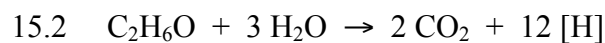


## CHAPTER 15: ANSWERS TO SELECTED PROBLEMS

### SAMPLE PROBLEMS (“Try it yourself”)

15.1 Our bodies can carry out the second reaction, because it requires less energy than we get from breaking down a molecule of ATP. However, the first reaction requires substantially more than 7.3 kcal of energy, so ATP does not supply enough energy for the first reaction.



15.4 We obtain a total of 34.5 molecules of ATP.

$$12 \text{NADH} \times 2.5 = 30 \text{ATP}$$

$$3 \text{FADH}_2 \times 1.5 = 4.5 \text{ATP}$$

$$\text{Total} = 34.5 \text{ATP}$$

15.5 Breaking down a molecule of myristic acid requires 6 cycles of beta oxidation, and produces 7 molecules of acetyl-CoA.

15.6 We obtain 92 molecules of ATP when we break down one molecule of myristic acid. In Sample Problem 15.5, we found that breaking down myristic acid requires 6 beta oxidation cycles and produces 7 molecules of acetyl-CoA:

$$6 \text{ cycles of beta oxidation produce } 6 \text{ NADH} + 6 \text{ FADH}_2$$

$$7 \text{ citric acid cycles produce } 21 \text{ NADH} + 7 \text{ FADH}_2 + 7 \text{ ATP}$$

We make a total of  $6 + 21 = 27$  molecules of NADH.

$$27 \text{ NADH} \times 2.5 = 67.5 \text{ molecules of ATP}$$

We make a total of  $6 + 7 = 13$  molecules of FADH<sub>2</sub>.

$$13 \text{ FADH}_2 \times 1.5 = 19.5 \text{ molecules of ATP}$$

Now we can add up all of the ATP. Remember that we made 7 ATP in the citric acid cycle, and we must break down 2 ATP to activate the fatty acid.

$$7 \text{ ATP} \quad (\textit{formed during the citric acid cycle})$$

$$67.5 \text{ ATP} \quad (\textit{from the oxidation of NADH})$$

$$19.5 \text{ ATP} \quad (\textit{from the oxidation of FADH}_2)$$

$$-2 \text{ ATP} \quad (\textit{broken down to activate the myristic acid})$$

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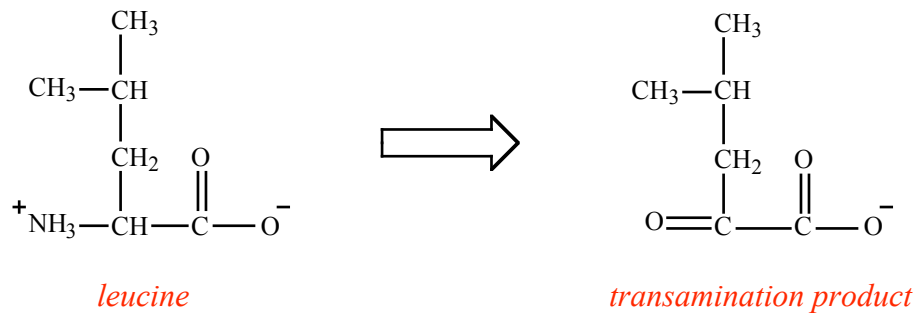
$$\mathbf{92 \text{ ATP}}$$

15.7 We make 117 molecules of ATP when we oxidize a molecule of linoleic acid. Since linoleic acid contains two double bonds, we make two fewer molecules of FADH<sub>2</sub>, which translates to  $2 \times 1.5 = 3$  fewer molecules of ATP.

15.8 We make 19.5 moles of ATP when we burn 100 g of glycerol (the calculator answer is 19.54524724 moles). The formula weight of glycerol is 92.094, so we make 18 moles of ATP when we burn 92.094 g of glycerol:

$$100 \text{ g glycerol} \times \frac{18 \text{ moles ATP}}{92.094 \text{ g glycerol}} = 19.5 \text{ moles ATP}$$

15.9 Here are the structures of leucine and the product of the transamination.



15.10 The overall ATP yield is 26 molecules of ATP.

$$\begin{array}{r}
 9 \text{ NADH} \times 2.5 = 22.5 \text{ ATP (from the oxidation of the NADH)} \\
 3 \text{ FADH}_2 \times 1.5 = 4.5 \text{ ATP (from the oxidation of the FADH}_2\text{)} \\
 1 \text{ ATP (formed by substrate-level phosphorylation)} \\
 1 \text{ NH}_4^+ \times 2 = -2 \text{ ATP (broken down in the urea cycle)} \\
 \hline
 \mathbf{26 \text{ ATP}}
 \end{array}$$

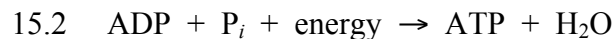
15.11 We must break down 800 molecules of ATP to make this protein. It takes 4 molecules of ATP to place one amino acid into the polypeptide chain:

$$200 \text{ amino acids} \times 4 = 800 \text{ ATP}$$

## END OF SECTION PROBLEMS

### Section 15.1

15.1 ATP stores the energy that is produced by catabolic reactions, and makes that energy available for anabolic reactions (and all other energy-requiring processes).



15.3 This is an anabolic process, because it is building a large molecule from small pieces. Like all anabolic processes, building an enzyme absorbs energy.

15.4 ATP contains three phosphate groups, whereas ADP contains only two.

15.5 The first reaction requires energy from ATP. The chemical equation has the energy (3.4 kcal) on the left side, so the reaction consumes energy. (The second reaction produces energy and does not need any additional energy from ATP.)

15.6 The first reaction goes to completion, because ATP supplies more than enough energy for this reaction to occur. The second reaction requires more energy than ATP can supply, so it produces only a small concentration of product.

## Section 15.2

15.7 The carbon atoms become incorporated into CO<sub>2</sub> molecules. The hydrogen atoms are transferred to a redox coenzyme (NAD<sup>+</sup> or FAD).

15.8 The additional hydrogen atoms come from water molecules. (The oxygen atoms from water are used to make CO<sub>2</sub>.)

15.9 Our bodies oxidize NADH and FADH<sub>2</sub>, producing energy that is stored in the form of ATP.

15.10 The molecular formula of 3-hydroxybutyric acid is C<sub>4</sub>H<sub>8</sub>O<sub>3</sub>, and the chemical equation is:  
$$\text{C}_4\text{H}_8\text{O}_3 + 5 \text{H}_2\text{O} \rightarrow 4 \text{CO}_2 + 18 [\text{H}]$$

15.11  $\text{C}_4\text{H}_8\text{O}_3 + 5 \text{H}_2\text{O} + 2 \text{FAD} + 7 \text{NAD}^+ \rightarrow 4 \text{CO}_2 + 2 \text{FADH}_2 + 7 \text{NADH} + 7 \text{H}^+$   
Four of the H atoms are transferred to FAD, so we need two molecules of FAD (remember that each FAD bonds to two H atoms) and we make two molecules of FADH<sub>2</sub>. The other 14 hydrogen atoms are transferred to NAD<sup>+</sup>, but only 7 of them actually bond to NAD<sup>+</sup> (to make NADH); the other 7 become H<sup>+</sup> ions.

## Section 15.3

15.12 Mitochondria carry out the oxidation reactions in a cell, harnessing the energy of these reactions to make ATP.

15.13 The electron transport chain is a sequence of reactions that removes hydrogen atoms from NADH and FADH<sub>2</sub> and transfers them to O<sub>2</sub>. The final products of the electron transport chain are NAD<sup>+</sup>, FAD, and H<sub>2</sub>O. In the process, the electron transport chain moves hydrogen ions through the inner membrane of the mitochondrion, producing a concentration gradient (that will be harnessed to make ATP).

15.14 ATP synthase combines ADP with phosphate to make ATP. The enzyme gets the energy it needs by allowing H<sup>+</sup> ions to move back into the matrix, harnessing the energy of the concentration gradient.

15.15 The electrons come from the hydrogen atoms that were removed from NADH and FADH<sub>2</sub>, and the end up on oxygen atoms (converting the oxygen into O<sup>2-</sup>).

15.16 In a concentration gradient, there is a higher concentration of a solute on one side of a membrane than on the other side. In a charge gradient, one side of a membrane has a higher concentration of positive ions than negative ions, and the other side has a higher concentration of negative ions than positive ions. The electron transport chain produces both types of gradient by moving H<sup>+</sup> across the inner membrane. The concentration of H<sup>+</sup> becomes higher outside the membrane than inside the membrane (a concentration gradient). In addition, the extra H<sup>+</sup> outside the membrane produces an excess of positive charge, while the missing H<sup>+</sup> inside the membrane leaves an excess of negative charge (a charge gradient).

15.17 The electron transport chain moves 10 H<sup>+</sup> ions for each NADH that it oxidizes, so it moves a total of 10 x 4 = 40 H<sup>+</sup> ions when it oxidizes four molecules of NADH. Four H<sup>+</sup> ions must return to the matrix for each ATP that is made available to the cell, so the cell will gain a total of 40 ÷ 4 = 10 molecules of ATP.

15.18 The fourth hydrogen ion is used to transport ATP out of the mitochondrion.

15.19 The cell will obtain 8 molecules of ATP.

$$2 \text{ NADH} \times 2.5 = 5 \text{ ATP}$$

$$2 \text{ FADH}_2 \times 1.5 = 3 \text{ ATP}$$

$$\text{Total} = 8 \text{ ATP}$$

#### Section 15.4

15.20 In an activation reaction, a cell uses energy from ATP to build a high-energy molecule (usually a compound that contains a phosphate group attached to an organic fragment). The ATP breaks down into ADP and phosphate.

15.21 In glycolysis, glucose is broken down into two pyruvate ions.

15.22 Lactic acid fermentation is anaerobic because it does not make any NADH or FADH<sub>2</sub>, so the body does not require oxygen when it carries out this pathway. Any pathway that makes NADH or FADH<sub>2</sub> requires oxygen, because these coenzymes must be converted back into NAD<sup>+</sup> and FAD. The electron transport chain uses oxygen from the air to do this.

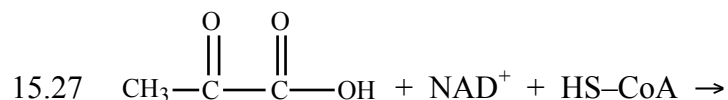
15.23 The NADH for this reaction is made in one of the earlier reactions of glycolysis.

15.24 Normal glycolysis makes 2 molecules of ATP and two molecules of NADH.

15.25 A substrate-level phosphorylation is a reaction that makes ATP without involving the electron-transport chain.

15.26 Two of the reactions of glycolysis break down a molecule of ATP into ADP and phosphate. Therefore, when we break down one molecule of glucose to pyruvate ions, our net gain is two molecule of ATP (i.e. we end up with two more molecules of ATP than we started with).

#### Section 15.5



15.28 There are two decarboxylation reactions in the citric acid cycle (reactions 3 and 4). This is reasonable, because the citric acid cycle must convert citrate ion into oxaloacetate ion. Citrate ion contains six carbon atoms and oxaloacetate ion contains only four, so the citric acid cycle must remove two carbon atoms from the original citrate skeleton.

15.29 There are four oxidation steps in the citric acid cycle (reactions 3, 4, 6 and 8). This is reasonable, because each oxidation step produces two hydrogen atoms (bonded to NAD or FAD), and the overall cycle must produce eight hydrogen atoms.

15.30 The first step of the cycle combines the acetyl group with oxaloacetate ion. The product of this reaction is citrate ion.

15.31 The alcohol group in citrate is a tertiary alcohol, so it cannot be oxidized. Step 2 of the citric acid cycle converts the tertiary alcohol to a secondary alcohol, so the alcohol group can be oxidized in the next step.

15.32 The citric acid cycle produces three molecules of NADH, one molecule of FADH<sub>2</sub>, and one molecule of ATP. (Actually, the cycle produces GTP rather than ATP, but these two compounds are functionally equivalent to one another.)

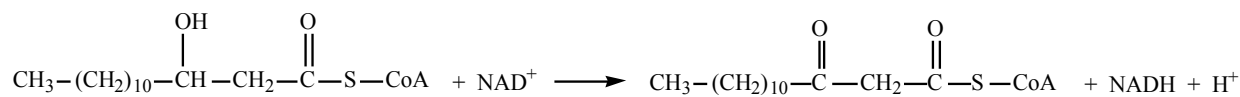
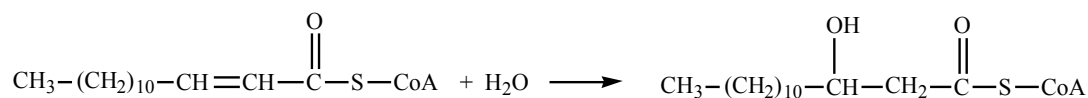
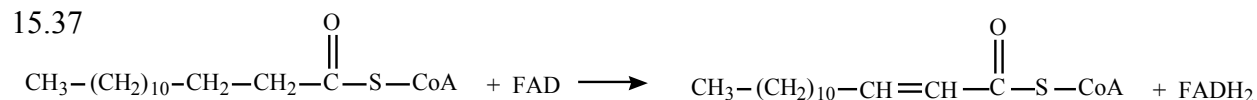
15.33 A total of 10 molecules of ATP are formed when one molecule of acetyl-CoA is broken down.

15.34 As shown on page 15-33, a total of 32 molecules of ATP are formed when one molecule of glucose is broken down. Four of these ATP molecules are made by substrate-level phosphorylations (two in glycolysis and two in the citric acid cycle), so the other 28 ATP molecules are formed by oxidative phosphorylation.

## Section 15.6



15.36 This reaction activates the fatty acid so it can be broken down into acetyl-CoA.



15.38 Stearic acid contains 18 carbon atoms, so 8 cycles of beta oxidation are required to break it down, and 9 molecules of acetyl-CoA are formed.

15.39 The total ATP yield is 120 molecules of ATP.

8 cycles of beta oxidation produce 8 NADH + 8 FADH<sub>2</sub>

9 citric acid cycles produce 27 NADH + 9 FADH<sub>2</sub> + 9 ATP

We make a total of 8 + 27 = 35 molecules of NADH.

35 NADH x 2.5 = 87.5 molecules of ATP

We make a total of 8 + 9 = 17 molecules of FADH<sub>2</sub>.

17 FADH<sub>2</sub> x 1.5 = 25.5 molecules of ATP

Now we can add up all of the ATP. Remember that we made 9 ATP in the citric acid cycle, and we must break down 2 ATP to activate the fatty acid.

9 ATP	<i>(formed during the citric acid cycle)</i>
87.5 ATP	<i>(from the oxidation of NADH)</i>
25.5 ATP	<i>(from the oxidation of FADH<sub>2</sub>)</i>
- 2 ATP	<i>(broken down to activate the stearic acid)</i>
<b>120 ATP</b>	

15.40 Your body makes 42.2 moles of ATP (the calculator answer is 42.18400663 moles). The molecular formula of stearic acid is C<sub>18</sub>H<sub>36</sub>O<sub>2</sub>, and the formula weight is 284.468. The calculation is:

$$100 \text{ g stearic acid} \times \frac{120 \text{ moles ATP}}{284.468 \text{ g stearic acid}} = 42.2 \text{ moles ATP}$$

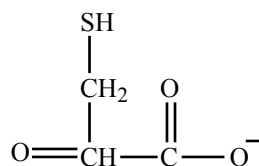
(In Problem 15.39, we found that we get 120 molecules of ATP from one molecule of stearic acid.)

15.41 For each double bond in an unsaturated fatty acid, we lose one molecule of FADH<sub>2</sub>, because the dehydrogenation step of beta oxidation will not occur when a double bond is already present.

### Section 15.7

15.42 This reduces the number of different reactions our bodies must carry out. As a result, we do not need to make as many different enzymes. Building an enzyme requires a lot of energy, so we reduce the amount of energy we must expend to break down amino acids.

15.43



15.44 The ion is ammonium ion (NH<sub>4</sub><sup>+</sup>).

15.45 The urea cycle converts ammonium ions into the NH<sub>2</sub> groups of urea. Urea is much less toxic than ammonium ion, so we can store urea rather than excreting it continuously.



15.56 A futile cycle is a pair of metabolic pathways that occur at the same time and that undo one another (wasting energy in the process). One pathway builds a molecule, while the other breaks the molecule down.

15.57 Cells prevent futile cycles by using different enzymes for each pathway, and by carrying out the pathways in different locations in the cell.

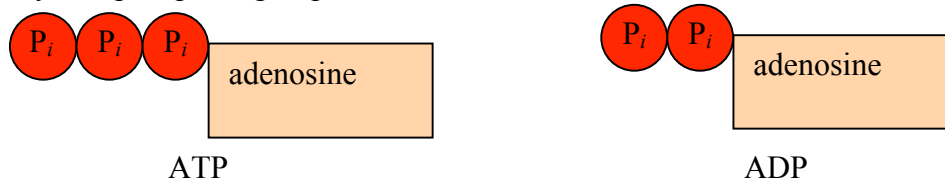
15.58 A high concentration of ATP should have the opposite effect on enzymes 1 and 2, to prevent a futile cycle. Therefore, a high concentration of ATP should speed up enzyme 2.

### CUMULATIVE PROBLEMS (Odd-numbered problems only)

15.59 Some examples of catabolic pathways are glycolysis, the citric acid cycle, and the beta oxidation of fatty acids. All of these pathways (and all other catabolic pathways) produce energy.

15.61 a) This is an anabolic pathway, since it builds a large molecule from small pieces.  
b) Like all anabolic pathways, this pathway breaks down ATP to supply the needed energy.

15.63 ATP contains adenosine bonded to three phosphate groups, and ADP is similar but contains only two phosphate groups.



15.65 This reaction produces a similar amount of energy to the breakdown of ATP, because both reactions break the bond between two phosphate groups.

15.67 The first reaction can be harnessed to make a molecule of ATP (from ADP and phosphate), because it produces more than 7.3 kcal of energy.

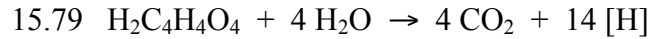
15.69 The enzymes of the electron transport chain remove electrons from NADH and  $FADH_2$ , and pass these electrons from one enzyme to another, eventually placing them on an oxygen atom. Each enzyme simultaneously pumps hydrogen ions from the mitochondrial matrix to the intermembrane space, using the energy from the electron transport reactions to carry out this active transport.

15.71 The products of this reaction are  $NAD^+$ , an  $H^+$  ion, and two electrons. The chemical equation is:  $NADH \rightarrow NAD^+ + H^+ + 2 e^-$

15.73 A total of ten hydrogen ions are transferred through the inner membrane.

15.75 Mitochondria can break down stearic acid and phenylalanine to produce energy. They cannot break down glucose, because the enzymes of glycolysis are located in the cytosol.

15.77 Choices b, c and d all produce energy that is used to make ATP.



15.81 The mitochondrion can make 10 molecules of ATP. Mitochondria can make 2.5 molecules of ATP for each NADH that they oxidize, so  $2.5 \times 4 = 10$  ATP.

15.83 The total ATP yield is 12.5 molecules of ATP.

$$\begin{array}{r} 4 \text{ NADH} \times 2.5 = 10 \text{ ATP (from the oxidation of NADH)} \\ 1 \text{ FADH}_2 \times 1.5 = 1.5 \text{ ATP (from the oxidation of FADH}_2) \\ \hline 1 \text{ ATP (formed by substrate-level phosphorylation)} \\ \hline \text{Total} = 12.5 \text{ ATP} \end{array}$$

15.85 The starting materials are glucose, 2 molecules of ADP, 2 phosphate ions, and 2 molecules of  $\text{NAD}^+$ . The products are 2 pyruvate ions, 2 molecules of ATP, and 2 molecules of NADH. (I've ignored hydrogen ions in this answer.)

15.87 This is an example of alcoholic fermentation, in which the starch is broken down into ethanol and  $\text{CO}_2$ . The  $\text{CO}_2$  is responsible for the "fizz" in the beer.

15.89 a) The starting materials are glucose, 2 molecules of ADP, and 2 phosphate ions. The products are 2 lactate ions and 2 molecules of ATP.

b) Two molecules of ATP are produced for each molecule of glucose that breaks down.

15.91 The breakdown of acetyl-CoA produces 10 molecules of ATP (via the citric acid cycle).

15.93 Four molecules of ATP are produced in substrate-level phosphorylations (two during glycolysis and two during the citric acid cycle). The other 28 ATP molecules are made by oxidative phosphorylation.

$$\text{Percentage of ATP formed by substrate-level phosphorylations: } \frac{4 \text{ ATP}}{32 \text{ ATP}} \times 100\% = 12.5\%$$

$$\text{Percentage of ATP formed by oxidative phosphorylation: } \frac{28 \text{ ATP}}{32 \text{ ATP}} \times 100\% = 87.5\%$$

15.95 We get 12.5 molecules of ATP when we break down one oxaloacetate ion. The first reaction (breaking oxaloacetate into pyruvate and  $\text{CO}_2$ ) does not make a high-energy molecule, so oxaloacetate ion and pyruvate ion give us the same number of ATP molecules:

Oxidative decarboxylation of pyruvate: 1 NADH

Citric acid cycle: 3 NADH, 1  $\text{FADH}_2$ , 1 ATP

Total high-energy molecules: 4 NADH, 1  $\text{FADH}_2$ , 1 ATP

$$4 \text{ NADH} \times 2.5 = 10 \text{ ATP}$$

$$1 \text{ FADH}_2 \times 1.5 = 1.5 \text{ ATP}$$

$$\text{Total ATP} = 10 + 1.5 + 1 = 12.5$$

15.97 a) We get 80 molecules of ATP when we break down three molecules of ribose. It helps to think of this in two steps.

Step 1: breaking down 3 ribose molecules into 5 pyruvate ions

This step produces 5 NADH and 5 ATP for every three molecules of ribose.

Step 2: breaking down 5 pyruvate ions into CO<sub>2</sub>

As we saw in problem 15.95, we get 4 NADH, 1 FADH<sub>2</sub>, and 1 ATP when we break down one pyruvate ion. Since we are breaking down five pyruvate ions, we get a total of 20 NADH, 5 FADH<sub>2</sub>, and 5 ATP.

Now we can work out the total:

5 NADH in step 1 + 20 NADH in step 2 = 25 NADH total

no FADH<sub>2</sub> in step 1 + 5 FADH<sub>2</sub> in step 2 = 5 FADH<sub>2</sub> total

5 ATP in step 1 + 5 ATP in step 2 = 10 ATP total

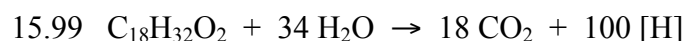
Finally, we account for oxidative phosphorylation:

25 NADH x 2.5 = 62.5 ATP

5 FADH<sub>2</sub> x 1.5 = 7.5 ATP

Total ATP = 62.5 + 7.5 + 10 = 80 ATP

b) In part a, we saw that we get 80 molecules of ATP from three molecules of ribose. For one molecule of ribose, we get  $80 \div 3 = 26.7$  molecules of ATP.



15.101 a) The ATP yield is 50 molecules of ATP from one molecule of caprylic acid. Caprylic acid has eight carbon atoms, so it must undergo three cycles of beta oxidation, which produce four molecules of acetyl-CoA.

3 cycles of beta oxidation produce 3 NADH + 3 FADH<sub>2</sub>

4 citric acid cycles produce 12 NADH + 4 FADH<sub>2</sub> + 4 ATP

We make a total of 3 + 12 = 15 molecules of NADH.

15 NADH x 2.5 = 37.5 molecules of ATP

We make a total of 3 + 4 = 7 molecules of FADH<sub>2</sub>.

7 FADH<sub>2</sub> x 1.5 = 10.5 molecules of ATP

Now we can add up all of the ATP. Remember that we made 4 ATP in the citric acid cycle, and we must break down 2 ATP to activate the fatty acid.

4 ATP	<i>(formed during the citric acid cycle)</i>
37.5 ATP	<i>(from the oxidation of NADH)</i>
10.5 ATP	<i>(from the oxidation of FADH<sub>2</sub>)</i>
-2 ATP	<i>(broken down to activate the caprylic acid)</i>
<hr/>	
<b>50 ATP</b>	

b) We get four molecules of ATP from substrate-level phosphorylations (the four ATP molecules that are formed in the citric acid cycle).

15.103 The overall yield is 336 molecules of ATP (wow!).

Table 15.6 (on page 15-50) gives the ATP yield from one molecule of glycerol as 18 molecules of ATP. We can calculate the ATP yield from palmitic acid in the usual fashion, noting first that palmitic acid contains 16 carbon atoms, so it requires 7 cycles of beta oxidation and produces 8 molecules of acetyl-CoA. For one molecule of palmitic acid, we get:

7 cycles of beta oxidation produce 7 NADH + 7 FADH<sub>2</sub>

8 citric acid cycles produce 24 NADH + 8 FADH<sub>2</sub> + 8 ATP

We make a total of 7 + 24 = 31 molecules of NADH.

31 NADH x 2.5 = 77.5 molecules of ATP

We make a total of 7 + 8 = 15 molecules of FADH<sub>2</sub>.

15 FADH<sub>2</sub> x 1.5 = 22.5 molecules of ATP

Now we can add up all of the ATP we get from a molecule of palmitic acid. Remember that we made 4 ATP in the citric acid cycle, and we must break down 2 ATP to activate the fatty acid.

8 ATP	<i>(formed during the citric acid cycle)</i>
77.5 ATP	<i>(from the oxidation of NADH)</i>
22.5 ATP	<i>(from the oxidation of FADH<sub>2</sub>)</i>
- 2 ATP	<i>(broken down to activate the palmitic acid)</i>
<b>106 ATP</b>	<i>(from one molecule of palmitic acid)</i>

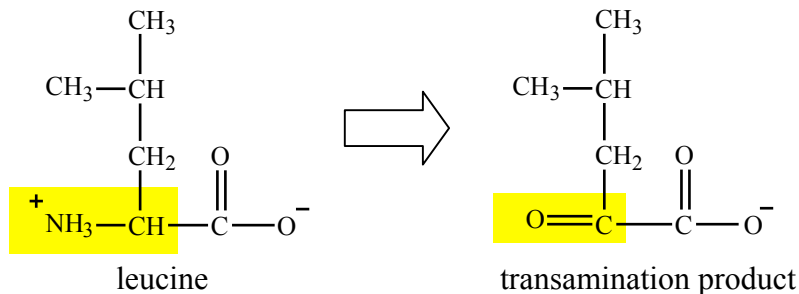
Finally, we can calculate the overall ATP yield. We get 106 x 3 = 318 molecules of ATP from the three molecules of palmitic acid, and we get an additional 18 molecules of ATP from the glycerol, giving us a total of 318 + 18 = 336 molecules of ATP.

15.105 You get 41.6 moles of ATP per 100 grams of tripalmitin. The formula weight of tripalmitin is 807.294, so the calculation is:

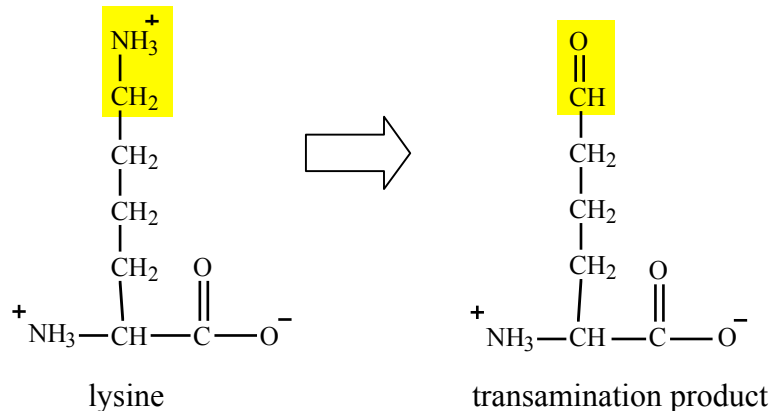
$$100 \text{ g tripalmitin} \times \frac{336 \text{ moles ATP}}{807.294 \text{ g tripalmitin}} = 41.6 \text{ moles ATP}$$



15.109



15.111



15.113 The overall yield is 10.5 molecules of ATP.

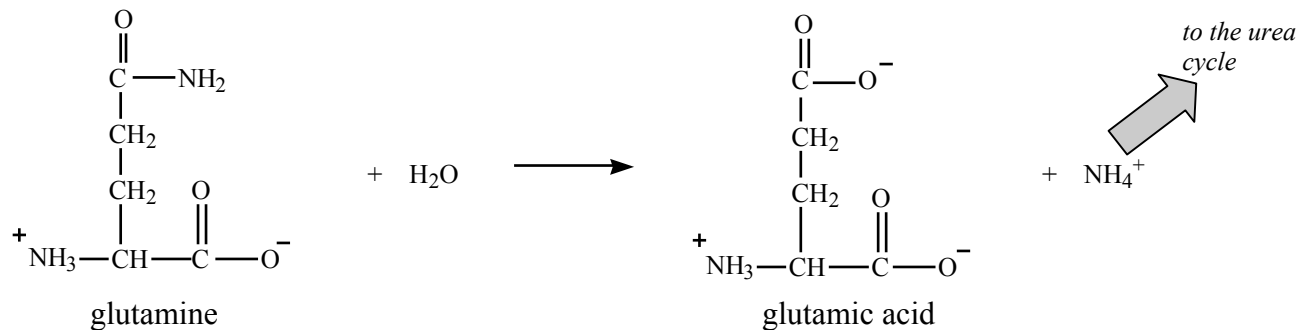
$$\begin{aligned}
 4 \text{ NADH} \times 2.5 &= 10 \text{ ATP (from the oxidation of NADH)} \\
 1 \text{ FADH}_2 \times 1.5 &= 1.5 \text{ ATP (from the oxidation of FADH}_2\text{)} \\
 &1 \text{ ATP (formed directly during the pathway)}
 \end{aligned}$$

$$\text{Total ATP formed} = 10 + 1.5 + 1 = 12.5 \text{ ATP}$$

The  $\text{NH}_4^+$  ion is metabolized in the urea cycle, which consumes 2 ATP. We must subtract this from the total to get the overall ATP yield.

$$\text{Overall ATP yield} = 12.5 - 2 = 10.5 \text{ ATP}$$

15.115 Glutamine contains a nitrogen atom in the side chain, while glutamic acid does not. When your body breaks down glutamine, it must remove the nitrogen from the amide group in the side chain. This amide nitrogen is removed in the form of  $\text{NH}_4^+$ , which is then processed by the urea cycle. The urea cycle consumes 2 molecules of ATP, so the overall ATP yield for glutamine is two molecules of ATP less than the yield for glutamic acid.



15.117 The reaction given in the problem makes one molecule of NADH and one molecule of  $\text{FADH}_2$ , and it breaks down one molecule of ATP. It also makes a  $\text{NH}_4^+$  ion, which must be processed by the urea cycle. The net ATP yield from this reaction is 1 molecule of ATP, as shown below:

$$\begin{array}{r}
 2.5 \text{ ATP (from NADH)} \\
 + 1.5 \text{ ATP (from FADH}_2\text{)} \\
 - 1 \text{ ATP (broken down in the reaction)} \\
 - 2 \text{ ATP (broken down in the urea cycle)} \\
 \hline
 1 \text{ ATP (overall yield from the reaction in the problem)}
 \end{array}$$

The three molecules of acetyl-CoA are broken down to  $\text{CO}_2$  by the citric acid cycle. The citric acid cycle makes one ATP, three NADH, and one  $\text{FADH}_2$  each time it consumes a molecule of acetyl-CoA. Since we have three molecules of acetyl-CoA, we multiply these amounts by three: we get 3 ATP, 9 NADH, and 3  $\text{FADH}_2$ . Converting these into ATP:

$$\begin{array}{r}
 9 \text{ NADH} \times 2.5 = 22.5 \text{ ATP (from NADH)} \\
 3 \text{ FADH}_2 \times 1.5 = 4.5 \text{ ATP (from FADH}_2\text{)} \\
 + 3 \text{ ATP (formed directly)} \\
 \hline
 30 \text{ ATP (total from the citric acid cycle)}
 \end{array}$$

The grand total is  $1 + 30 = 31$  ATP from the breakdown of one molecule of leucine.

15.117 The reaction in the problem makes one molecule of NADH and one  $\text{NH}_4^+$  ion. We get 2.5 ATP from the NADH, but we must break down 2 ATP to deal with the  $\text{NH}_4^+$  ion, so the net yield of ATP from this reaction is  $2.5 - 2 = 0.5$  ATP.

This reaction also makes a molecule of pyruvate. Your body first converts pyruvate into acetyl-CoA, making one molecule of NADH in the process. This NADH gives you an additional 2.5 molecules of ATP.

You then break down acetyl-CoA via the citric acid cycle, which gives 3 NADH, 1  $\text{FADH}_2$ , and 1 ATP. The overall ATP yield from the citric acid cycle is 10 ATP (7.5 from the NADH, 1.5 from the  $\text{FADH}_2$ , and 1 formed directly).

The grand total is  $0.5 + 2.5 + 10 = 13$  molecules of ATP.

15.121 a) The ATP yield is 22.2 moles of ATP per 100 g of valine (the calculator answer is 22.19414757). The molecular formula of valine is  $\text{C}_5\text{H}_{11}\text{NO}_2$ , and the formula weight of valine is 117.148. The calculation is:

$$100 \text{ g valine} \times \frac{26 \text{ moles ATP}}{117.148 \text{ g valine}} = 22.2 \text{ moles ATP}$$

b) The ATP yield is 26.2 moles of ATP per 100 g of valine (the calculator answer is 26.22765605). When we use valine within a polypeptide, the molecular formula is  $\text{C}_5\text{H}_9\text{NO}$ , and the formula weight is 99.132. The calculation is:

$$100 \text{ g valine} \times \frac{26 \text{ moles ATP}}{99.132 \text{ g valine}} = 26.2 \text{ moles ATP}$$

15.123 There is no pathway that converts acetyl-CoA into glucose. (Acetyl-CoA can be broken to  $\text{CO}_2$  by the citric acid cycle, and it can be used to build fatty acids, but it cannot be used to build carbohydrates.) Therefore, leucine can be converted to fatty acids, or burned to produce energy, but it cannot be converted to glucose.

15.125 a) Glycolysis is involved in the metabolism of carbohydrates.

b) Beta oxidation is involved in the metabolism of fatty acids.

c) The citric acid cycle is involved in the metabolism of all three types of nutrients.

d) Transamination is involved in the metabolism of amino acids.

15.127

Pathway	Starting material	Final product
Glycolysis	glucose	pyruvate ions
Beta oxidation	fatty acid and coenzyme A	acetyl-CoA
Citric acid cycle	acetyl-CoA	$\text{CO}_2$
Transamination	an amino acid and an $\alpha$ -ketoacid (usually $\alpha$ -ketoglutarate)	a different $\alpha$ -ketoacid and a different amino acid (usually glutamic acid)

15.129 Our bodies cannot convert fatty acids into glucose because there is no reaction that converts acetyl-CoA into pyruvate. We can break down fatty acids into acetyl-CoA, and we can convert pyruvate into glucose, but we have no way to connect these two pathways.

- 15.131 a) We must break down two molecules of ATP to activate a fatty acid.  
 b) When we activate a fatty acid, we make a fatty-acyl CoA.

15.133 Breaking down one molecule of palmitic acid into eight molecules of acetyl-CoA requires seven cycles of beta oxidation. Each cycle produces 1 NADH and 1 FADH<sub>2</sub>, so we make a total of 7 NADH and 7 FADH<sub>2</sub>. In addition, we must activate the palmitic acid before we can carry out beta oxidation, so we must break down 2 ATP. The net ATP yield is:

$$7 \text{ NADH} \times 2.5 = 17.5 \text{ ATP}$$

$$7 \text{ FADH}_2 \times 1.5 = 10.5 \text{ ATP}$$

$$\text{Total} = 28 \text{ ATP formed} - 2 \text{ ATP broken down} = 26 \text{ ATP}$$

The problem tells us that we break down 44 molecules of ATP when we build palmitic acid from acetyl-CoA. Therefore, the futile cycle consumes  $44 - 26 = 18$  molecules of ATP.

15.135 a) Citrate is a negative effector for one enzyme in glycolysis, and a positive effector for one enzyme in gluconeogenesis. Therefore, the concentration of citrate helps to control which pathway predominates. When the concentration of citrate is high, gluconeogenesis is fast and glycolysis is slow. When the concentration of citrate is low, glycolysis is fast and gluconeogenesis is slow.

b) We can predict that citrate will have the effect that it does on FBP and PFK. When the concentration of citrate is low, the cell cannot carry out the citric acid cycle to make ATP. Therefore, when the concentration of citrate is low, the cell needs to make more citrate. It can do so by carrying out glycolysis, so a low citrate concentration should speed up glycolysis. (If a low citrate concentration slowed down glycolysis, the cell could not obtain energy when it needed to!). In contrast, when the concentration of citrate is high, the cell does not need to make more citrate, so it slows down glycolysis. It also speeds up gluconeogenesis, which converts pyruvate into glucose and prevents the pyruvate from being converted to acetyl-CoA (which must then form citrate).

15.137 Acetyl-CoA is a negative effector of pyruvate kinase. When the cell has a high concentration of acetyl-CoA, it does not need to make more acetyl-CoA. Pyruvate kinase converts PEP into pyruvate, which is normally broken down into acetyl-CoA and CO<sub>2</sub>. The cell does not need more acetyl-CoA, so pyruvate kinase slows down.

15.139 a) Immediately after a meal, the concentrations of both glucose and amino acids in the blood increase. The liver does not need to supply glucose to the blood, so it absorbs excess amino acids from the blood, converts them to glucose (that's the gluconeogenesis pathway), and uses the glucose to build glycogen for storage.

b) A couple of hours after the meal, the excess amino acids have been broken down, so gluconeogenesis stops. (The liver is now breaking down glycogen into glucose and delivering the glucose to the bloodstream.)

c) After 12 hours or so, the liver has broken down most of its glycogen. It must continue to deliver glucose to the blood, because the brain needs a constant supply of glucose. Therefore, the liver begins to carry out gluconeogenesis once again, using amino acids (from the breakdown of body proteins) to build glucose.

15.141 a) You make roughly 61 g of ethanol (the calculator answer is 61.37081196 g). The molecular formulas for glucose and ethanol are  $C_6H_{12}O_6$  and  $C_2H_6O$ , respectively. The balanced equation for alcoholic fermentation is:



The formula weight of glucose is 180.156, and the formula weight of ethanol is 46.068. The reaction produces two molecules of ethanol, so the relative weights are 180.156 g of glucose to 92.136 g of ethanol. Use this relationship as a conversion factor:

$$120 \text{ g glucose} \times \frac{92.136 \text{ g ethanol}}{180.156 \text{ g glucose}} = 61 \text{ g ethanol}$$

b) You make roughly 59 g of  $CO_2$  (the calculator answer is 58.62918804 g). The formula weight of  $CO_2$  is 44.01, and the reaction calls for two molecules of  $CO_2$ , so the relative weights are 180.156 g of glucose to 88.02 g of  $CO_2$ :

$$120 \text{ g glucose} \times \frac{88.02 \text{ g } CO_2}{180.156 \text{ g glucose}} = 59 \text{ g } CO_2$$

c) The volume of the  $CO_2$  is roughly 32 liters (the calculator answer is 31.97229067 liters). We first convert the mass of  $CO_2$  into moles:

$$58.62918804 \text{ g } CO_2 \times \frac{1 \text{ mole}}{44.01 \text{ g}} = 1.33217878 \text{ moles of } CO_2$$

Then we convert the moles of  $CO_2$  into liters, using the fact that 1 mole occupies 24 liters:

$$1.33217878 \text{ moles} \times \frac{24 \text{ L}}{1 \text{ mole}} = 32 \text{ L}$$

15.143 a) Here are the ATP yields for each of the amino acids in casein:

$$\begin{aligned} 9 \text{ ala} &\times 13 = 117 \text{ ATP} \\ 6 \text{ arg} &\times 23.5 = 141 \text{ ATP} \\ 8 \text{ asn} &\times 11 = 88 \text{ ATP} \\ 7 \text{ asp} &\times 13 = 91 \text{ ATP} \\ 25 \text{ glu} &\times 20.5 = 512.5 \text{ ATP} \\ 14 \text{ gln} &\times 18.5 = 259 \text{ ATP} \\ 9 \text{ gly} &\times 5.5 = 49.5 \text{ ATP} \\ 5 \text{ his} &\times 19 = 95 \text{ ATP} \\ 11 \text{ ile} &\times 33.5 = 368.5 \text{ ATP} \\ 17 \text{ leu} &\times 32.5 = 552.5 \text{ ATP} \\ 14 \text{ lys} &\times 30 = 420 \text{ ATP} \\ 5 \text{ met} &\times 21.5 = 107.5 \text{ ATP} \\ 8 \text{ phe} &\times 32 = 256 \text{ ATP} \\ 17 \text{ pro} &\times 23 = 391 \text{ ATP} \\ 16 \text{ ser} &\times 10.5 = 168 \text{ ATP} \\ 5 \text{ thr} &\times 18 = 90 \text{ ATP} \\ 2 \text{ trp} &\times 35 = 70 \text{ ATP} \\ 10 \text{ tyr} &\times 34.5 = 345 \text{ ATP} \\ 11 \text{ val} &\times 26 = 286 \text{ ATP} \end{aligned}$$

Adding all of these numbers gives 4407.5 molecules of ATP from one molecule of casein.

b) There are a total of 199 amino acids in casein. The ATP yield per amino acid is then  $4407.5 \div 199 = 22.1$  molecules of ATP per amino acid (the calculator answer is 22.14824121).

c) The ATP yield is 19.2 moles of ATP per 100 g of casein (the calculator answer is 19.20479303):

$$100 \text{ g casein} \times \frac{4407.5 \text{ moles ATP}}{22950 \text{ g casein}} = 19.2 \text{ moles ATP}$$

d) The ATP yield for casein is similar to that of starch, and much less than that of tristearin. This agrees with the nutritional energy values for proteins, carbohydrates, and fats; the values for protein and carbohydrate are the same (4 Cal per gram) and the value for fats is more than twice as high (9 Cal per gram).