Chapter 15 Review Problems

INSTRUCTIONS:

You do not need to write the question, ONLY WRITE THE PROBLEM NUMBER and ANSWERS/SOLUTIONS.

- For problems that involve calculations, you must show your work to get full credit.
- For multiple choice questions, you can simply write the letter (a, b, c, or d) of the correct response.
- Use the navigation buttons at the bottom of the pages to get hints, check your answers, move to the next problem, or go back to previous pages.

Chapter Review Problems are due at the end of class period on the dates shown in the CHEM 108 Schedule.

- Late submissions will not be accepted unless the student can prove to the instructor that something outside of their control prevented them from turning in the problem set on the due date (see the course syllabus for more details).
15.1) The terms that are listed below are used throughout chapter 15. Check your understanding of these terms by defining them.

a) metabolism

b) metabolic pathway

c) coenzyme

d) acyl group
15.1) The terms that are listed below are used throughout chapter 15. Check your understanding of these terms by defining them.

a) metabolism

b) metabolic pathway

c) coenzyme

d) acyl group

HINT:

Review the videos that discuss these topics (or read/re-read about them in the textbook, chapter 15, section 2).

Videos links: chapter 15 part 1 and part 2
15.1) The terms that are listed below are used throughout chapter 15. Check your understanding of these terms by defining them.

a) metabolism - The entire set of life-sustaining chemical reactions that occur in organisms.
   • These reactions number in the thousands and include reactions such as those responsible for getting energy from food, processing and removal of waste, building up muscles, growth, photosynthesis in plants, cell division, and reproduction.

b) metabolic pathway - sets of sequential metabolic reactions
   • Many of the reactions in metabolic pathways require enzymes, therefore organisms can control (accelerate or suppress) metabolic pathways, according to their current needs, by upregulating, downregulating, inhibiting, or activating one or more of the enzymes involved in the pathway.

c) coenzyme - a species that must bind to an enzyme in order for the enzyme to function.
   • In most cases, a coenzyme is actually one of the substrates (reactants) in the catalyzed reaction. The reason that certain substrates are also referred to as coenzymes is that these substrates are common substrates in many different enzymatic reactions in which they donate electrons, atoms, or groups of atoms to other substrates, or accept electrons, atoms or groups of atoms from other substrates.

d) acyl group - An acyl group consists of a carbonyl group bonded to an organic group (R), as shown below.

   ![general form of an acyl group](image)

For more details: See chapter 15 part 1 and part 2 videos or chapter 15 section 2 in the textbook.
15.2) Name the **products** of the *phosphorylation* of ADP reaction shown below.

- **NOTE:** You do not need to draw the structural formulas of the products, just name them or use their abbreviations.

![Diagram of phosphorylation of ADP]
15.2) Name the **products** of the *phosphorylation* of ADP reaction shown below.

- NOTE: You do not need to draw the structural formulas of the products, just name them or use their abbreviations.

**HINT**: There are two products in this reaction, one of the products is ATP. What is the other product?

For more help: See chapter 15 part 1 video or chapter 15 section 2 in the textbook.
15.2) Name the **products** of the *phosphorylation* of ADP reaction shown below.

- NOTE: You do not need to draw the structural formulas of the products, just name them or use their abbreviations.

**ANSWER:** adenosine triphosphate (ATP) and water (H₂O)

**EXPLANATION:**

When a compound gains/accepts a phosphoryl group in a reaction, we say that the compound became “*phosphorylated.*”

The chemical equation for the transfer of a *phosphoryl group* (PO₃) **from** inorganic phosphate (Pᵢ) **to** ADP is shown above.

**For more details:** See [chapter 15 part 1 video](#) or chapter 15 section 2 in the textbook.
15.3) In the previous problem, you drew the products for the phosphorylation of ADP reaction (shown below). Does that reaction require energy or release energy when it occurs?
15.3) In the previous problem, you drew the products for the phosphorylation of ADP reaction (shown below). Does that reaction require energy or release energy when it occurs?

**HINT:** \( \Delta G \) for this reaction is 7300 Joules per mole of ADP that reacts.
15.3) In the previous problem, you drew the products for the phosphorylation of ADP reaction (shown below). Does that reaction require energy or release energy when it occurs?

**ANSWER:** This reaction **requires energy** in order to occur.

**EXPLANATION:**

Adding a *phosphoryl group* to ADP in order to form ATP **requires** energy. The positive value of $\Delta G$ for this reaction (7300 Joules per mole of ADP) indicates that the reaction **requires energy** in order to occur. This reaction will not occur spontaneously unless external energy is provided. Catabolic metabolic pathways often use the energy contained in food to drive the transfer of *phosphoryl groups* to ADP, thereby forming ATP.

For more details: See [chapter 15 part 1 video](#) or chapter 15 section 2 in the textbook.
15.4) a) Name the **products** of the *dephosphorylation* of ATP reaction shown below.
   - NOTE: You do not need to draw the structural formulas of the products, just name them or use their abbreviations.

\[
\text{H}_2\text{O} + \text{ATP} \rightarrow \text{ADP} + \text{Pi} + \text{H}_2\text{O}
\]

b) Does the *dephosphorylation* of ATP reaction **require energy** or **release energy**?
15.4) 

a) Name the **products** of the *dephosphorylation* of ATP reaction shown below.

- **NOTE:** You do not need to draw the structural formulas of the products, just name them or use their abbreviations.

![Reaction diagram](image)

b) Does the *dephosphorylation* of ATP reaction **require energy** or **release energy**?

**HINT:** $\Delta G$ for this reaction is -7300 Joules per mole of ATP that reacts.

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**For more help:** See [chapter 15 part 1 video](#) or chapter 15 section 2 in the textbook.
15.4) a) Name the **products** of the *dephosphorylation* of ATP reaction shown below.

- **NOTE:** You do not need to draw the structural formulas of the products, just name them or use their abbreviations.

**ANSWER:** inorganic phosphate (**P**<sub>i</sub>), **H**<sup>+</sup>, and adenosine diphosphate (**ADP**)

b) Does the *dephosphorylation* of ATP reaction **require energy** or **release energy**?

**Energy is released** from ATP when it is converted to ADP.

- This energy is used by organisms to drive energy-requiring reactions or physical processes that would otherwise not occur spontaneously. *One* way that energy can be released from ATP is by reacting it with **H**<sub>2</sub>**O** to **form** ADP, inorganic phosphate, and an **H**<sup>+</sup> ion. Although this reaction is spontaneous (ΔG is negative), the reaction rate is quite slow, therefore organisms employ enzymes in order for the reaction to proceed at a useful rate.

**For more details:** See chapter 15 part 1 video or chapter 15 section 2 in the textbook.
15.5)  

i) Coenzyme A is classified as a coenzyme because it is involved in the transfer of an _____________ in many different enzymatically catalyzed reactions.
   a) carbonyl  
   b) acyl  
   c) hydroxyl  
   d) carboxyl  

ii) An acyl group that is central to the metabolism of food is the _____________ group.
   a) hydroxyl  
   b) acetyl  
   c) carbonyl  
   d) carboxyl  

iii) When NAD$^+$ accepts a hydride ion from another species, it is _____________ to NADH.
   a) oxidized  
   b) reduced  

iv) FADH$_2$ is _____________ to FAD by donating two electrons (and two H$^+$ ions) to other species.
   a) oxidized  
   b) reduced
i) Coenzyme A is classified as a coenzyme because it is involved in the transfer of an _____________ in many different enzymatically catalyzed reactions.

HINT: a) carbonyl  b) acyl  c) hydroxyl  d) carboxyl

ii) An acyl group that is central to the metabolism of food is the _____________ group.

HINT: a) hydroxyl  b) acetyl  c) carbonyl  d) carboxyl

iii) When NAD$^+$ accepts a hydride ion from another species, it is _____________ to NADH.

a) oxidized  b) reduced

iv) FADH$_2$ is _____________ to FAD by donating two electrons (and two H$^+$ ions) to other species.

a) oxidized  b) reduced

For more help: See chapter 15 part 2 videos or chapter 15 section 2 in the textbook.
Coenzyme A is classified as a coenzyme because it is involved in the transfer of an \textbf{acetyl group} in many different enzymatically catalyzed reactions.

1. Coenzyme A is classified as a coenzyme because it is involved in the transfer of an \underline{acetyl group} in many different enzymatically catalyzed reactions.
   - a) hydroxyl
   - b) acetyl
   - c) hydroxyl
   - d) carboxyl

2. An acetyl group that is central to the metabolism of food is the \underline{acetyl group}.
   - a) hydroxyl
   - b) acetyl
   - c) carbonyl
   - d) carboxyl

3. When NAD$^+$ accepts a hydride ion from another species, it is \underline{reduced} to NADH.
   - a) oxidized
   - b) reduced

4. FADH$_2$ is \underline{reduced} to FAD by donating two electrons (and two H$^+$ ions) to other species.
   - a) oxidized
   - b) reduced

Many oxidation-reduction reactions involve the transfer of an electron by way of the hydride ion (H:-). Recall that a hydrogen atom has one electron, whereas a hydride ion has an “extra” (second) electron. A substance that accepts a hydride ion is reduced because of the hydride’s “extra” electron.

For more details: See chapter 15 part 2 video or chapter 15 section 2 in the textbook.
15.6) Match each of the coenzymes listed below with the *species that they transport.*

i) ADP

ii) Coenzyme A (CoA)

iii) FAD

iv) Coenzyme Q (CoQ)

v) NAD$^+$

**transported species choices:**

a) acyl groups

b) phosphate groups

c) hydride ions (H$^-$)/electrons
15.6) Match each of the coenzymes listed below with the species that they transport.

i) ADP
ii) Coenzyme A (CoA)
iii) FAD
iv) Coenzyme Q (CoQ)
v) NAD⁺

transported species choices:

a) acyl groups
b) phosphate groups
c) hydride ions (H⁻)/electrons

HINT:

A coenzyme is a species that must bind to an enzyme in order for the enzyme to function. In most cases, a coenzyme is actually one of the substrates (reactants) in the catalyzed reaction. The reason that certain substrates are also referred to as coenzymes is that these substrates are common substrates in many different enzymatic reactions in which they donate electrons, atoms, or groups of atoms to other substrates, or accept electrons, atoms or groups of atoms from other substrates. The five group-transfer coenzymes in this problem, that are central to the metabolization of food, along with the species each transfers are listed in your lecture notes and the textbook.

For more help: See chapter 15 part 1 and part 2 videos or chapter 15 section 2 in the textbook.
15.6) Match each of the coenzymes listed below with the species that they transport.

i) ADP  (b) phosphate groups  

ii) Coenzyme A (CoA)  (a) acyl groups  

iii) FAD  (c) hydride ions (H⁻) or electrons  

iv) Coenzyme Q (CoQ)  (c) hydride ions (H⁻)/electrons  

v) NAD⁺  (c) hydride ions (H⁻)/electrons  

EXPLANATION: A coenzyme is a species that must bind to an enzyme in order for the enzyme to function. In most cases, a coenzyme is actually one of the substrates (reactants) in the catalyzed reaction. The reason that certain substrates are also referred to as coenzymes is that these substrates are common substrates in many different enzymatic reactions in which they donate electrons, atoms, or groups of atoms to other substrates, or accept electrons, atoms or groups of atoms from other substrates. The five group-transfer coenzymes that are central to the metabolization of food, along with the species each transfers are listed in the table on the right.

For more details: See chapter 15 part 1 and part 2 videos or chapter 15 section 2 in the textbook.
15.7) Determine whether each of the following changes is an **oxidation** or **reduction**.

a) gain of electrons

b) loss of electrons

c) \( \text{Fe}^{2+} \) to \( \text{Fe}^{3+} \)

d) NADH to NAD\(^+\)

e) FAD to FAD\(_2\)

f) \( \text{CH}_4 \) to \( \text{CO}_2 \)

g) NAD\(^+\) to NADH
15.7) Determine whether each of the following changes is an **oxidation** or **reduction**.

- **a)** gain of electrons
- **b)** loss of electrons
- **c)** Fe\(^{2+}\) to Fe\(^{3+}\)
- **d)** NAD to NAD\(^+\)
- **e)** FAD to FADH\(_2\)
- **f)** CH\(_4\) to CO\(_2\)
- **g)** NAD\(^+\) to NADH

**HINT:** A useful mnemonic to differentiate **oxidation** and **reduction** is the term “**OILRiG**” (Oxidation is the Loss of electrons; Reduction is the Gain of electrons).

It is possible to identify redox reactions for inorganic compounds by inspecting the chemical equation and determining if electrons are **transferred from one species to another**.

- **If the charge** of an atom or ion in a reactant was **increased** (toward positive) in the conversion of reactants to products, **an oxidation occurred**.
- **If the charge** of an atom or ion in a reactant was **decreased** (toward negative) in the conversion of reactants to products, **a reduction occurred**.

**HINT:** For **covalent compounds**, such as organic and biological compounds, the gaining and losing of electrons is the result of a **gain** or **loss** of bond(s) to oxygen atoms or hydrogen atoms.
15.7) Determine whether each of the following changes is an **oxidation** or **reduction**.

a) gain of electrons  **reduction**

b) loss of electrons  **oxidation**

c) Fe$^{2+}$ to Fe$^{3+}$  **oxidation**

- If the charge of an atom or ion in a reactant was **increased** (toward positive) in the conversion of reactants to products, an **oxidation** occurred.

- If the charge of an atom or ion in a reactant was **decreased** (toward negative) in the conversion of reactants to products, a **reduction** occurred.

d) NADH to NAD$^+$  **oxidation**

- lost bond to **hydrogen atom**

e) FAD to FADH$_2$  **reduction**

- gained bond to **hydrogen atom**

f) CH$_4$ to CO$_2$  **oxidation**

- gained bonds to **oxygen atoms**

- and **lost** bonds to **hydrogen atoms**

g) NAD$^+$ to NADH  **reduction**

- gained bond to **hydrogen atom**

For **covalent compounds**, such as organic and biological compounds, the gaining and losing of electrons is the result of a **gain** or **loss** of bond(s) to **oxygen atoms** or **hydrogen atoms**.

For more details on NAD$^+/NADH$ and FAD/FADH:  See [chapter 15 part 2 video](#) or chapter 15 section 2 in the textbook.
15.8) Explain the difference between *catabolism* and *anabolism*. 
15.8) Explain the difference between catabolism and anabolism.

**HINT:**
Metabolic pathways can usually be classified as catabolic (catabolism) or anabolic (anabolism). One of these pathways involves the breakdown of larger organic compounds into smaller compounds. The other pathway involves building up of larger organic compounds from smaller ones.

**For more help:** See chapter 15 part 1 video or chapter 15 section 2 in the textbook.
15.8) Explain the difference between catabolism and anabolism.

YOUR ANSWER SHOULD BE SOMETHING LIKE THIS:

Metabolic pathways can usually be classified as catabolic (catabolism) or anabolic (anabolism). Catabolic pathways involve the breakdown of larger organic compounds into smaller compounds. Anabolic pathways involve building up of larger organic compounds from smaller ones.

For more details: See chapter 15 part 1 video or chapter 15 section 2 in the textbook.
15.9)

i) What type of chemical bonds are broken in the digestion of starch?
   a) ester bonds
   b) peptide bonds
   c) glycosidic bonds
   d) phosphoester bonds

ii) What is the name of the monosaccharide that is produced in the digestion of starch?

iii) Why can’t humans digest cellulose?

iv) Digestion is the **first stage** of carbohydrate catabolism. In **stage 2** of carbohydrate catabolism, *glucose* is converted into acetyl-coenzyme A, CO\(_2\), and H\(_2\)O. This process begins with a catabolic pathway called **glycolysis**. **Glycolysis** is a series of ten sequential reactions. Complete the overall chemical equation (below) for glycolysis by adding the products.

   **NOTE:** You do not need to write the structural formulas of the products; you can use their chemical formulas, names, or their abbreviations.

   \[
   \text{glucose} + 2 \text{ADP} + 2\text{P}_i + 2\text{NAD}^+ \rightleftharpoons 2\text{pyruvate ions} + 2\text{ATP} + 2\text{NADH} + 2\text{H}_2\text{O} + 2\text{H}^+ \\
   \]
15.9)

i) What type of chemical bonds are broken in the digestion of starch?

HINT: a) ester bonds  
b) peptide bonds  
c) glycosidic bonds  
d) phosphoester bonds

ii) What is the name of the monosaccharide that is produced in the digestion of starch?

HINT: Amylose and amylpectin, the two components of starch, are homopolysaccharides. Which monosaccharide residues do they contain?

iii) Why can’t humans digest cellulose?

iv) Digestion is the first stage of carbohydrate catabolism. In stage 2 of carbohydrate catabolism, glucose is converted into acetyl-coenzyme A, CO₂, and H₂O. This process begins with a catabolic pathway called glycolysis. Glycolysis is a series of ten sequential reactions. Complete the overall chemical equation (below) for glycolysis by adding the products.

NOTE: You do not need to write the structural formulas of the products; you can use their chemical formulas, names, or their abbreviations.

\[
glucose + 2 \text{ADP} + 2\text{P}_i + 2\text{NAD}^+ \rightleftharpoons \text{2 pyruvate ions} + 2\text{ATP} + 2\text{NADH} + 2\text{H}_2\text{O} + 2\text{H}^+
\]

HINT: There are five products. One of them is NADH, another is ATP.

For more help: See chapter 15 part 3 and part 4 videos or chapter 15 section 3 in the textbook.
i) What type of chemical bonds are broken in the digestion of starch?
   a) ester bonds
   b) peptide bonds
   c) glycosidic bonds
   d) phosphoester bonds

ii) What is the name of the monosaccharide that is produced in the digestion of starch? glucose

Amylose and amylopectin, the two components of starch, are homopolysaccharides; they contain glucose residues only.

iii) Why can’t humans digest cellulose? Not all dietary carbohydrates can be digested. Cellulose cannot be digested because humans do not have a dietary enzyme capable of hydrolyzing β-(1→4) glucose-glucose glycosidic bonds.

iv) Digestion is the first stage of carbohydrate catabolism. In stage 2 of carbohydrate catabolism, glucose is converted into acetyl-coenzyme A, CO₂, and H₂O. This process begins with a catabolic pathway called glycolysis. Glycolysis is a series of ten sequential reactions. Complete the overall chemical equation (below) for glycolysis by adding the products.

   \[
   \text{glucose} + 2 \text{ADP} + 2\text{P}_1 + 2 \text{NAD}^+ \rightleftharpoons 2 \text{pyruvate ions} + 2 \text{ATP} + 2 \text{NADH} + 2 \text{H}_2\text{O} + 2 \text{H}^+ 
   \]

For more help: See chapter 15 part 3 and part 4 videos or chapter 15 section 3 in the textbook.

For more details: See chapter 15 part 3 and part 4 videos or chapter 15 section 3 in the textbook.
15.10) The fate of the pyruvate that is produced in glycolysis by aerobic organisms (organisms that require O\textsubscript{2} to grow), such as humans and most other organisms, depends on the availability of oxygen in cells. The term “aerobic condition” is used to describe a situation where a significant amount of oxygen is present. The term “anaerobic condition” is used to describe a situation where a significant amount of oxygen is not present.

An illustrative summary of stage 2 of food catabolism and the fate of pyruvate is shown below. Match the compounds listed below with the numbered boxes in the illustration.

a) pyruvate

b) acetyl-coenzyme A

c) lactate
15.10) The fate of the pyruvate that is produced in glycolysis by aerobic organisms (organisms that require O\textsubscript{2} to grow), such as humans and most other organisms, depends on the availability of oxygen in cells. The term “aerobic condition” is used to describe a situation where a significant amount of oxygen is present. The term “anaerobic condition” is used to describe a situation where a significant amount of oxygen is not present.

An illustrative summary of stage 2 of food catabolism and the fate of pyruvate is shown below. Match the compounds listed below with the numbered boxes in the illustration.

- a) pyruvate Box #2
- b) acetyl-coenzyme A
- c) lactate

For more help: See chapter 15 part 3 and part 4 videos or chapter 15 section 3 in the textbook.
15.10) The fate of the pyruvate that is produced in glycolysis by aerobic organisms (organisms that require \( \text{O}_2 \) to grow), such as humans and most other organisms, depends on the availability of oxygen in cells. The term “aerobic condition” is used to describe a situation where a significant amount of oxygen is present. The term “anaerobic condition” is used to describe a situation where a significant amount of oxygen is not present.

An illustrative summary of stage 2 of food catabolism and the fate of pyruvate is shown below. Match the compounds listed below with the numbered boxes in the illustration.

- a) pyruvate  Box #2
- b) acetyl-coenzyme A  Box #1
- c) lactate  Box #3

EXPLANATION:

Under aerobic conditions, the pyruvate made in glycolysis passes from the cytoplasm into the mitochondria and is then converted to acetyl-coenzyme A and \( \text{CO}_2 \). Under anaerobic conditions, the pyruvate that is made in glycolysis remains in the cytoplasm and is converted (reduced) to lactate.

For more details: See chapter 15 part 3 and part 4 videos or chapter 15 section 3 in the textbook.
15.11) The reactions of the citric acid cycle are shown here.

When one acetyl-CoA molecule is completely processed in the citric acid cycle:

a) how many NADH molecules are produced?

b) how many FADH$_2$ molecules are produced?

c) how many ATP ions are produced?
15.11) The reactions of the citric acid cycle are shown here.

When one acetyl-CoA molecule is completely processed in the citric acid cycle:

a) how many NADH molecules are produced?

b) how many FADH$_2$ molecules are produced?

c) how many ATP ions are produced?

HINT

For more help: See chapter 15 part 5 video or chapter 15 section 3 in the textbook.
The reactions of the citric acid cycle are shown here.

When one acetyl-CoA molecule is completely processed in the citric acid cycle:

a) how many NADH molecules are produced? **three**

b) how many FADH$_2$ molecules are produced? **one**

c) how many ATP ions are produced? **one**

For more details: See chapter 15 part 5 video or chapter 15 section 3 in the textbook.
15.12) Determine whether each of the following metabolic processes occurs in the cytoplasm (outside of the mitochondria) or in the mitochondria.

a) glycolysis
b) citric acid cycle
c) beta oxidation
d) oxidative phosphorylation
15.12) Determine whether each of the following metabolic processes occurs in the cytoplasm (outside of the mitochondria) or in the mitochondria.

a) glycolysis
b) citric acid cycle
c) beta oxidation
d) oxidative phosphorylation

HINT: All but one of these processes occur in the mitochondria.
15.12) Determine whether each of the following metabolic processes occurs in the cytoplasm (outside of the mitochondria) or in the mitochondria.

a) glycolysis cytoplasm
b) citric acid cycle mitochondria
c) beta oxidation mitochondria
d) oxidative phosphorylation mitochondria

**EXPLANATION:**
The enzymes that catalyze the reactions of the citric acid cycle, beta-oxidation, and oxidative phosphorylation are all located in the mitochondria.
15.13) The NADH that is produced by glycolysis is not able to pass through the inner mitochondrial membrane to enter the matrix region and undergo oxidative phosphorylation. **Name** the two processes in which the energy from NADH made in glycolysis can enter the mitochondrial matrix.
15.13) The NADH that is produced by glycolysis is not able to pass through the inner mitochondrial membrane to enter the matrix region and undergo oxidative phosphorylation. **Name** the two processes in which the energy from NADH made in glycolysis can enter the mitochondrial matrix.

**HINT:**

In order for the energy from the NADH that is produced by glycolysis to be utilized, it must be processed through “**NADH shuttles**.”

What are the names of the **NADH** shuttles?

**For more help:** See chapter 15 part 6 video or chapter 15 section 3 in the textbook.
The NADH that is produced by glycolysis is not able to pass through the inner mitochondrial membrane to enter the matrix region and undergo oxidative phosphorylation. **Name** the two processes in which the energy from NADH made in glycolysis can enter the mitochondrial matrix.

**EXPLANATION:**

Oxidative phosphorylation requires that NADH be located within the mitochondrial matrix. Since pyruvate oxidation/decarboxylation and the reactions of the citric acid cycle occur in the mitochondrial matrix, the NADH created in those processes can immediately undergo oxidative phosphorylation. The NADH that is produced by glycolysis is able to pass through the outer mitochondrial membrane and enter the intermembrane space; however, it is not able to pass through the inner mitochondrial membrane to enter the matrix region. In order for the energy from this NADH to be utilized, it must be processed through “NADH shuttles.”

The two most important NADH shuttles are the malate-aspartate shuttle and the glycerol 3-phosphate shuttle. The malate-aspartate shuttle works by oxidizing the NADH produced by glycolysis to NAD$^+$ in the intermembrane space, then transferring the electrons through the inner mitochondrial matrix to an NAD$^+$ that is already inside the matrix, thereby producing an NADH that can undergo oxidative phosphorylation. In the glycerol 3-phosphate shuttle, NADH produced by glycolysis is oxidized in the intermembrane space by transferring electrons to an inner mitochondrial membrane-bound FAD, thereby producing an FADH$_2$ that can undergo oxidative phosphorylation.

**ANSWER:**

1) malate-aspartate shuttle
2) glycerol 3-phosphate shuttle

For more details: See [chapter 15 part 6 video](#) or chapter 15 section 3 in the textbook.
15.14) The metabolic strategy of oxidative phosphorylation is to convert the chemical potential energy in reduced coenzymes, NADH and FADH$_2$ into chemical potential energy in ATP.

   a) How many ATP are produced, on average, for each NADH that undergoes oxidative phosphorylation?

   b) How many ATP are produced, on average, for each FADH$_2$ that undergoes oxidative phosphorylation?
15.14) The metabolic strategy of oxidative phosphorylation is to convert the chemical potential energy in reduced coenzymes, NADH and FADH$_2$ into chemical potential energy in ATP.

HINT: 

a) How many ATP are produced, on average, for each NADH that undergoes oxidative phosphorylation? 2.5 ATP

b) How many ATP are produced, on average, for each FADH$_2$ that undergoes oxidative phosphorylation?

For more help: See chapter 15 part 7 and part 8 videos or chapter 15 section 3 in the textbook.
15.14) The metabolic strategy of oxidative phosphorylation is to convert the chemical potential energy in reduced coenzymes, NADH and FADH$_2$ into chemical potential energy in ATP.

a) How many ATP are produced, on average, for each NADH that undergoes oxidative phosphorylation?  **2.5 ATP**

b) How many ATP are produced, on average, for each FADH$_2$ that undergoes oxidative phosphorylation?  **1.5 ATP**

**EXPLANATION:**
The number of ATP that can be produced from NADH or FADH$_2$ depends on the cell and its current conditions. The latest research indicates that, on average, one NADH produces about 2.5 ATP, and one FADH$_2$ produces about 1.5 ATP.

For more details: See chapter 15 part 7 and part 8 videos or chapter 15 section 3 in the textbook.
15.15) The reduced coenzymes generated by the citric acid cycle (and beta-oxidation) donate electrons in oxidative phosphorylation. Answer each of the questions below by selecting the appropriate species from the list of species choices. NOTE: You will need to select more than one species for some of these questions.

a) Which species donate electrons to the proteins of the electron transport chain?

b) Which species is the final acceptor of electrons in oxidative phosphorylation?

c) Which species are the final products of oxidative phosphorylation?
15.15) The reduced coenzymes generated by the citric acid cycle (and beta-oxidation) donate electrons in oxidative phosphorylation. Answer each of the questions below by selecting the appropriate species from the list of species choices. NOTE: You will need to select more than one species for some of these questions.

a) Which species donate electrons to the proteins of the electron transport chain?
   HINT: Two species donate electrons to the proteins of the electron transport chain.

b) Which species is the final acceptor of electrons in oxidative phosphorylation?

c) Which species are the final products of oxidative phosphorylation?
   HINT: One of the final products of oxidative phosphorylation is $\text{H}_2\text{O}$; there are three other products.

For more help: See chapter 15 part 7 and part 8 videos or chapter 15 section 3 in the textbook.
15.15) The reduced coenzymes generated by the citric acid cycle (and beta-oxidation) donate electrons in oxidative phosphorylation. Answer each of the questions below by selecting the appropriate species from the list of species choices.

NOTE: You will need to select more than one species for some of these questions.

a) Which species donate electrons to the proteins of the electron transport chain?
   NADH and FADH$_2$

b) Which species is the final acceptor of electrons in oxidative phosphorylation?
   O$_2$

c) Which species are the final products of oxidative phosphorylation?
   H$_2$O, NAD$^+$, FAD, and ATP

EXPLANATION: The primary goal of food catabolism is the production of ATP. Before oxidative phosphorylation, most of the chemical potential energy extracted from food is still in the form of reduced coenzymes (NADH and FADH$_2$). Oxidative phosphorylation is the process in which electrons from NADH or FADH$_2$ are transferred, through a series of electron transfer intermediates (first to the proteins of the electron transport chain) to dissolved oxygen (O$_2$) in order to provide the energy required to produce ATP. In this process, ADP and an inorganic phosphate (P$_i$) are converted to ATP. The formation of ATP from ADP and P$_i$ would not occur spontaneously without the input of energy that is provided when electrons are transferred to O$_2$.

For more details: See chapter 15 part 7 and part 8 videos or chapter 15 section 3 in the textbook.
15.16) Determine whether each of the statements below is true or false.

a) The pH in the mitochondrial matrix is less than the pH in the intermembrane space.

b) The energy that results from the difference in hydrogen ion concentration between the mitochondrial matrix and the cytoplasm is used to generate ATP.

c) ATP synthase provides energy in the form of ATP to actively transport H^+ into the intermembrane space.

d) Hydrogen ions enter the mitochondrial matrix via facilitated diffusion.

e) The hydrogen ion concentration is lower in the mitochondrial matrix that in the intermembrane space.

f) Oxidative phosphorylation does not happen in exactly the same way for NADH as it does for FADH_2.
15.16) Determine whether each of the statements below is **true** or **false**.

a) The pH in the mitochondrial matrix is less than the pH in the intermembrane space.
   **HINT:** Review the oxidative phosphorylation images in your lecture notes or the textbook. Remember that H$_3$O$^+$ is represented by “H$^+$” in those images. Is the H$_3$O$^+$ concentration in the mitochondrial matrix greater or less than the H$_3$O$^+$ concentration in the intermembrane space? As the H$_3$O$^+$ increases, the pH decreases.

b) The energy that results from the difference in hydrogen ion concentration between the mitochondrial matrix and the cytoplasm is used to generate ATP.
   **HINT:** Does oxidative phosphorylation occur in the cytoplasm outside of the mitochondria or entirely within the mitochondria?

c) ATP synthase provides energy in the form of ATP to actively transport H$^+$ into the intermembrane space.
   **HINT:** Review the role of ATP synthase.

d) Hydrogen ions enter the mitochondrial matrix via facilitated diffusion.
   **HINT:** The diffusion of ions and polar molecules through protein channels is referred to as **facilitated diffusion**.

e) The hydrogen ion concentration is lower in the mitochondrial matrix than in the intermembrane space.
   **HINT:** Review the oxidative phosphorylation images in your lecture notes or the textbook. Remember that H$_3$O$^+$ is represented by “H$^+$” in those images.

f) Oxidative phosphorylation does not happen in exactly the same way for NADH as it does for FADH$_2$.
   **HINT:** Is the amount of ATP generated from one NADH equal to the amount of ATP generated from one FADH$_2$?

---

For more help: See chapter 15 part 7 and part 8 videos or chapter 15 section 3 in the textbook.
15.16) Determine whether each of the statements below is **true** or **false**.

a) The pH in the mitochondrial matrix is less than the pH in the intermembrane space. **false** - The H$_3$O$^+$ concentration in the mitochondrial matrix is less than the H$_3$O$^+$ concentration in the intermembrane space, therefore the pH in the mitochondrial matrix is greater than the pH in the intermembrane space. H$_3$O$^+$ is represented by “H$^+$” in the oxidative phosphorylation images in the lecture notes and textbook.

b) The energy that results from the difference in hydrogen ion concentration between the mitochondrial matrix and the cytoplasm is used to generate ATP. **false** - The energy that results from the difference in hydrogen ion concentration between the mitochondrial matrix and the **intermembrane space** is used to generate ATP.

c) ATP synthase provides energy in the form of ATP to actively transport H$^+$ into the intermembrane space. **false** - The transfer of electrons through the electron transport chain provides energy to actively transport H$^+$ into the intermembrane space.

d) Hydrogen ions enter the mitochondrial matrix via facilitated diffusion. **true** - Hydrogen spontaneously diffuse from the intermembrane space (higher concentration) to the matrix region (lower concentration). The only path between these regions in which hydrogen ions can passively diffuse is through the ATP synthase enzyme (facilitated diffusion).

e) The hydrogen ion concentration is lower in the mitochondrial matrix that in the intermembrane space. **true**

f) Oxidative phosphorylation does not happen in exactly the same way for NADH as it does for FADH$_2$. **true** - Because this statement is true, one NADH produces about 2.5 ATP, whereas one FADH$_2$ produces about 1.5 ATP.

For more details: See chapter 15 **part 7** and **part 8** videos or chapter 15 section 3 in the textbook.
15.17) How many ATP can be produced from the catabolism of one glucose molecule when the two NADH from glycolysis use the glycerol 3-phosphate shuttle? For this calculation, assume that each NADH that undergoes oxidative phosphorylation produces 2.5 ATP, and each FADH$_2$ produces 1.5 ATP.
15.17) How many ATP can be produced from the catabolism of one glucose molecule when the two NADH from glycolysis use the glycerol 3-phosphate shuttle? For this calculation, assume that each NADH that undergoes oxidative phosphorylation produces 2.5 ATP, and each FADH$_2$ produces 1.5 ATP.

**HINT:**

In the glycerol 3-phosphate shuttle, NADH produced by glycolysis is oxidized in the intermembrane space by transferring electrons to an inner mitochondrial membrane-bound FAD, thereby producing an FADH$_2$ that can undergo oxidative phosphorylation.
15.17) How many ATP can be produced from the catabolism of one glucose molecule when the two NADH from glycolysis use the glycerol 3-phosphate shuttle? For this calculation, assume that each NADH that undergoes oxidative phosphorylation produces 2.5 ATP, and each FADH$_2$ produces 1.5 ATP.

**ANSWER:** 30 ATP
15.18) Determine whether the following statements describe insulin, glucagon, or both insulin and glucagon.

a) secreted by pancreas

b) released when blood glucose concentration is high

c) released when blood glucose concentration is low

d) immediately increases the amount of glucose entering cells

e) is a hormone

f) lowers blood glucose concentration

g) not enough is produced by individuals with type-1 diabetes

h) stimulates glycogen breakdown (glycogenolysis)
15.18) Determine whether the following statements describe **insulin**, **glucagon**, or **both insulin and glucagon**.

a) secreted by pancreas

b) released when blood glucose concentration is high

c) released when blood glucose concentration is low

d) *immediately* increases the amount of glucose entering cells

e) is a hormone

f) lowers blood glucose concentration

g) not enough is produced by individuals with type-1 diabetes

h) stimulates glycogen breakdown (glycogenolysis)

---

**HINT:**

When **insulin** binds to liver and muscle cell receptors, it triggers a series of events that result in the activation of an enzyme in the glycogenesis pathway and the inhibition of an enzyme in the glycogenolysis pathway.

**Glucagon** has the **opposite effect** of insulin on liver cells; it accelerates glycogenolysis and suppresses glycogenesis.

**For more help:** See chapter 15 part 9 video or chapter 15 section 3 in the textbook.
15.18) Determine whether the following statements describe insulin, glucagon, or both insulin and glucagon.

a) secreted by pancreas
   **both insulin and glucagon**

b) released when blood glucose concentration is high
   **insulin**

c) released when blood glucose concentration is low
   **glucagon**

d) immediately increases the amount of glucose entering cells
   **insulin**

e) is a hormone
   **both insulin and glucagon**

f) lowers blood glucose concentration
   **insulin**

g) not enough is produced by individuals with type-1 diabetes
   **insulin**

h) stimulates glycogen breakdown (glycogenolysis)
   **glucagon**

EXPLANATION: When **insulin** binds to liver and muscle cell receptors, it triggers a series of events that result in the activation of an enzyme in the glycogenesis pathway and the inhibition of an enzyme in the glycogenolysis pathway. **Glucagon** has the **opposite effect** of insulin on liver cells; it accelerates glycogenolysis and suppresses glycogenesis.

causes a **decrease** in blood glucose levels
- accelerated by **insulin**
- suppressed by **glucagon**

causes an **increase** in blood glucose levels
- accelerated by **glucagon**
- suppressed by **insulin**

For more details: See [chapter 15 part 9 video](#) or chapter 15 section 3 in the textbook.
15.19) Diabetes is a metabolic disease in which the body does not appropriately process glucose. If not treated, it results in dangerously high blood glucose concentration. Determine whether the following statements describe type I, type II, or both type I and type II diabetes.

a) also known as adult onset diabetes

b) also known as juvenile diabetes

c) also known as insulin-resistant diabetes

d) results from lack of insulin production

e) the most common type of diabetes

f) leads to hyperglycemia if untreated

g) can be treated with insulin injections
15.19) Diabetes is a metabolic disease in which the body does not appropriately process glucose. If not treated, it results in dangerously high blood glucose concentration. Determine whether the following statements describe type I, type II, or both type I and type II diabetes.

a) also known as adult onset diabetes
b) also known as juvenile diabetes
c) also known as insulin-resistant diabetes
d) results from lack of insulin production
e) the most common type of diabetes
f) leads to hyperglycemia if untreated
g) can be treated with insulin injections

**HINT:**

In diabetes type I, also called insulin dependent diabetes, the pancreas produces too little insulin. This can be a result of genetic disease, viral infection, or damage to the pancreas. Diabetes type I can be treated with insulin injections. Individuals must use a glucometer to frequently measure the concentration of glucose in their blood, and then inject insulin when elevated glucose levels are observed. Because diabetes type I often begins in childhood, it is sometimes referred to as juvenile diabetes.

Diabetes type II, also called insulin-resistant diabetes, occurs when sufficient insulin is produced, however the insulin receptors are unable to respond appropriately. About 90% of diabetes cases are type II. This type of diabetes can be even more difficult to manage than type I diabetes because it does not respond to insulin injections. Diabetes type II occurs after childhood and is therefore sometimes referred to as adult-onset diabetes.

**For more help:** See chapter 15 part 9 video or chapter 15 section 3 in the textbook.
Diabetes is a metabolic disease in which the body does not appropriately process glucose. If not treated, it results in dangerously high blood glucose concentration. Determine whether the following statements describe type I, type II, or both type I and type II diabetes.

a) also known as adult onset diabetes  
   type II

b) also known as juvenile diabetes  
   type I

c) also known as insulin-resistant diabetes  
   type II

d) results from lack of insulin production  
   type I

e) the most common type of diabetes  
   type II

f) leads to hyperglycemia if untreated  
   both type I and type II

g) can be treated with insulin injections  
   type I

EXPLANATION:

In diabetes type I, also called insulin dependent diabetes, the pancreas produces too little insulin. This can be a result of genetic disease, viral infection, or damage to the pancreas. Diabetes type I can be treated with insulin injections. Individuals must use a glucometer to frequently measure the concentration of glucose in their blood, and then inject insulin when elevated glucose levels are observed. Because diabetes type I often begins in childhood, it is sometimes referred to as juvenile diabetes.

Diabetes type II, also called insulin-resistant diabetes, occurs when sufficient insulin is produced, however the insulin receptors are unable to respond appropriately. About 90% of diabetes cases are type II. This type of diabetes can be even more difficult to manage than type I diabetes because it does not respond to insulin injections. Diabetes type II occurs after childhood and is therefore sometimes referred to as adult-onset diabetes.

For more details: See chapter 15 part 9 video or chapter 15 section 3 in the textbook.
15.20) In the digestion of triglycerides, pancreatic lipase enzymes catalyze the hydrolysis of emulsified triglycerides. Note that these enzymes only lyse (break) **two** of the three ester bonds. The enzymes will specifically lyse the top and bottom ester bonds, leaving the ester bond to the middle carbon on the glycerol backbone unchanged. Draw the **products** for the pancreatic lipase catalyzed hydrolysis of the triglyceride shown below.

![Diagram of a triglyceride and the pancreatic lipase reaction](image)

a triglyceride
15.20) In the digestion of triglycerides, pancreatic lipase enzymes catalyze the hydrolysis of emulsified triglycerides. Note that these enzymes only lyse (break) two of the three ester bonds. The enzymes will specifically lyse the top and bottom ester bonds, leaving the ester bond to the middle carbon on the glycerol backbone unchanged. Draw the products for the pancreatic lipase catalyzed hydrolysis of the triglyceride shown below.

HINT:

There are two more products to add, what are they?

For more help: See chapter 15 part 10 video or chapter 15 section 4 in the textbook.
15.20) In the digestion of triglycerides, pancreatic lipase enzymes catalyze the hydrolysis of emulsified triglycerides. Note that these enzymes only lyse (break) two of the three ester bonds. The enzymes will specifically lyse the top and bottom ester bonds, leaving the ester bond to the middle carbon on the glycerol backbone unchanged. Draw the products for the pancreatic lipase catalyzed hydrolysis of the triglyceride shown below.

**EXPLANATION:**
Triglycerides are first hydrolyzed to diglycerides, and then to monoglycerides. Each one of these reactions produces a fatty acid, as shown on the right.

**For more details:** See chapter 15 part 10 video or chapter 15 section 4 in the textbook.
15.21) The first reaction in the catabolism of fatty acids is called **activation**. In this reaction, the acyl group of a fatty acid is transferred to coenzyme A. The fatty acid is converted to a fatty acyl-coenzyme A. The reaction is shown below using a fatty acid that contains only eight carbons (for simplicity); in biological systems fatty acids typically contain twelve to twenty carbons.

\[
\text{fatty acid} \quad \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3 \quad \overset{\text{O}}{\longrightarrow} \quad \text{H-CoA} \quad \text{ATP} + \text{H}_2\text{O} \quad \text{AMP} + 2\text{P}_i \\
\quad \downarrow \quad \downarrow \quad \downarrow \\
\text{fatty acyl-CoA} \quad \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3 - \text{CoA} + \text{H}^+ 
\]

When fatty acyl-CoA enters the mitochondrial matrix, it undergoes a catabolic pathway called **beta-oxidation (β-oxidation)**. In β-oxidation, a fatty acyl-CoA, goes through a repeated series of **four reactions**, each time losing two of its carbons. Explain why the term “**β-oxidation**” is used for this pathway.
The first reaction in the catabolism of fatty acids is called **activation**. In this reaction, the acyl group of a fatty acid is transferred to coenzyme A. The fatty acid is converted to a fatty acyl-coenzyme A. The reaction is shown below using a fatty acid that contains only eight carbons (for simplicity); in biological systems fatty acids typically contain twelve to twenty carbons.

\[
\text{fatty acid} \quad \text{ATP} + \text{H}_2\text{O} \quad \text{AMP} + 2\text{P}_i
\]

\[
\begin{array}{c}
\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{C}^- \quad \text{O}^- + \text{H-CoA} \\
\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{C}^- \quad \text{CoA} + \text{H}^+
\end{array}
\]

When fatty acyl-CoA enters the mitochondrial matrix, it undergoes a catabolic pathway called **beta-oxidation** (β-oxidation). In β-oxidation, a fatty acyl-CoA, goes through a repeated series of **four reactions**, each time losing two of its carbons. Explain why the term “β-oxidation” is used for this pathway.

**HINT:**

The carbon that is next to a fatty acyl’s carbonyl group is designated as the “α-carbon,” and the carbon that is two carbons away from the carbonyl group is designated as the “β-carbon.”

Consider what occurs in Reaction 3 of β-oxidation (shown on the right).

**For more help:** See chapter 15 part 11 video or chapter 15 section 4 in the textbook.
15.21) The first reaction in the catabolism of fatty acids is called activation. In this reaction, the acyl group of a fatty acid is transferred to coenzyme A. The fatty acid is converted to a fatty acyl-coenzyme A. The reaction is shown below using a fatty acid that contains only eight carbons (for simplicity); in biological systems fatty acids typically contain twelve to twenty carbons.

\[
\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{C} - \text{O} + \text{H-CoA} \rightarrow \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{C} - \text{CoA} + \text{H}^+ 
\]

When fatty acyl-CoA enters the mitochondrial matrix, it undergoes a catabolic pathway called beta-oxidation (\(\beta\)-oxidation). In \(\beta\)-oxidation, a fatty acyl-CoA goes through a repeated series of four reactions, each time losing two of its carbons. Explain why the term “\(\beta\)-oxidation” is used for this pathway.

YOUR ANSWER SHOULD BE SOMETHING LIKE THIS:

The carbon that is next to a fatty acyl’s carbonyl group is designated as the “\(\alpha\)-carbon,” and the carbon that is two carbons away from the carbonyl group is designated as the “\(\beta\)-carbon.” In reaction 3 of \(\beta\)-oxidation (shown on the right), the \(\beta\)-carbon is oxidized. It is for this reason that the reaction pathway is called \(\beta\)-oxidation. In this oxidation, a hydrogen and electron are transferred to NAD\(^+\), reducing it to NADH.

For more details: See chapter 15 part 11 video or chapter 15 section 4 in the textbook.
15.22) What is the net gain in ATP for β-oxidation of palmitic acid (a sixteen-carbon fatty acid)?

\[
\begin{align*}
\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{C} \quad &\quad \text{OH} \\
\end{align*}
\]

\textit{palmitic acid}

(a sixteen-carbon fatty acid)

\textbf{NOTES:}

• Assume that oxidative phosphorylation produces, on average, 2.5 ATP per NADH and 1.5 ATP per FADH\(_2\).

• Because we are using average values for the calculation of ATP from oxidative phosphorylation, you will come up with fractional ATP subtotals; that is not a problem because you’re calculating average ATP production. For example, you will calculate that, on average, 16.5 ATP are produced from the FADH\(_2\) in this problem.

• Remember to subtract one ATP to account for the ATP that was consumed in the activation step.
15.22) What is the net gain in ATP for β-oxidation of palmitic acid (a sixteen-carbon fatty acid)?

HINT:
First, palmitic acid is activated to produce a 16-carbon fatty acyl-CoA. The activation step consumes one ATP. A 16-carbon fatty acyl-CoA will undergo six β-oxidation spirals. Each of the first six cycles of the β-oxidation spiral produces one acetyl-CoA, one NADH, and one FADH$_2$. The final cycle of the spiral produces two acetyl-CoA, one NADH, and one FADH$_2$. The acetyl-CoA are processed through the citric acid cycle, producing ATP and more reduced coenzymes. The NADH, and FADH$_2$ formed in β-oxidation, and the NADH, and FADH$_2$ formed in the citric acid cycle undergo oxidative phosphorylation. Because one ATP is consumed in the activation reaction, it is subtracted when calculating the net gain of ATP.

For more help: See chapter 15 part 11 video or chapter 15 section 4 in the textbook.
15.22) What is the net gain in ATP for β-oxidation of palmitic acid (a sixteen-carbon fatty acid)?

**ANSWER:** 107 ATP

**EXPLANATION:**

First, palmitic acid is activated to produce a 16-carbon fatty acyl-CoA. The activation step *consumes* one ATP. A 16-carbon fatty acyl-CoA will undergo *seven* β-oxidation spirals. Each of the first *six* spirals of β-oxidation produces one acetyl-CoA, one NADH, and one FADH$_2$. The *final cycle* of the spiral produces *two* acetyl-CoA, one NADH, and one FADH$_2$. The acetyl-CoA are processed through the citric acid cycle, producing ATP and *more* reduced coenzymes. The NADH, and FADH$_2$ formed in β-oxidation, and the NADH, and FADH$_2$ formed in the citric acid cycle undergo oxidative phosphorylation. Because one ATP was consumed in the activation reaction, it is subtracted when calculating the *net gain* of ATP. β-oxidation of a sixteen-carbon fatty acid, *on average*, results in a net gain of *107 ATP*.

For more details: See chapter 15 part 11 video or chapter 15 section 4 in the textbook.
15.23) Explain the difference between *ketogenesis* and *ketoacidosis*. 
15.23) Explain the difference between *ketogenesis* and *ketoacidosis*.

**HINT:**

Acetyl-CoA that is produced in excess of the amount that can be metabolized in the citric acid cycle results in a high concentration of acetyl-CoA. When this occurs, acetyl-CoA reacts with *other* acetyl-CoA to produce the three compounds that are referred to as *ketone bodies*. This process is referred to as *ketogenesis*. When individuals diet, they begin to metabolize the triglycerides that are stored in fat cells. This leads to *ketogenesis*. Now discuss *ketoacidosis*....

**For more help:** See chapter 15 part 12 video or chapter 15 section 4 in the textbook.
15.23) Explain the difference between *ketogenesis* and *ketoacidosis*.

**YOUR ANSWER SHOULD BE SOMETHING LIKE THIS** (perhaps a bit less detailed):

Acetyl-CoA that is produced in excess of the amount that can be metabolized in the citric acid cycle results in a high concentration of acetyl-CoA. When this occurs, acetyl-CoA reacts with other acetyl-CoA to produce the three compounds that are referred to as ketone bodies. This process is referred to as *ketogenesis*. Ketone bodies are produced as shown in the reactions below. When individuals diet, they begin to metabolize the triglycerides that are stored in fat cells. This leads to *ketogenesis*.

In cases of starvation, poorly treated diabetes, and conditions related to alcoholic binge drinking, the cells cannot get glucose and extremely high rates of fatty acid catabolism results in dangerous, and even fatal levels of ketone bodies. β-hydroxybutyric acid and acetoacetic acid (the acid forms of β-hydroxybutyrate and acetoacetate, respectively) have significant acid strength. Their production results in a higher concentration of H$_3$O$^+$, which can overcome the blood’s buffering capacity. When this occurs, the blood becomes acidic. When blood pH is less than the normal range (7.35-7.45), the condition is called *acidosis*. When acidosis is caused by excess ketone bodies, the condition is called *ketoacidosis*.

*For more details:* See chapter 15 part 12 video or chapter 15 section 4 in the textbook.
15.24) Explain how chemical potential energy that is present in the protein that we eat is metabolized to provide energy in the form of ATP.
15.24) Explain how chemical potential energy that is present in the protein that we eat is metabolized to provide energy in the form of ATP.

**HINT:**

The protein we eat is digested to produce *amino acids*. Some of the *amino acids* produced in digestion are used for the synthesis of *proteins*, the synthesis of other *amino acids*, and the synthesis of other *nitrogen-containing compounds*.

*Amino acids* that are ingested in surplus of these biosynthesis needs are *catabolized* as fuel for the production of *ATP*. Summarize how this is done.

**For more help:** See [chapter 15 part 13 video](#) or chapter 15 section 5 in the textbook.
15.24) Explain how chemical potential energy that is present in the protein that we eat is metabolized to provide energy in the form of ATP.

**YOUR ANSWER SHOULD BE SOMETHING LIKE THIS:**

The protein we eat is digested to produce amino acids. Some of the amino acids produced in digestion are used for the synthesis of **proteins**, the synthesis of other **amino acids**, and the synthesis of other **nitrogen-containing compounds**. Amino acids that are ingested in surplus of these biosynthesis needs are **catabolized** as fuel for the production of **ATP**. This is done by transforming them into **intermediate metabolites** that can be converted to **glucose**, **ketone bodies**, or undergo the citric **acid cycle**.

For more details: See [chapter 15 part 13 video](#) or chapter 15 section 5 in the textbook.
All **twenty common amino acids** can be converted into either pyruvate, acetyl-CoA, acetoacetyl-CoA, or a citric acid cycle intermediate. The details of how the **twenty common amino acids** are converted into the metabolic intermediates are far beyond the scope of this course. What is important to understand is that these conversions involve one or both of two important amino acid reactions: **transamination** and **oxidative deamination**. The general form for the transamination reaction is shown below.

In **transamination reactions**, the $\text{NH}_3^+$ from an amino acid is usually transferred to $\alpha$-ketoglutarate (an $\alpha$-keto acid).

Draw the products for the **transamination reaction** (shown below) of aspartic acid with $\alpha$-ketoglutarate.
All twenty common amino acids can be converted into either pyruvate, acetyl-CoA, acetoacetyl-CoA, or a citric acid cycle intermediate. The details of how the twenty common amino acids are converted into the metabolic intermediates are far beyond the scope of this course. What is important to understand is that these conversions involve one or both of two important amino acid reactions: transamination and oxidative deamination. The general form for the transamination reaction is shown below.

In transamination reactions, the NH$_3^+$ from an amino acid is usually transferred to $\alpha$-ketoglutarate (an $\alpha$-keto acid). Draw the products for the transamination reaction (shown below) of aspartic acid with $\alpha$-ketoglutarate.

For more help: See chapter 15 part 13 video or chapter 15 section 5 in the textbook.
15.25) All twenty common amino acids can be converted into either pyruvate, acetyl-CoA, acetoacetyl-CoA, or a citric acid cycle intermediate. The details of how the twenty common amino acids are converted into the metabolic intermediates are far beyond the scope of this course. What is important to understand is that these conversions involve one or both of two important amino acid reactions: transamination and oxidative deamination. The general form for the transamination reaction is shown below.

\[
\begin{align*}
\text{an amino acid} & \quad + \quad \text{an } \alpha\text{-keto acid} \\
\text{a new } \alpha\text{-keto acid} & \quad + \quad \text{a new amino acid}
\end{align*}
\]

In transamination reactions, the NH$_3^+$ from an amino acid is usually transferred to $\alpha$-ketoglutarate (an $\alpha$-keto acid). Draw the products for the transamination reaction (shown below) of aspartic acid with $\alpha$-ketoglutarate.

\[
\begin{align*}
\text{aspartic acid (Asp)} & \quad + \quad \text{$\alpha$-ketoglutarate} \\
\text{glutamic acid (Glu)} & \quad + \quad \text{(a new } \alpha\text{-keto acid)}
\end{align*}
\]

**ANSWER:**

For more details: See chapter 15 part 13 video or chapter 15 section 5 in the textbook.
15.26) In transamination reactions, α-ketoglutarate is converted to glutamic acid. The other important reaction in amino acid catabolism is oxidative deamination. In the previous problem, and most other transaminase reactions, α-ketoglutarate is converted to glutamic acid (an amino acid). In oxidative deamination, a quaternary ammonium group (\(-\text{NH}_3^+\)) is removed from glutamic acid, thereby producing ammonium (\(\text{NH}_4^+\)), NADH, \(\text{H}^+\) and one other product. Complete the oxidative deamination reaction below by drawing and naming the missing product.

\[
\begin{align*}
\text{NH}_3^+ &\quad \text{C} &\quad \text{C} &\quad O^- \\
\text{CH}_2 &\quad | &\quad | &\quad \text{O} \\
\text{CH}_2 &\quad \text{NH}_3^3 &\quad \text{O} \\
\text{O} &\quad \text{CH}_2 &\quad \text{O} \\
\text{C} &\quad \text{O^-} &\quad \text{H}_2\text{O} &\quad \text{NAD}^+ &\quad \text{NADH} &\quad \text{H}^+ &\quad \text{NH}_4^+ &\quad ?
\end{align*}
\]

 glutamic acid (Glu)
15.26) In transamination reactions, α-ketoglutarate is converted to glutamic acid. The other important reaction in amino acid catabolism is oxidative deamination. In the previous problem, and most other transaminase reactions, α-ketoglutarate is converted to glutamic acid (an amino acid). In oxidative deamination, a quaternary ammonium group (−NH₃⁺) is removed from glutamic acid, thereby producing ammonium (NH₄⁺), NADH, H⁺ and one other product. Complete the oxidative deamination reaction below by drawing and naming the missing product.

For more help: See chapter 15 part 13 video or chapter 15 section 5 in the textbook.
15.26) In **transamination** reactions, \( \alpha \)-ketoglutarate is converted to glutamic acid. The other important reaction in amino acid catabolism is **oxidative deamination**. In the previous problem, and most other transaminase reactions, \( \alpha \)-ketoglutarate is converted to glutamic acid (an amino acid). In oxidative deamination, a quaternary ammonium group (-\( \text{NH}_3^+ \)) is removed from glutamic acid, thereby producing ammonium (\( \text{NH}_4^+ \)), NADH, H\(^+\) and one other product. Complete the oxidative deamination reaction below by drawing and naming the missing product.

\[
\begin{align*}
\text{NH}_3^+ & \quad \text{C} & \quad \text{C} & \quad \text{O}^- & \quad + & \quad \text{H}_2\text{O} & \quad \text{NAD}^+ & \quad \text{NADH} & \quad + & \quad \text{H}^+ \\
\text{CH}_2 & \quad \text{CH}_2 & \quad \text{C} & \quad \text{O}^- & \quad \text{deaminase} & \quad \text{NH}_4^+ & \quad \text{C} & \quad \text{C} & \quad \text{O}^- \\
\text{glutamic acid (Glu)} & & & & & & \text{\( \alpha \)-ketoglutarate}
\end{align*}
\]

**NOTE:** The \( \alpha \)-ketoglutarate that is produced in the reaction is now free to accept a new quaternary ammonium group from another amino acid in a transamination reaction, as illustrated below.

For more details: See chapter 15 part 13 video or chapter 15 section 5 in the textbook.
15.27) Fill in the blanks in each of the statements below:

a) The free ammonium ions (NH$_4^+$) that are produced in oxidative deamination are toxic at elevated concentrations. Humans and most other terrestrial vertebrates are capable of converting the ammonium ions to ________.  

b) Kidney disease can result in the build up of dangerous amounts of urea. The urea concentration in blood is referred to as blood urea nitrogen (BUN). In cases of endstage renal (kidney) failure, safe BUN levels are exceeded, and patients must undergo ________ treatments.
15.27) Fill in the blanks in each of the statements below:

a) The free ammonium ions ($\text{NH}_4^+$) that are produced in oxidative deamination are toxic at elevated concentrations. Humans and most other terrestrial vertebrates are capable of converting the ammonium ions to ________.

b) Kidney disease can result in the build up of dangerous amounts of urea. The urea concentration in blood is referred to as blood urea nitrogen (BUN). In cases of endstage renal (kidney) failure, safe BUN levels are exceeded, and patients must undergo ________ treatments.

HINTS:

Part (a) choices:
- aldehydes
- fatty acids
- ethanol
- urea
- carbohydrates

Part (b) choices:
- blood transfusion
- dialysis
- chemotherapy
- massage
- hypnosis

For more help: See chapter 15 part 13 video or chapter 15 section 5 in the textbook.
15.27) Fill in the blanks in each of the statements below:

a) The free ammonium ions (NH$_4^+$) that are produced in oxidative deamination are toxic at elevated concentrations. Humans and most other terrestrial vertebrates are capable of converting the ammonium ions to **urea**.

b) Kidney disease can result in the build up of dangerous amounts of urea. The urea concentration in blood is referred to as blood urea nitrogen (BUN). In cases of endstage renal (kidney) failure, safe BUN levels are exceeded, and patients must undergo **dialysis** treatments.

**EXPLANATION:** A typical adult produces about 25 to 30 grams of urea per day. This occurs in a series of reactions called the **urea cycle**. Urea is filtered, by the kidneys, into the urinary track and then removed from the body during urination. Kidney disease can result in the build up of dangerous amounts of urea. In cases of **end-stage renal (kidney) failure**, safe blood urea nitrogen (BUN) levels are exceeded, and patients must undergo dialysis treatments. Dialysis involves artificial methods of urea removal. The most common of these is called **hemodialysis**. In hemodialysis, a patient’s blood is passed along one side of a porous membrane, while a dialyzing (urea-free) solution is passed along the other. The pores allow the diffusion of urea (but not cells, proteins, or other large compounds) from the blood into the dialyzing solution. After the blood is dialyzed, it is continuously returned to the patient. Hemodialysis takes several hours and is usually done multiple times per week. This process is not only time-consuming, but far from ideal because of many complications and side effects.

**For more details:** See chapter 15 part 13 video or chapter 15 section 5 in the textbook.
15.28)

a) A *metabolic pathway* in which a series of reactions is used to repeatedly break down or build up a compound is defined as a ______________ pathway.
   a) spiral
   b) walking
   c) circular
   d) linear

b) Give one example (from chapter 15), of each of the following types *metabolic pathways*:

i) linear pathway: ________________

ii) circular pathway: ________________

iii) spiral pathway: ________________
15.28)

a) A metabolic pathway in which a series of reactions is used to repeatedly break down or build up a compound is defined as a ∅ ___________ pathway.

HINT:  
- a) spiral
- b) walking
- c) circular
- d) linear

b) Give one example (from chapter 15) of each of the following types metabolic pathways:

i) linear pathway: ____________________

ii) circular pathway: ____________________

iii) spiral pathway: ____________________

HINTS:
A linear pathway is a series of reactions that are not repeated.
A circular pathway is a repeating series of reactions in which the final product is also an initial reactant.
a) A **metabolic pathway** in which a series of reactions is used to repeatedly break down or build up a compound is defined as a __________ pathway.

   a) spiral  
b) walking  
c) circular  
d) linear

b) Give one example (from chapter 15), of each of the following types **metabolic pathways**:

   i) linear pathway: __________ glycolysis ________ (or gluconeogenesis)

   ii) circular pathway: __________ citric acid cycle ________

   iii) spiral pathway: __________ β-oxidation ________ (or fatty acid anabolism)

---

**EXPLANATION:**

A **linear pathway** is a series of reactions that are not repeated. *Glycolysis* is characterized as a linear pathway.

A **circular pathway** is a repeating series of reactions in which the final product is also an initial reactant. The *citric acid cycle* is characterized as a circular pathway. In the citric acid cycle, *oxaloacetate* is not only a reactant in the first reaction, it is also the product of the last reaction.

A **spiral pathway** is a metabolic pathway in which a series of repeated reactions is used to break down (or build up) a compound. In a circular pathway, such as the citric acid cycle, the final product is exactly the same as one of the initial reactants. This is not the case for a spiral pathway. *β-oxidation* is an example of a spiral pathway.
15.29) Fill in the blanks in each of the statements below:

a) Digestion of carbohydrates involve breaking \( \text{glycosidic} \) bonds; breaking these bonds produces \( \text{monosaccharides} \).

b) Digestion of triglycerides involve breaking \( \text{ester} \) bonds; breaking these bonds produces \( \text{fatty acids} \) and \( \text{monoglycerides} \).

c) Digestion of proteins involve breaking \( \text{peptide} \) bonds; breaking these bonds produces \( \text{amino acids} \).
15.29) Fill in the blanks in each of the statements below:

a) Digestion of carbohydrates involve breaking _______ bonds; breaking these bonds produces ____________.

b) Digestion of triglycerides involve breaking_______ bonds; breaking these bonds produces ___________ and monoglycerides.

c) Digestion of proteins involve breaking_______ bonds; breaking these bonds produces ___________.

For more help:
Review the digestion of carbohydrates, protein, and triglycerides in your lecture notes or in these videos:
digestion of carbohydrates - chapter 15 part 3 video
digestion of protein - chapter 15 part 13 video
digestion of triglycerides - chapter 15 part 10 video
15.29) Fill in the blanks in each of the statements below:

a) Digestion of carbohydrates involve breaking **glycosidic** bonds; breaking these bonds produces **monosaccharides**.

b) Digestion of triglycerides involve breaking **ester** bonds; breaking these bonds produces **fatty acids** and monoglycerides.

c) Digestion of proteins involve breaking **peptide** bonds; breaking these bonds produces **amino acids**.

For more details:
Review the digestion of carbohydrates, protein, and triglycerides in your lecture notes or in these videos:
- digestion of carbohydrates - [chapter 15 part 3 video](#)
- digestion of protein - [chapter 15 part 13 video](#)
- digestion of triglycerides - [chapter 15 part 10 video](#)
15.30) Match each of the following **descriptions** with the appropriate **catabolic processes**.

<table>
<thead>
<tr>
<th>Descriptions:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>a)</strong> Carbohydrates are hydrolyzed to monosaccharides. Triglycerides are “partially” hydrolyzed to fatty acid salts and monoglyceride. Proteins are hydrolyzed to amino acids.</td>
</tr>
<tr>
<td><strong>b)</strong> A quaternary ammonium group (-NH$_3^+$) is removed from glutamic acid, thereby producing ammonium (NH$_4^+$) and α-ketoglutarate.</td>
</tr>
<tr>
<td><strong>c)</strong> Glycogen is converted to glucose.</td>
</tr>
<tr>
<td><strong>d)</strong> A spiral metabolic pathway in which fatty acids are converted to acetyl-CoA, NADH and FADH$_2$.</td>
</tr>
<tr>
<td><strong>e)</strong> Triglycerides that are stored primarily in adipose (fat) cells and muscle cells are broken down into fatty acids and glycerol.</td>
</tr>
<tr>
<td><strong>f)</strong> A linear metabolic pathway in which glucose is converted into two pyruvate ions.</td>
</tr>
<tr>
<td><strong>g)</strong> A circular metabolic pathway in which acetyl-CoA is metabolized to produce ATP, NADH, and FADH$_2$.</td>
</tr>
</tbody>
</table>

**Catabolic Processes Choices:**
- Glycolysis
- Glycogenolysis
- Digestion
- Oxidative Deamination
- Citric Acid Cycle
- β-oxidation
- Lypolysis
15.30) Match each of the following **descriptions** with the appropriate **catabolic processes**.

**Descriptions:**

a) Carbohydrates are hydrolyzed to monosaccharides. Triglycerides are “partially” hydrolyzed to fatty acid salts and monoglyceride. Proteins are hydrolyzed to amino acids. **HINT:** The answer to part (a) is **Digestion**. Review the descriptions of the other processes in your lecture notes.

b) A quaternary ammonium group (-NH₃⁺) is removed from glutamic acid, thereby producing ammonium (NH₄⁺) and α-ketoglutarate.

c) Glycogen is converted to glucose.

d) A spiral metabolic pathway in which fatty acids are converted to acetyl-CoA, NADH and FADH₂.

e) Triglycerides that are stored primarily in adipose (fat) cells and muscle cells are broken down into fatty acids and glycerol.

f) A linear metabolic pathway in which glucose is converted into two pyruvate ions.

g) A circular metabolic pathway in which acetyl-CoA is metabolized to produce ATP, NADH, and FADH₂.

**Catabolic Processes Choices:**
- Glycolysis
- Glycogenolysis
- Digestion
- Oxidative Deamination
- Citric Acid Cycle
- β-oxidation
- Lypolysis

For more help: See chapter 15 part 14 video or chapter 15 section 6 in the textbook.
15.30) Match each of the following **descriptions** with the appropriate **catabolic processes**.

### Descriptions:

**a)** Carbohydrates are hydrolyzed to monosaccharides. Triglycerides are “partially” hydrolyzed to fatty acid salts and monoglyceride. Proteins are hydrolyzed to amino acids.  **Digestion**

**b)** A quaternary ammonium group (-NH$_3^+$) is removed from glutamic acid, thereby producing ammonium (NH$_4^+$) and $\alpha$-ketoglutarate.  **Oxidative Deamination**

**c)** Glycogen is converted to glucose.  **Glycogenolysis**

**d)** A spiral metabolic pathway in which fatty acids are converted to acetyl-CoA, NADH and FADH$_2$.  **$\beta$-oxidation**

**e)** Triglycerides that are stored primarily in adipose (fat) cells and muscle cells are broken down into fatty acids and glycerol.  **Lypolysis**

**f)** A linear metabolic pathway in which glucose is converted into two pyruvate ions.  **Glycolysis**

**g)** A circular metabolic pathway in which acetyl-CoA is metabolized to produce ATP, NADH, and FADH$_2$.  **Citric Acid Cycle**

### Catabolic Processes Choices:

- Glycolysis
- Glycogenolysis
- Digestion
- Oxidative Deamination
- Citric Acid Cycle
- $\beta$-oxidation
- Lypolysis

For more details: See [chapter 15 part 14 video](#) or chapter 15 section 6 in the textbook.
15.31) Match each of the following **descriptions** with the appropriate **anabolic processes**.

**Descriptions:**

a) Glucose is converted to glycogen.

b) Amino acids are converted to proteins.

c) The conversion of non-carbohydrate species into glucose. This process is similar to the reverse of glycolysis.

d) Fatty acids are produced by a spiral pathway that works in the opposite direction of β-oxidation; it builds up fatty acyl-CoA by a repeating series of reactions that add acetyl-CoA to a growing fatty acyl-CoA structure.

**Anabolic Processes Choices:**
- Fatty Acid Synthesis
- Amino Acid Synthesis
- Gluconeogenesis
- Fatty Acid Cycle
- Protein Synthesis
- Glycogenesis
- Gluco-Glycosylation

This is the last question.
15.31) Match each of the following descriptions with the appropriate anabolic processes.

### Descriptions:

a) Glucose is converted to glycogen.

b) Amino acids are converted to proteins.

c) The conversion of non-carbohydrate species into glucose. This process is similar to the reverse of glycolysis.

d) Fatty acids are produced by a spiral pathway that works in the opposite direction of β-oxidation; it builds up fatty acyl-CoA by a repeating series of reactions that add acetyl-CoA to a growing fatty acyl-CoA structure.

### Anabolic Processes Choices:

HINT: Fatty Acid Synthesis
- Amino Acid Synthesis
- Gluconeogenesis
- Fatty Acid Cycle
- Protein Synthesis
- Glycogenesis
- Gluco-Glycosylation

### For more help:
See chapter 15 part 14 video or chapter 15 section 6 in the textbook.
15.31) Match each of the following descriptions with the appropriate anabolic processes.

### Descriptions:

a) Glucose is converted to glycogen. **Glycogenesis**

b) Amino acids are converted to proteins. **Protein Synthesis**

c) The conversion of non-carbohydrate species into glucose. This process is similar to the reverse of glycolysis. **Gluconeogenesis**

d) Fatty acids are produced by a spiral pathway that works in the opposite direction of β-oxidation; it builds up fatty acyl-CoA by a repeating series of reactions that add acetyl-CoA to a growing fatty acyl-CoA structure. **Fatty Acid Synthesis**

### Anabolic Processes Choices:

- Fatty Acid Synthesis
- Amino Acid Synthesis
- Gluconeogenesis
- Fatty Acid Cycle
- Protein Synthesis
- Glycogenesis
- Gluco-Glycosylation

**For more details:** See chapter 15 part 14 video or chapter 15 section 6 in the textbook.