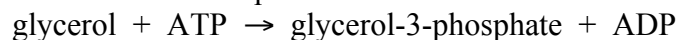


CHAPTER 15: ANSWERS TO SELECTED PROBLEMS

SAMPLE PROBLEMS (“Try it yourself”)

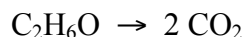
15.1 The second equation requires less than 7.3 kcal of energy, so it goes to completion (essentially all of the reactant molecules are converted into products). The first reaction requires more than 7.3 kcal of energy, so it forms an equilibrium mixture.

15.2 The combined chemical equation is:

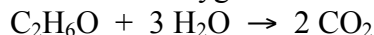


This is an activation reaction, because it breaks down ATP and uses the energy to make a new high-energy molecule (glycerol-3-phosphate).

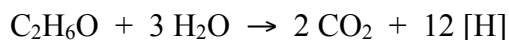
15.3 We start with the carbon atoms. Since ethanol contains two carbon atoms, we must make two molecules of CO_2 :



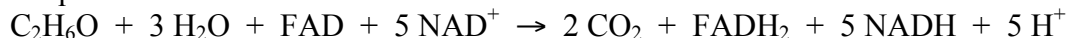
Next, we use water to balance the oxygen atoms. Ethanol contains one oxygen atom, but the two molecules of carbon dioxide contain a total of four oxygen atoms. Therefore, we need three water molecules to supply the three additional oxygen atoms.



Finally, we balance the hydrogen atoms. The right side of our equation contains twelve hydrogen atoms, so we must add twelve hydrogen atoms to the left side. The balanced equation is:



15.4 We transfer two hydrogen atoms to FAD, so we need one molecule of FAD and we form one molecule of FADH_2 . The other ten hydrogen atoms are removed by NAD^+ , so we need five molecules of NAD^+ and we make five molecules of NADH , plus five hydrogen ions. The balanced equation is:



15.5 The total concentration of solutes in each solution is 0.201 M, so there is no overall concentration gradient. However, each solute has its own concentration gradient, because the concentration of each solute (Na^+ and Cl^-) is different in each solution.

Solution X contains more negative ions than positive ions, and solution Y contains more positive ions than negative ions. Therefore, there is also a charge gradient.

15.6 We obtain a total of 34.5 molecules of ATP.

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

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

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

15.7 We must break six carbon-carbon bonds in order to chop up a fourteen-carbon chain into two-carbon fragments, so we need **6 cycles of beta oxidation** and we produce **7 molecules of acetyl-CoA**.

15.8 In Sample Problem 15.7, we found that breaking down myristic acid requires 6 beta oxidation cycles and produces 7 molecules of acetyl-CoA.

Each cycle of beta oxidation makes one molecule of NADH and one molecule of FADH₂, so 6 cycles of beta oxidation produce 6 NADH + 6 FADH₂

Each citric acid cycle makes one molecule of ATP, three molecules of NADH, and one molecule of FADH₂, so 7 citric acid cycles produce 7 ATP + 21 NADH + 7 FADH₂

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 FADH₂.

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

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 ATP	<i>(formed during the citric acid cycle)</i>
67.5 ATP	<i>(from the oxidation of NADH)</i>
19.5 ATP	<i>(from the oxidation of FADH₂)</i>
- 2 ATP	<i>(broken down to activate the myristic acid)</i>
92 ATP	<i>(total from one molecule of myristic acid)</i>

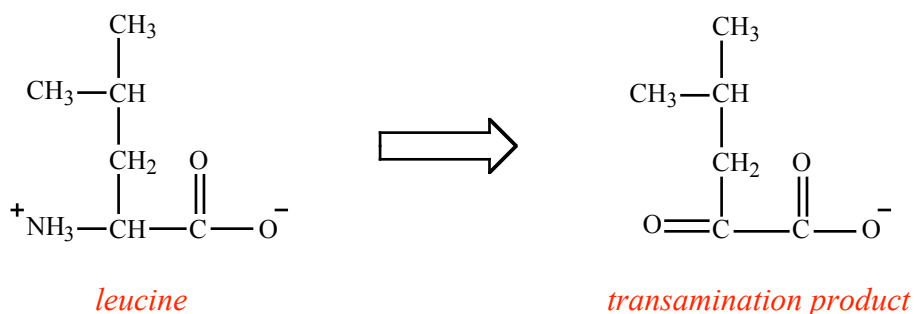
15.9 We make 117 molecules of ATP when we oxidize a molecule of linoleic acid. Since linoleic acid contains two double bonds, we make two fewer molecules of FADH₂, which translates to 2 x 1.5 = 3 fewer molecules of ATP.

15.10 The formula weight of glycerol is 92.094, so we make 18 moles of ATP when we burn 92.094 g (one mole) of glycerol:

$$100 \text{ g glycerol} \times \frac{18 \text{ moles ATP}}{92.094 \text{ g glycerol}} = 19.54524725 \text{ moles of ATP (calculator answer)}$$

Rounding this to three significant figures, we can say that we make **19.5 moles of ATP** when we burn 100 g of glycerol.

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



15.12 The overall ATP yield is 26 molecules of ATP.

$$9 \text{ NADH} \times 2.5 = 22.5 \text{ ATP (from the oxidation of the NADH)}$$

$$3 \text{ FADH}_2 \times 1.5 = 4.5 \text{ ATP (from the oxidation of the FADH}_2)$$

$$1 \text{ ATP (formed by substrate-level phosphorylation)}$$

$$1 \text{ NH}_4^+ \times 2 = -2 \text{ ATP (broken down in the urea cycle)}$$

$$\mathbf{26 \text{ ATP}}$$

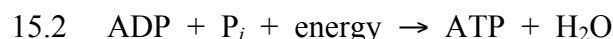
15.13 We must break down 800 molecules of ATP to make this protein. It takes 4 molecules of ATP to place one amino acid into the polypeptide chain:

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

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).



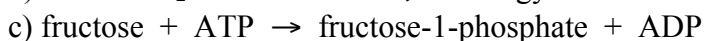
15.3 This is an anabolic process, because it builds a large molecule from small pieces and it consumes energy.

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 this reaction consumes energy, which is supplied by breaking down ATP. (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.

15.7 a) Our bodies break down ATP to supply the energy for the reaction in this problem.



15.8 This reaction is an activation reaction, because it breaks down ATP and uses the energy to build a different high-energy molecule (acetyl-coenzyme A, which contains a high-energy thioester group).

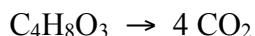
Section 15.2

15.9 The carbon atoms become incorporated into CO_2 molecules. The hydrogen atoms are transferred to a redox coenzyme (NAD^+ or FAD).

15.10 The additional hydrogen atoms come from water molecules. (The oxygen atoms from water are used to make CO_2 .)

15.11 The other three oxygen atoms come from water molecules.

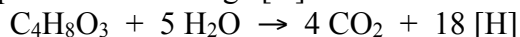
15.12 The molecular formula of 3-hydroxybutyric acid is $C_4H_8O_3$. To write the equation for the breakdown of this compound, we start with the carbon-containing substances and balance the carbon atoms. The carbon-containing reactant is $C_4H_8O_3$ and the carbon-containing product is CO_2 . We need four molecules of CO_2 to balance the carbon atoms:



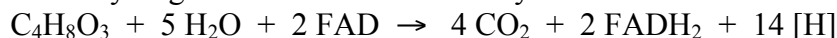
Next, we use water to balance the oxygen atoms. The reaction above has three oxygen atoms on the left and eight on the right, so we need to add five water molecules to the left side:



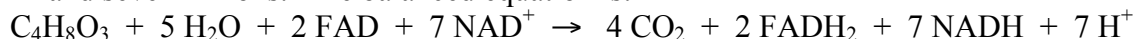
Finally, we balance the hydrogen atoms. These atoms actually end up attached to NAD^+ and/or FAD , but here we simply represent them using “[H]”. The balanced chemical equation is:



15.13 We start with our final answer to Problem 15.12. Of the eighteen hydrogen atoms in the product, four are removed by FAD . One molecule of FAD can remove two hydrogen atoms (becoming $FADH_2$), so we need two molecules of FAD and we make two molecules of $FADH_2$. This leaves us with 14 hydrogen atoms to be removed by NAD^+ .



One molecule of NAD^+ can remove two hydrogen atoms, so we need seven molecules of NAD^+ . When NAD^+ removes hydrogen atoms, one hydrogen bonds to the NAD^+ (forming $NADH$) and the other hydrogen loses its electron and becomes H^+ . Therefore, we form seven molecules of $NADH$ and seven H^+ ions. The balanced equation is:



Section 15.3

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

15.15 The electron transport chain is a sequence of reactions that removes hydrogen atoms from $NADH$ and $FADH_2$ and transfers them to O_2 . The final products of the electron transport chain are NAD^+ , FAD , and H_2O . 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).

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

15.17 The electrons come from the hydrogen atoms that were removed from $NADH$ and $FADH_2$, and they end up combining with H^+ ions and oxygen atoms to make water.

15.18 a) The two solutions have different concentrations of both Na^+ and Cl^- , so there is a concentration gradient across the membrane.

b) Solution A contains equal concentrations of Na^+ and Cl^- ions, so it is electrically neutral. The same is true of solution B. Therefore, the overall charge is zero on both sides of the membrane. Since the overall charge is the same on both sides, there is no charge gradient.

15.19 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, the solutions on each side of the membrane have different electrical charges. The electron transport chain produces both types of gradient by moving H^+ across the inner membrane. The concentration of H^+ becomes higher outside the membrane than inside the membrane (a concentration gradient). In addition, the extra H^+ outside the membrane produces an excess of positive charge, while the missing H^+ inside the membrane leaves an excess of negative charge (a charge gradient).

15.20 The electron transport chain moves 10 H^+ ions for each NADH that it oxidizes, so it moves a total of $10 \times 4 = 40 H^+$ ions when it oxidizes four molecules of NADH. Four H^+ ions must return to the matrix for each ATP that is made available to the cell, so the cell will gain a total of $40 \div 4 = 10$ molecules of ATP.

15.21 The fourth hydrogen ion is used to transport ATP out of the mitochondrion and to move ADP and P_i into the mitochondrion.

15.22 The cell will obtain 8 molecules of ATP.

$$\begin{array}{rcl} 2 \text{ NADH} & \times & 2.5 & = & 5 \text{ ATP} \\ 2 \text{ FADH}_2 & \times & 1.5 & = & 3 \text{ ATP} \\ \text{Total} & & & = & 8 \text{ ATP} \end{array}$$

Section 15.4

15.23 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.

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

15.25 Glycolysis makes two molecules of ATP and two molecules of NADH.

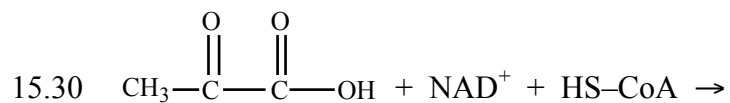
15.26 Lactic acid fermentation is anaerobic because it does not make any NADH or $FADH_2$, so the body does not require oxygen when it carries out this pathway. (Any pathway that makes NADH or $FADH_2$ requires oxygen, because these coenzymes must be converted back into NAD^+ and FAD. The electron transport chain uses oxygen from the air to do this.)

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

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

15.29 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 molecules of ATP (i.e. we end up with two more molecules of ATP than we started with).

Section 15.5



15.31 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.

15.32 There are four oxidation steps in the citric acid cycle (reactions 3, 4, 6 and 8). This is reasonable, because the overall cycle produces eight hydrogen atoms, and an oxidation always removes two hydrogen atoms, so it takes four oxidations to remove eight hydrogen atoms.

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

15.34 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.

15.35 The citric acid cycle produces three molecules of NADH, one molecule of FADH₂, and one molecule of ATP. (Actually, the cycle produces GTP rather than ATP, but these two compounds are functionally equivalent to one another.)

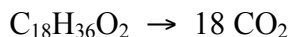
15.36 A total of 10 molecules of ATP are formed when one molecule of acetyl-CoA is broken down. Here is how we can calculate this number, starting from the high-energy molecules that are formed during the citric acid cycle:

$$\begin{array}{r} 3 \text{ NADH} \times 2.5 = 7.5 \text{ ATP} \\ 1 \text{ FADH}_2 \times 1.5 = 1.5 \text{ ATP} \\ \hline \qquad \qquad \qquad + 1 \text{ ATP (from the substrate-level phosphorylation, step 5)} \\ \text{Total:} \qquad \qquad \qquad \mathbf{10 \text{ ATP}} \end{array}$$

15.37 As shown on page 15-38, 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 during glycolysis and two during the citric acid cycle), so the other 28 ATP molecules are formed by oxidative phosphorylation.

Section 15.6

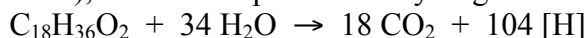
15.38 We start with the carbon-containing substances. The carbon-containing reactant is $C_{18}H_{36}O_2$ and the carbon-containing product is CO_2 . To balance carbon atoms, we need to make eighteen molecules of CO_2 :



Next, we use H_2O to balance the oxygen atoms. We have two oxygen atoms on the left side of the reaction and thirty-six on the right side, so we need thirty-four molecules of oxygen:

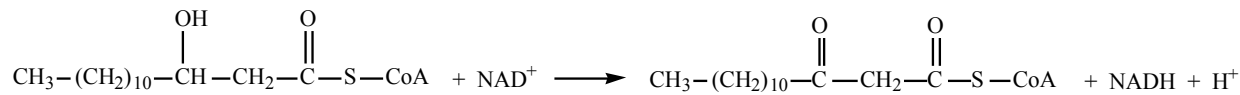
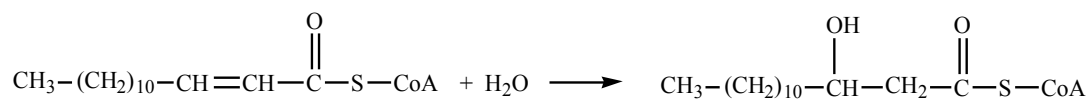
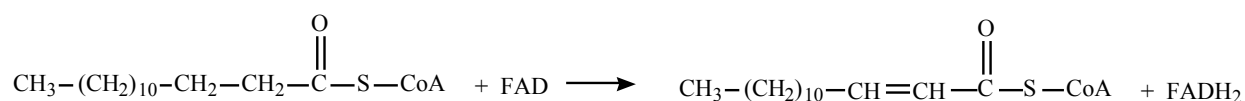


Finally, we add hydrogen atoms, using “[H]” to represent hydrogen atoms that are removed by NAD^+ or FAD . There are 36 hydrogen atoms in the stearic acid and a total of 68 hydrogen atoms in the water ($34 \times 2 = 68$), so we end up with 104 hydrogen atoms!



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

15.40 The four reactions are shown below.



15.41 Stearic acid contains 18 carbon atoms. We must break eight bonds in order to chop up an 18-carbon chain into two-carbon fragments, so 8 cycles of beta oxidation are required to break it down. We make 9 molecules of acetyl-CoA.

15.42 In Problem 15.41, we found that breaking down stearic acid requires eight cycles of beta oxidation and nine citric acid cycles. Each cycle of beta oxidation makes one molecule of $NADH$ and one molecules of $FADH_2$, so 8 cycles of beta oxidation produce $8 NADH + 8 FADH_2$. Each citric acid cycle makes three molecules of $NADH$, one molecule of $FADH_2$, and one molecule of ATP , so 9 citric acid cycles produce $27 NADH + 9 FADH_2 + 9 ATP$.

We make a total of $8 + 27 = 35$ molecules of $NADH$. “Converting” this into ATP gives us:

$$35 NADH \times 2.5 = 87.5 \text{ molecules of } ATP$$

We make a total of $8 + 9 = 17$ molecules of $FADH_2$. “Converting” this into ATP gives us:

$$17 FADH_2 \times 1.5 = 25.5 \text{ molecules of } ATP$$

Finally, 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 FADH₂)</i>
-2	ATP	<i>(broken down to activate the stearic acid)</i>
120	ATP	<i>(total)</i>

We make **120 molecules of ATP** when we break down one molecule of stearic acid.

15.43 In Problem 15.42, we found that we make 120 molecules of ATP when we break down one molecule of stearic acid. The molecular formula of stearic acid is C₁₈H₃₆O₂, and its formula weight is 284.468 amu. Therefore, we make 120 moles of ATP when we break down 284.468 grams (one mole) of stearic acid. Using this relationship, we can calculate the ATP yield for 100 g of stearic acid:

$$100 \text{ g stearic acid} \times \frac{120 \text{ moles ATP}}{284.468 \text{ g stearic acid}} = 42.18400664 \text{ moles of ATP (calculator answer)}$$

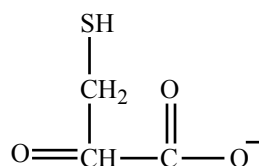
Rounding this answer to three significant figures gives us **42.2 moles of ATP** per 100 g of stearic acid.

15.44 For each double bond in an unsaturated fatty acid, we lose one molecule of FADH₂, because the dehydrogenation step of beta oxidation will not occur when a double bond is already present.

Section 15.7

15.45 Limiting oxidative deamination to just one amino acid reduces the number of different reactions a cell must carry out. As a result, the cell does not need to make as many different enzymes. Building an enzyme requires a lot of energy, so the cell reduces the amount of energy it must expend to break down amino acids.

15.46



15.47 The ion is ammonium ion (NH₄⁺).

15.48 The urea cycle converts ammonium ions into the NH₂ groups of urea. Urea is much less toxic than ammonium ion, so we can store urea rather than excreting it continuously.

15.49 It takes two molecules of ATP to incorporate one NH₄⁺ ion into urea.

15.50 The liver converts most of the amino acids into glucose (removing nitrogen and sulfur atoms as needed) and releases the glucose into the blood, where it can be used as fuel by other cells.

15.51 The overall yield is 23 molecules of ATP.

$$\begin{array}{r}
 8 \text{ NADH} \times 2.5 = 20 \text{ ATP (from the oxidation of the NADH)} \\
 2 \text{ FADH}_2 \times 1.5 = 3 \text{ ATP (from the oxidation of the FADH}_2\text{)} \\
 \phantom{2 \text{ FADH}_2 \times 1.5 = 3 \text{ ATP}} 2 \text{ ATP (formed by substrate-level phosphorylation)} \\
 1 \text{ NH}_4^+ \times 2 = \underline{-2 \text{ ATP (broken down in the urea cycle)}} \\
 \hline
 \mathbf{23 \text{ ATP}}
 \end{array}$$

(The CO₂ is a waste product and is not used to make additional ATP.)

15.52 Succinyl-CoA is also the product of one of the reactions of the citric acid cycle. Therefore, when a cell burns valine, it must make the enzymes that convert valine into succinyl-CoA, but it does not need to make additional enzymes to oxidize the succinyl-CoA, since they are already present as part of the citric acid cycle.

Section 15.8

15.53 Our bodies can use amino acids and lactic acid to build glucose, but we cannot use fatty acids.

15.54 Gluconeogenesis is a sequence of reactions that converts pyruvate ions into glucose.

15.55 The liver carries out gluconeogenesis in the following situations:

- 1) immediately after a meal, to help replenish the glycogen supply in the liver
- 2) when the concentration of lactate in the blood is high as a result of heavy exercise
- 3) during a prolonged fast, to maintain an appropriate blood glucose level

15.56 Our body breaks down 6 molecules of ATP and 2 molecules of NADH to convert pyruvate into glucose. In contrast, we obtain only 2 molecules of ATP and 2 molecules of NADH when we break down glucose into pyruvate.

15.57 It takes 2 molecules of ATP to add a molecule of glucose to a glycogen chain.

15.58 a) The body activates a fatty acid by linking it to coenzyme A. This reaction consumes two molecules of ATP. (Note that when we build a triglyceride, we must activate three molecules of fatty acid.)

b) The body activates glycerol by linking it to a phosphate group, forming glycerol-1-phosphate. This reaction consumes one molecule of ATP.

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

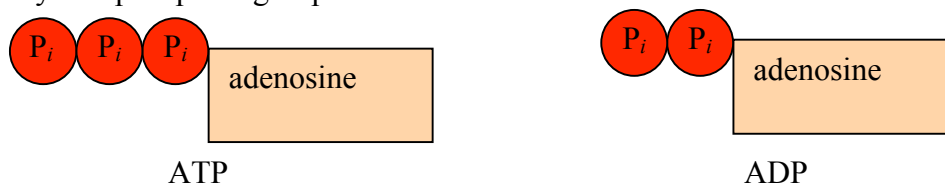
15.60 ATP might not have any effect of enzyme 2. If ATP does affect the activity of enzyme 2, though, it should have the opposite effect on enzymes 1 and 2 to prevent a futile cycle. Therefore, a high concentration of ATP should speed up enzyme 2.

CUMULATIVE PROBLEMS (Odd-numbered problems only)

15.61 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.

15.63 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.

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



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

15.69 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.

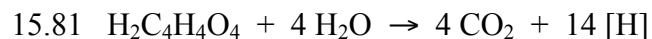
15.71 The enzymes of the electron transport chain remove H^+ ions and electrons from NADH and $FADH_2$, and then combine the H^+ ions and electrons with oxygen to make water. This process produces a great deal of energy, which the electron transport enzymes use to pump hydrogen ions from the mitochondrial matrix to the intermembrane space.

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

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

15.77 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.

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



15.83 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.

15.85 The total ATP yield is 12.5 molecules of ATP.

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

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

15.89 This is an example of alcoholic fermentation, in which the starch is broken down into ethanol and CO_2 . The CO_2 is responsible for the “fizz” in the beer.

15.91 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.

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

15.95 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.

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

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

15.97 We get 12.5 molecules of ATP when we break down one oxaloacetate ion. The first reaction (breaking oxaloacetate into pyruvate and 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 FADH_2 , 1 ATP

Total high-energy molecules: 4 NADH, 1 FADH_2 , 1 ATP

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

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

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

15.99 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_2

As we saw in problem 15.97, we get 4 NADH, 1 FADH_2 , 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_2 , and 5 ATP.

Now we can work out the total:

5 NADH in step 1 + 20 NADH in step 2 = 25 NADH total
 no FADH₂ in step 1 + 5 FADH₂ in step 2 = 5 FADH₂ total
 5 ATP in step 1 + 5 ATP in step 2 = 10 ATP total

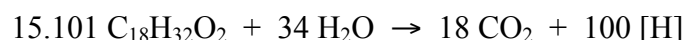
Finally, we account for oxidative phosphorylation:

25 NADH x 2.5 = 62.5 ATP

5 FADH₂ x 1.5 = 7.5 ATP

Total ATP = 62.5 + 7.5 + 10 =

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 $80 \div 3 = \mathbf{26.7 \text{ molecules of ATP}}$.



15.103 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 FADH₂

4 citric acid cycles produce 12 NADH + 4 FADH₂ + 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 FADH₂.

7 FADH₂ 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 FADH₂)</i>
- 2 ATP	<i>(broken down to activate the caprylic acid)</i>
50 ATP	

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

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

Table 15.8 (on page 15-55) 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 FADH₂

8 citric acid cycles produce 24 NADH + 8 FADH₂ + 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 FADH₂.

15 FADH₂ 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 FADH₂)</i>
-2 ATP	<i>(broken down to activate the palmitic acid)</i>
106 ATP	<i>(from one molecule of palmitic acid)</i>

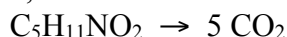
Finally, we can calculate the overall ATP yield. We get $106 \times 3 = 318$ molecules of ATP from the three molecules of palmitic acid, and we get an additional 18 molecules of ATP from the glycerol, giving us a total of $318 + 18 = 336$ molecules of ATP.

15.107 In Problem 15.105, we found that we make 336 molecules of ATP when we break down one molecule of tripalmitin. The formula weight of tripalmitin (C₅₁H₉₈O₆) is 807.294 amu, so we get 336 moles of ATP when we break down 807.294 grams (one mole) of tripalmitin. Using this relationship as a conversion factor:

$$100 \text{ g tripalmitin} \times \frac{336 \text{ moles ATP}}{807.294 \text{ g tripalmitin}} = 41.62052486 \text{ moles of ATP (calculator answer)}$$

Rounding this answer to three significant figures gives us **41.6 moles of ATP** per 100 grams of tripalmitin.

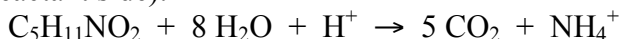
15.109 As always, we start with the carbon-containing compounds, which are valine (C₅H₁₁NO₂) and CO₂. To balance the carbon atoms, we need five molecules of CO₂:



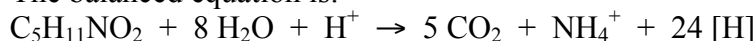
Next, we use water to balance the oxygen atoms. The reaction above has two oxygen atoms on the left and ten on the right, so we need eight water molecules:



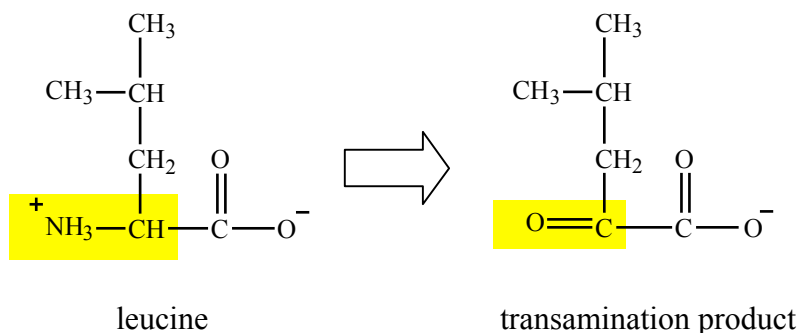
Before we balance the hydrogen atoms, we need to add in the NH₄⁺ ion (on the product side) and a hydrogen ion (on the reactant side):



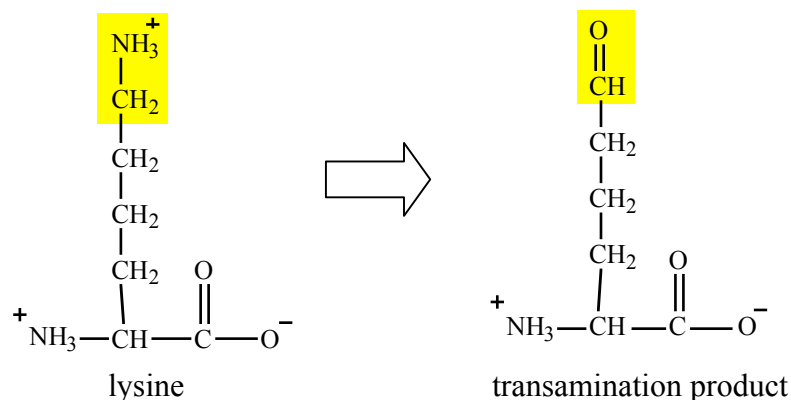
Finally, we balance the hydrogen atoms, using [H] to represent hydrogen atoms that are removed by NAD⁺ or FAD. The balanced equation is:



15.111



15.113 Transamination converts $^+\text{NH}_3\text{-CH}$ into $\text{O}=\text{C}$. Applying this basic reaction to the side chain amino group in lysine gives us:



15.115 The overall yield is 10.5 molecules of ATP.

$$4 \text{ NADH} \times 2.5 = 10 \text{ ATP (from the oxidation of NADH)}$$

$$1 \text{ FADH}_2 \times 1.5 = 1.5 \text{ ATP (from the oxidation of FADH}_2\text{)}$$

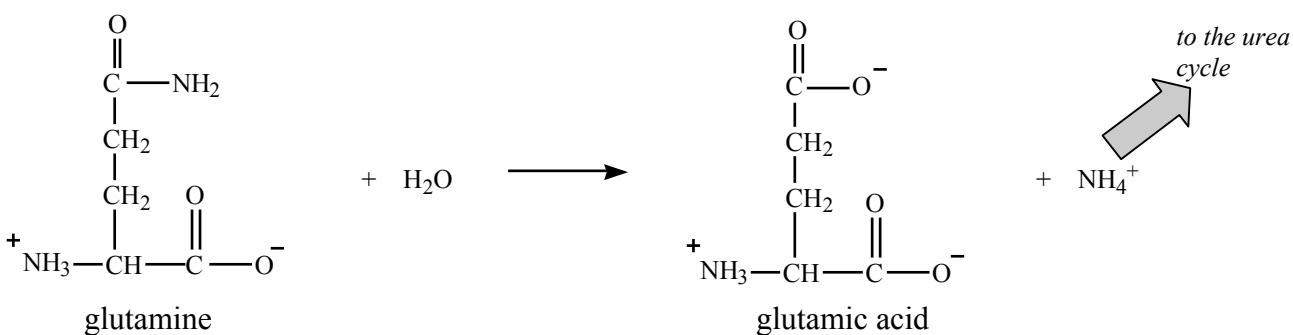
$$1 \text{ ATP (formed directly during the pathway)}$$

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

The 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.

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

15.117 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 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.



15.119 The reaction given in the problem makes one molecule of NADH and one molecule of FADH_2 , and it breaks down one molecule of ATP. It also makes a 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 CO_2 by the citric acid cycle. The citric acid cycle makes one ATP, three NADH, and one 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 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 $1 + 30 = \mathbf{31 \text{ molecules of ATP}}$ from the breakdown of one molecule of leucine.

15.121 The reaction in the problem makes one molecule of NADH and one NH_4^+ ion. We get 2.5 ATP from the NADH, but we must break down 2 ATP to deal with the NH_4^+ ion, so the net yield of ATP from this reaction is $2.5 - 2 = 0.5 \text{ ATP}$.

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 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 FADH_2 , and 1 formed directly).

The grand total is $0.5 + 2.5 + 10 = \mathbf{13 \text{ molecules of ATP}}$ from the breakdown of one molecule of alanine.

15.123 a) The molecular formula of free valine is $\text{C}_5\text{H}_{11}\text{NO}_2$, and the formula weight of valine is 117.148 amu. Therefore, our bodies make 26 moles of ATP when we break down 117.148 g (one mole) of valine. The calculation is:

$$100 \text{ g valine} \times \frac{26 \text{ moles ATP}}{117.148 \text{ g valine}} = 22.19414757 \text{ moles of ATP (calculator answer)}$$

Rounding this answer to three significant figures gives us **22.2 moles of ATP** per 100 g of valine.

b) When valine is incorporated into a polypeptide, its molecular formula is $\text{C}_5\text{H}_9\text{NO}$, and its formula weight is 99.132 amu. Therefore, our bodies make 26 moles of ATP when we break down 99.132 g of valine-containing protein. The calculation is:

$$100 \text{ g valine} \times \frac{26 \text{ moles ATP}}{99.132 \text{ g valine}} = 26.22765605 \text{ moles of ATP (calculator answer)}$$

To three significant figures, we get **26.2 moles of ATP** per 100 g of valine-containing protein.

15.125 There is no pathway that converts acetyl-CoA into glucose. Acetyl-CoA can be broken down into CO₂ 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.

- 15.127 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.

15.129

Pathway	Starting material	Final product
Glycolysis	glucose	pyruvate ions
Beta oxidation	fatty acid and coenzyme A	acetyl-CoA
Citric acid cycle	acetyl-CoA	CO ₂
Transamination	an amino acid and an α -ketoacid (usually α -ketoglutarate)	a different α -ketoacid and a different amino acid (usually glutamic acid)

(Note: the citric acid cycle also requires a molecule of oxaloacetate, but this is regenerated at the end of the cycle.)

15.131 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.

- 15.133 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.

15.135 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 FADH₂, so we make a total of 7 NADH and 7 FADH₂. 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 $44 - 26 = \mathbf{18 \text{ molecules of ATP}}$.

15.137 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).

15.139 Acetyl-CoA is a negative effector of pyruvate kinase. Pyruvate kinase converts PEP into pyruvate, which is normally broken down into acetyl-CoA and CO₂. However, when the cell has a high concentration of acetyl-CoA, it does not need to make more acetyl-CoA. Therefore, acetyl-CoA must make pyruvate kinase less active.

15.141 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.

15.143 a) The molecular formulas for glucose and ethanol are C₆H₁₂O₆ and C₂H₆O, respectively. The balanced equation for alcoholic fermentation is:



The formula weight of glucose is 180.156 amu, and the formula weight of ethanol is 46.068 amu. The reaction produces two molecules of ethanol, so 180.156 amu of glucose will produce 92.136 amu (2 x 46.068 amu) of ethanol. This in turn tells us that 180.156 grams of glucose will produce 92.136 grams of ethanol. We can use this mass relationship as a conversion factor:

$$120 \text{ g glucose} \times \frac{92.136 \text{ g ethanol}}{180.156 \text{ g glucose}} = 61.37081196 \text{ g of ethanol (calculator answer)}$$

Rounding this answer to two significant figures (because the grape juice contains “roughly” 120 g of sugar) gives us **61 g of ethanol**.

b) We can do this part the same way we did part a, or we can recognize that if we start with 120 g of glucose, we must end up with 120 g of products. The ethanol weighs 61 grams (from part a), so the carbon dioxide must weigh **59 grams** (120 g – 61 g = 59 g).

c) We first convert the mass of CO₂ into moles, using the formula weight of CO₂ (44.01 amu). To avoid a rounding error, we should use the mass of CO₂ before rounding off, which is 58.62918804 grams (120 g – 61.37081196 g).

$$58.62918804 \text{ g CO}_2 \times \frac{1 \text{ mole}}{44.01 \text{ g}} = 1.33217878 \text{ moles of CO}_2$$

Now we can convert the moles of CO₂ into liters, using the fact that 1 mole occupies 24 liters:

$$1.33217878 \text{ moles} \times \frac{24 \text{ L}}{1 \text{ mole}} = 31.97229072 \text{ L (calculator answer)}$$

Rounding this number to two significant figures gives us **32 liters of CO₂**. (That's over eight gallons of carbon dioxide!)

15.145 a) Here are the ATP yields for the amino acids in casein.

$$9 \text{ molecules of alanine} \times 13 \text{ ATP per molecule} = 117 \text{ ATP}$$

$$6 \text{ molecules of arginine} \times 23.5 \text{ ATP per molecule} = 141 \text{ ATP}$$

$$8 \text{ molecules of asparagine} \times 11 \text{ ATP per molecule} = 88 \text{ ATP}$$

$$7 \text{ molecules of aspartic acid} \times 13 \text{ ATP per molecule} = 91 \text{ ATP}$$

$$25 \text{ molecules of glutamic acid} \times 20.5 \text{ ATP per molecule} = 512.5 \text{ ATP}$$

$$14 \text{ molecules of glutamine} \times 18.5 \text{ ATP per molecule} = 259 \text{ ATP}$$

$$9 \text{ molecules of glycine} \times 5.5 \text{ ATP per molecule} = 49.5 \text{ ATP}$$

$$5 \text{ molecules of histidine} \times 19 \text{ ATP per molecule} = 95 \text{ ATP}$$

$$11 \text{ molecules of isoleucine} \times 33.5 \text{ ATP per molecule} = 368.5 \text{ ATP}$$

$$17 \text{ molecules of leucine} \times 32.5 \text{ ATP per molecule} = 552.5 \text{ ATP}$$

$$14 \text{ molecules of lysine} \times 30 \text{ ATP per molecule} = 420 \text{ ATP}$$

$$5 \text{ molecules of methionine} \times 21.5 \text{ ATP per molecule} = 107.5 \text{ ATP}$$

$$8 \text{ molecules of phenylalanine} \times 32 \text{ ATP per molecule} = 256 \text{ ATP}$$

$$17 \text{ molecules of proline} \times 23 \text{ ATP per molecule} = 391 \text{ ATP}$$

$$16 \text{ molecules of serine} \times 10.5 \text{ ATP per molecule} = 168 \text{ ATP}$$

$$5 \text{ molecules of threonine} \times 18 \text{ ATP per molecule} = 90 \text{ ATP}$$

$$2 \text{ molecules of tryptophan} \times 35 \text{ ATP per molecule} = 70 \text{ ATP}$$

$$10 \text{ molecules of tyrosine} \times 34.5 \text{ ATP per molecule} = 345 \text{ ATP}$$

$$11 \text{ molecules of valine} \times 26 \text{ ATP per molecule} = 286 \text{ ATP}$$

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 $4407.5 \div 199 = \mathbf{22.1 \text{ molecules of ATP per amino acid}}$ (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).