Introduction to Biology
Respiration Chapter 5

Introduction

Being alive is work. Cells organize small organic molecules into polymers such as the proteins, carbohydrates, and so forth you studied last week. Cells move substances across membranes, change shape, grow and reproduce. Cells have complex structures that are intrinsically unstable; work is required to maintain this structure and order. To do work, cells must extract energy from nutritive molecules. Plants and animals both utilize the process of cellular respiration to obtain energy from complex molecules. The chemical reactions involved in this process release energy which is harnessed at the cellular level in the form of ATP. The summary chemical equation for this process is:

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

Note the relationship of this equation to the photosynthesis equation. One is the reverse of the other. This relationship expresses the fact that these two processes are inextricably linked in the living world. Aerobic cellular respiration is dependent on the products of photosynthesis and photosynthesis utilizes the products of cellular respiration.

The process of respiration takes place over two distinctly different regions of the cell. First a six carbon saccharide -glucose- is break down into 2 three carbon organic acids. Step one takes place in the cytoplasm of a eukaryotic cell yielding a net of 2 ATP's and some NADH. Chapter 7 we discussed the electron bus being NADPH. The process of respiration uses a similar electron bus: NADH. The second step in the respiratory process occurs when the three carbon organic acids produced in the first pathway of glucose breakdown (Glycolysis) is taken into the mitochondria where upon it is further degraded yielding electrons and H^+ ions necessary to drive the third stage of respiration. Electrons stripped from carbon during the first and second stages of the respiratory process are channeled into a series of trans-spanning membranes (commonly referred to as the electron transport system) located between the inner and outer mitochondrial spaces. Here the electrons do work: pumping H^+ ions against a concentration gradient. Finally, these electrons are absorbed by O_2 forming H_2O as H^+ stream through a ATPase channel protein.

Course Outcomes

Describe cellular respiration and how respiration relates to photosynthesis
Describe the differences between aerobic and anaerobic respiration

Learning Goals

- Understand where "energy" for cellular functions originates.
- Understand the relationship between photosynthesis and cellular respiration
- Know the steps in aerobic respiration and where each occurs in the cell.
- Understand the basic features of oxidation-reduction reactions.
- Be able to describe the role of the step wise break down (extraction of electrons) of glucose in the production of ATP and account for the location and number of each CO_2 produced during aerobic and anaerobic respiration.
- Master the "accounting sheet" for ATP formation found in the

cytoplasm and mitochondria.

Assignments:

1. Read Chapters Chapter 8 in your text.

Note that some portions of Chapter 7 and 8 are color-coded indicating the amount of detail in the presentation. You will not be responsible for the biochemical to biochemical detailed level of understanding. You will, however, be held responsible for the information presented in the study guides. Study guide information is fair game for lecture tests. Although you may not be asked to reproduce these biochemical pathways compound by compound you should be familiar with each of the processes (ETS and chemosmostic principle, ... etc.), such as starting and end compounds, and where energy is produced and required in the form of ATP. You should also be able fill in the ATP accounting sheet provide with this week's study guide set.

3. Go to the following Web site:

Study this page to augment your information and understanding of cellular respiration.

http://www.emc.maricopa.edu/faculty/farabee/BIOBK/BioBookGlyc.html

This link has a flow cartoon of the electron transport system. I strongly recommend this site.

http://faculty.uca.edu/~johnc/respir1440.htm

Great non-technical web site with diagrams and hot links to side bars for information amplification.

http://faculty.nl.edu/jste/cellular_respiration.htm

This site is fairly technical and to the point. If you have choose not to purchase the text book This chapter can easily substitute.

Chapter 8 THE ENERGY CONSUMING PROCESS OF RESPIRATION

INTRODUCTION

There are 3 reasons for glucose metabolism:

1) All cells metabolize glucose

a) Nerve cells in brains use glucose exclusively

2) Glucose metabolism is less complex than metabolism of other organic molecules

3) Cells converts other organic molecules to glucose

a) Sugars, fats and to some extent proteins can release energy by **oxidation**

b) Some energy is trapped as ATP

c) Sugars and proteins have about **4 k-calories/grams** of stored energy

1. Fats have about **9 kcal/gram of energy**
2. If Sugar is burned in a one step process it will release 686 kcal/mole of energy as heat

The breakdown of glucose to ATP is **not 100% efficient**. Rather energy is released in the form of heat (2^{ND} Law of Thermodynamics) as glucose is metabolized to CO_2 and H_2O

I. ATP PRODUCTION

A. ATP is the prime energy carrier for all cells

B. Comparison of three types of energy releasing pathways

1. AEROBIC RESPIRATION (O_2) is the main pathway for energy release from carbohydrate to ATP

Sugar + Oxygen ⟶ Carbon dioxide + Water

Oxygen is more electronegative than carbon (oxygen has a greater affinity for electrons than carbon) If carbon binds to oxygen the carbon is oxidized because electron shift toward oxygen.

In this reaction the oxygen is reduced Example: CO_2

2. FERMENTATION AND ANAEROBIC electron transport (both without O_2) release lesser amounts of energy for transfer to a small number of ATP (2)

3. All energy releasing pathways start with glycolysis

    a. Glucose is split into two pyruvate molecules

    b. Glycolysis reaction occur in the cytoplasm without the use of O_2

C. Overview of aerobic respiration

1. Fermentation yields 2 ATP aerobic respiration yield 36 ATP

2. A simplified equation for **AEROBIC** respiration:

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

    Note the similarities between this equation and photosynthesis

3. Three series of reactions are required for aerobic respiration

    a. Glycolysis is the breakdown of glucose to pyruvate; small amounts of ATP are generated in this pathway

    b. Krebs cycle degrades pyruvate to carbon dioxide, water, ATP, H^+ ions, and electrons

    c. Electron transport phosphorylation processes the H^+ ions and electrons to generate high yields of ATP; oxygen is the final acceptor of the electrons

II. GLYCOLYSIS The first stage of the energy-releasing pathway

A. Enzymes in the cytoplasm catalyze several steps in glucose breakdown

1. Glucose is the first phosphorylated in energy-requiring steps, then the six-carbon intermediate is split to form two molecules of PGAL

2. Enzymes remove H^+ and electrons from PGAL and transfer them to NAD^+ which becomes NADH (used later in the electron transport system)

3. By substrate-level phosphorylation - four ATP are produced but remember two ATPs are used to initiate the catabolism process.

B. The end products of glycolysis are: 2 pyruvates, 2 ATP (net gain) and 2 NADH for each molecule of glucose degraded

III. Completing the Aerobic Pathway

A. preparatory steps and the Krebs cycle

1. Pyruvate enters the mitochondria and is converted to acetyl-CoA

a) The first of the 3 CO_2 is lost

b) Acetyl-CoA then combines with oxaloacetae present in the mitochondria from the previous turn of the cycle to form Citric acid

2. During each turn of the Krebs cycle, the acetyl-CoA is further degraded leaving as two carbon dioxide (CO_2)

B. Functions of the second stage

1. H^+ and e^- are transferred to NAD^+ and FAD

2. Two molecules of ATP are produced by substrate-level phosphorylation

C. Third stage of aerobic pathway -- Electron transport phosphorylation

1. NADH and $FADH_2$ give up their electrons to transport (enzyme) systems embedded in the mitochondrial inner membrane.

2. According to the chemiosmotic theory, energy is released in the passage of electrons through components of the transport series.

a. The energy is used to pump hydrogen ions out the inner compartment

b. When hydrogen ions flow back through the ATP synthase in the channels, the coupling phosphate (P*i*) to ADP yields ATP

D. Summary of the energy harvest

1. Electron transport yields 32 ATP; glycolysis yields 2 ATP; Krebs yields 2 ATP for a grand total of 36 ATP per glucose molecule

2. Normally, for every NADH produced within the mitochondria and processed by the electron transport system, 3 ATP are formed; $FADH_2$ yields only 2 ATP

3. NADH from the cytoplasm cannot enter the mitochondrion and must transfer its electrons

a. In most cells (skeletal, brain) the electrons are transferred to FAD and thus yield two ATP (for a total of 36 ATP)

b. But in liver, heart, and kidney cells, NAD^+ accepts the electrons to yield 3 ATP; because 2 NADH are produced per glucose, this gives a total yield of 38 ATP

IV. ANAEROBIC Routes

A. Anaerobic pathway operate when oxygen is absent or limited; pyruvate from glycolysis is metabolized to produce molecules other than acetyl-CoA.

B. Fermentation Pathways

1. With an energy yield of only 2 ATPs, fermentation is restricted to single-celled organisms and cells of multi-celled organism only at certain limited times

2. Lactate fermentation

   a. Certain bacteria (as in milk) and muscle cells have the enzymes capable of converting pyruvate to lactate

   b. No additional ATP beyond the net 2 from glycolysis is produced by NAD^+ is regenerated

3. Alcohol Fermentation

   a. Fermentation begins with glucose degradation to pyruvate.

   b. Cellular enzymes convert pyruvate to acetaldehyde, which then accepts electrons from NADH to become alcohol.

   c. Yeasts are valuable in the baking industry (CO_2 by product makes dough rise) and in the alcoholic beverage production

$$C_6H_{12}O_6 \longrightarrow CO_2 + H_2O + \text{Alcohol}$$

TERMS:

Aerobic respiration - oxygen consumed in the process of metabolism
Anaerobic respiration - no oxygen consumed during metabolism
ATP - Adenosine Tri-phosphate
FAD - flavin adenine nucleotide
NAD - nicotiamide adenine dinucleotide
Glycolysis
Krebs cycle