram. Then draw a red line where each poison acts, to show how each of the poisons short-circuits the normal processes. Label the poisons **rotenone, cyanide, carbon monoxide, DNP,** and **oligomycin.**

1. Normal electron transport and chemiosmosis:



2. Effects of poisons:



Exercise 8 (Modules 6.8 – 6.14)

Web/CD Activity 6A *Overview of Cellular Respiration*
Web/CD Activity 6B *Glycolysis*
Web/CD Activity 6C *The Krebs Cycle*
Web/CD Activity 6D *Electron Transport and Chemiosmosis*

Check your overall understanding of cellular respiration by matching each of the phrases below with one of the three stages of the process. Use G for glycolysis, K for Krebs cycle, and E for electron transport and chemiosmosis.

_____ 1. Generates most of the ATP formed by cellular respiration
_____ 2. Begins the oxidation of glucose
_____ 3. Occurs outside the mitochondrion
_____ 4. Produces 4 ATPs per glucose by substrate-level phosphorylation, but 2 ATPs per glucose are used to get it started
_____ 5. Oxidizes NADH and $FADH_2$, producing NAD^+ and FAD
_____ 6. Carried out by enzymes in the matrix (fluid) of the mitochondrion
_____ 7. Here electrons and hydrogen combine with O_2 to form H_2O
_____ 8. Occurs along the inner mitochondrial membrane
_____ 9. Generates most of the CO_2 produced by cellular respiration
_____ 10. $FADH_2$ and NADH deliver hydrogen ions and electrons to this stage
_____ 11. ATP synthase makes ATP
_____ 12. Reduces NAD^+ and FAD, producing NADH and $FADH_2$

Exercise 9 (Module 6.15)

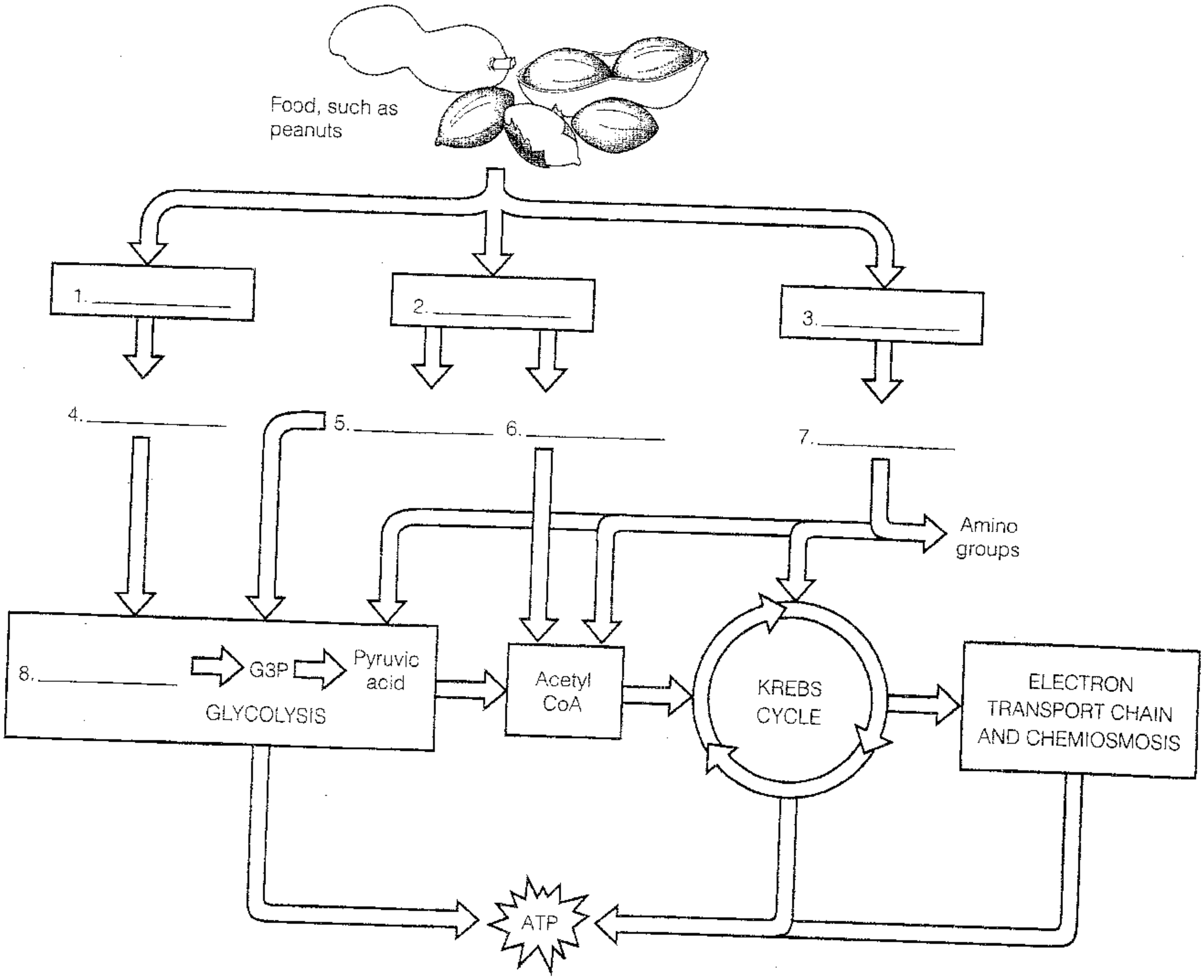
Web/CD Activity 6E *Fermentation*

Review fermentation by filling in the blanks below.

1. _______________ anaerobes can make their ATP by fermentation or aerobic respiration.
2. _______________ is an organism that normally uses aerobic respiration to produce ATP, but it can generate ATP without oxygen, via alcoholic fermentation.
3. Fermenters replenish their supply of NAD^+ by using NADH to oxidize _______________ acid.
4. When oxygen is scarce, human _______________ cells can make ATP by lactic acid fermentation.
5. Fermentation enables cells to make ATP in the absence of _______________ .
6. For every molecule of glucose consumed, glycolysis produces two molecules of pyruvic acid, two molecules of ATP, and two molecules of _______________ .
7. The waste products of alcoholic fermentation are _______________ and carbon dioxide.
8. _______________ acid fermentation is used to make cheese and yogurt.
9. Fermentation generates two _______________ molecules for every molecule of glucose consumed.
10. A cell can use _______________ to generate a small amount of ATP, but it must somehow recycle its supply of NAD^+.
11. Like aerobic respiration, alcoholic fermentation produces _______________ gas as a waste product.
12. Strict _______________ require anaerobic conditions and are poisoned by oxygen.

Exercise 10 (Module 6.16)

Review the molecules that can be used as fuel for cellular respiration by writing their names in the blanks in this diagram. Include **glucose, amino acids, fats, fatty acids, proteins, sugars, polysaccharides,** and **glycerol.**



Exercise 11 (Module 6.17)

Show how a cell obtains organic molecules for biosynthesis of proteins, polysaccharides, and fats by drawing the missing arrows on this diagram.