Chapter 8

Energy Metabolism Overview

The use of energy is a key for biochemical pathways to proceed. This chapter covers the basic tenets of biochemical energy utilization, storage, and production, as well as the body's energy needs.

QUESTIONS

Select the single best answer.

Questions 1 to 4 concern the following case. You see in your office a thin, anxious woman who is concerned about her weight. She is worried that she may have a parasite causing her to lose weight. She stands 5′5″ tall (1.67 m) and weighs 101 lb (45.85 kg).

1 An estimate of her body mass index (BMI) is which of the following?
(A) 14
(B) 16
(C) 18
(D) 20
(E) 22

2 The same patient then describes to you a typical day of eating, which consists of 250 g of carbohydrates, 10 g of fat, and 100 g of protein. She denies any ethanol intake. She also exercises about 2 h/day. Her daily caloric intake is about which of the following?
(A) 1,250
(B) 1,500
(C) 1,750
(D) 2,000
(E) 2,250

3 For the same patient, her daily caloric needs can be estimated to be which of the following?
(A) 1,250
(B) 1,500
(C) 1,750
(D) 2,000
(E) 2,250

4 Given this same patient's eating habits and lifestyle, which of the following best describes her metabolic state?
(A) She is gaining weight
(B) She is in caloric balance
(C) She is in the healthy range of BMI but is losing weight
(D) She is in an unhealthy range of BMI and is losing weight
(E) She has a tapeworm and needs lab testing

5 Given the following reaction:
$A + B \leftrightarrows C + D$ $\Delta G^{o\prime} = +15.5$ kcal/mol
And [A] = 5 mM, [B] = 4 mM, [C] = 0.5 mM, and [D] = 2.5 mM under cellular conditions, what is the overall Gibbs free energy change for the reaction at 25°C ($R = 1.98 \times 10^{-3}$ kcal/mol/°K) (in kcal/mol)?
(A) +13.86
(B) −13.86
(C) +15.50
(D) −15.50
(E) +17.13

6 Consider the following reaction sequence:
$A \leftrightarrows B$ $\Delta G^{o\prime} = +0.50$ kcal/mol
$B \leftrightarrows C$ $\Delta G^{o\prime} = -15.50$ kcal/mol
$C \leftrightarrows D$ $\Delta G^{o\prime} = -12.15$ kcal/mol
$D \leftrightarrows E$ $\Delta G^{o\prime} = +21.15$ kcal/mol
Under standard conditions, which intermediate would accumulate?
(A) A
(B) B
(C) C
(D) D
(E) E

Questions 7 and 8 refer to an unusual bacterium that has been shown to have a five-component electron transfer chain. Table 8-1 shows the $E^{o\prime}$ values for these five components.

Table 8-1.

$A + 2e^- + 2H^+ \rightarrow AH_2$	+0.55V
$B + 2e^- + 2H^+ \rightarrow BH_2$	+0.12V
$C + 2e^- + 2H^+ \rightarrow CH_2$	+0.03V
$D + 2e^- + 2H^+ \rightarrow DH_2$	–0.22V
$E + 2e^- + 2H^+ \rightarrow EH_2$	–0.47V

7 The order of electron flow in this bacterium is which of the following?

(A) A transfers to B, which transfers to C, which transfers to D, which transfers to E
(B) E transfers to D, which transfers to C, which transfers to B, which transfers to A
(C) C transfers to D, which transfers to E, which transfers to B, which transfers to A
(D) A transfers to E, which transfers to B, which transfers to D, which transfers to C
(E) E transfers to C, which transfers to A, which transfers to D, which transfers to B

8 For the bacterial strain referenced in the previous question, the amount of energy available from transporting a pair of electrons across this chain is which of the following? ($R = 1.98 \times 10^{-3}$ kcal/mol/K and $F = 23$ kcal/mol-V)

(A) 2.3 kcal/mol
(B) 23 kcal/mol
(C) 47 kcal/mol
(D) 70 kcal/mol
(E) 100 kcal/mol

9 A sedentary male medical student is 5′9″ tall and weighs 175 lb. Which of the following diets will allow maintenance of the current weight and also falls within current nutritional guidelines?

(A) About 100 g fat, 50 g of ethanol, 100 g of protein, and 300 g of carbohydrate
(B) About 80 g fat, 125 g of protein, and 310 g of carbohydrate
(C) About 125 g fat, 85 g protein, and 350 g of carbohydrate
(D) About 80 g fat, 60 g ethanol, 100 g protein, and 310 g carbohydrate
(E) About 50 g fat, 25 g protein, and 225 g carbohydrate

10 Which one of the following diets provides for the largest number of calories?

(A) 100 g protein, 100 g fat, 100 g carbohydrate, 25 g ethanol
(B) 50 g protein, 100 g fat, 150 g carbohydrate, 25 g ethanol
(C) 75 g protein, 125 g fat, 50 g carbohydrate, no ethanol
(D) 150 g protein, 75 g fat, 125 g carbohydrate, 20 g ethanol
(E) 150 g protein, 50 g fat, 125 g carbohydrate, no ethanol

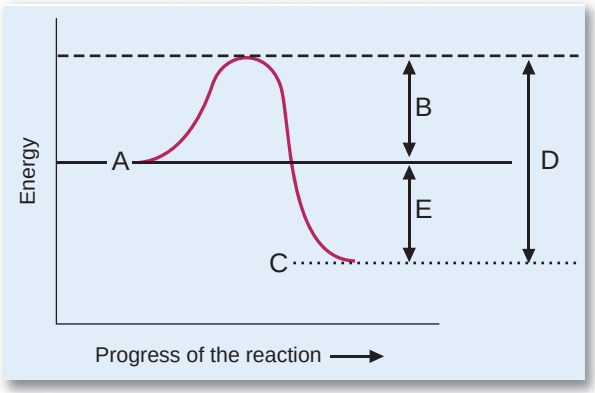
11 Ivan Applebod is an overweight accountant, with a height of 5′9″ (1.77 m) and a weight of 245 lb (111.4 kg). As a sedentary individual, his daily caloric need approximates which of the following?

(A) 2,500 cal
(B) 3,000 cal
(C) 3,500 cal
(D) 4,000 cal
(E) 4,500 cal

12 Which of the following diet plans will allow Mr Applebod to lose approximately 5 lb/month assuming he does not increase his activity?

(A) 2,000 cal/day
(B) 2,450 cal/day
(C) 2,900 cal/day
(D) 3,350 cal/day
(E) 3,800 cal/day

Questions 13 and 14 refer to the following figure indicating an energy curve for an enzyme-catalyzed reaction:



13 Which letter represents the Gibbs free energy of activation?

14 Which letter best represents the difference in energy between the substrates and products?

15 Consider the reaction shown below. If [A] = 5.00 mM, [B] = 2.50 mM, and [C] = 1.25 mM, what would the concentration of D have to be to allow this to be a favorable reaction under these conditions?

$A + B \leftrightarrows C + D \quad \Delta G^{o\prime} = +8.65$ kcal/mol

(A) <0.125 μM
(B) <0.43 μM
(C) <4.3 nM
(D) <43 nM
(E) <5.0 μM

Questions 16 and 17 refer to the following case. A 15-year-old girl has gone to the nutritionist as she is concerned about losing weight. She is 5′7″ tall and weighs 128 lb, down from 135 lb 3 weeks ago. She explains that she had made the cross-country team at her high school, and over the past 3 weeks her running has increased from about 1.5 miles/day to 10 miles/day.

16 Assuming that the patient's weight loss over the past 3 weeks was equally distributed over that time period, how many calories per day was she deficient in her diet?

(A) 800
(B) 1,000
(C) 1,200
(D) 1,400
(E) 1,600

17 After learning that her diet was deficient in calories, the runner decided to make up the deficit by eating equal amounts (in term of calories) of carbohdyrates and proteins, but no fat or alcohol. How many grams of carbs and proteins would she have to add to her diet in order to stop losing weight?

(A) 100 g of each
(B) 150 g of each
(C) 200 g of each
(D) 100 g of carbohydrates, 200 g of protein
(E) 100 g of protein, 200 g of carbohydrate

18 Calculation of the basal metabolic rate (BMR) for morbidly obese individuals using standard methodology is often incorrect due to which of the following?

(A) Underestimation of calories consumed
(B) Overestimation of calories consumed
(C) Preponderance of metabolically active adipocytes
(D) Preponderance of inert adipocytes
(E) Reduced metabolic need of the muscles

19 The BMI is most likely to yield incorrect data for which of the following?

(A) An anorexic 25-year-old woman
(B) An obese 50-year-old man
(C) A normal appearing 30-year-old man
(D) A 30-year-old female bodybuilder
(E) A slightly overweight 42-year-old biochemistry professor

20 Assume that beer contains 5% wt./vol. ethanol. How many calories derived from alcohol would 500 mL (about 17 ounces) of beer contain? Choose the closest answer to your calculated value.

(A) 100
(B) 140
(C) 180
(D) 220
(E) 260

ANSWERS

1 **The answer is B: 16.** The BMI is calculated as the weight of the person (in kg) divided by the height squared (in meters). Thus, for this patient, the BMI is equal to 45.85 divided by $(1.67)^2$, which is 16.44. The BMI stands for body mass index, and can be used to estimate body fat content. A value of <18.5 is considered underweight, values between 18.5 and 24.9 are considered in the normal range, values of 25 through 29.9 are considered overweight, and values of 30 or greater are considered obese. Values of 40 or more are considered morbidly obese, whereas values between 35 and 40 are considered clinically obese. The formulas in order to perform these calculations are summarized in a figure above. The second figure allows one to utilize a graph to calculate the BMI.

Calculation of body mass index (BMI)

Formula:

$$BMI = \frac{\text{Weight (kg)}}{\text{Height (m)}^2}$$

Conversion:

Kilograms = pounds ÷ 2.2

Meters = inches ÷ 39.4

Example:

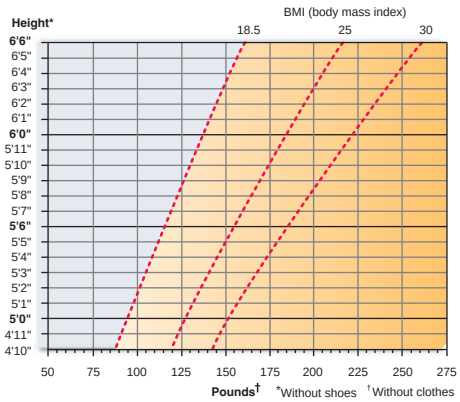
A woman who is 5´4˝ tall and weighs 134 lb has a BMI of 23.5.

Weight: 134 lb ÷ 2.2 = 61 kg

Height: 64 in. ÷ 39.4 = 1.6 m; $(1.6)^2 = 2.6$

$$BMI = \frac{61\text{ kg}}{2.6\text{ m}} = 23.5$$

How to calculate the BMI.



A nomogram used to calculate BMI, knowing the height in inches, and the weight in pounds.

2 **The answer is B: 1,500.** Carbohydrates contain 4 cal/g, protein also contains 4 cal/g, and fat contains 9 cal/g (because it is more reduced than either protein or carbohydrates). Given the patient's diet, she is consuming $(250 \times 4) + (10 \times 9) + (100 \times 4)$, or 1,490 cal/day.

3 **The answer is C: 1,750.** The BMR can be estimated by multiplying the weight (in kg) times 24 cal/kg, which is assuming an energy use of 1 cal/h/kg. Multiplying 45.85 times 24 yields 1,100 cal/day. Her metabolic need can be estimated by multiplying her BMR times an acitivty factor (how active the individual is). For someone who exercises 2 h/day (moderately active) the activity factor is 1.6, so her daily caloric needs are 1,100 × 1.6, or 1,760 cal/day. More accurate representations of the BMR can be obtained from using the formulas in Table 8-2, although for the purposes of this textbook the approximation of 24 cal/kg/day will be utilized for both males and females of all ages.

Table 8-2. Equation for predicting BMR from body weight (W) in kg

Males		Females	
Age Range (years)	**BMR kcal/day**	**Age Range (years)**	**BMR kcal/day**
0–3	60.9W – 54	0–3	61.0W – 51
3–10	22.7W + 495	3–10	22.5W + 499
10–18	17.5W + 651	10–18	12.2W + 746
18–30	15.3W + 679	18–30	14.7W + 496
30–60	11.6W + 879	30–60	8.7W + 829
>60	13.5W + 487	>60	10.5W + 596

Source: Energy and protein requirements: Report of a Joint FAO/WHO/UNU Expert Consultation. Technical report series no. 724. Geneva World Health Organization. 1987:71. See also Schofield et al. Hum Nutr Clin Nutr. 1985;39 (suppl).

4 **The answer is D: She is in an unhealthy range of BMI and is losing weight.** The BMI of 16.4 places the individual in an underweight situation, and she is currently consuming fewer calories (1,490) per day than she requires (1,760), which will lead to weight loss, and further exacerbate her underweight condition. You have a diagnosis, there is no reason to pursue further testing. She can be counseled on how to gain weight.

5 **The answer is A: +13.86.** Recall, $\Delta G = \Delta G^{o\prime} + RT\ln([C][D]/[A][B])$, so for this reaction, $\Delta G = 15.5 + (1.98 \times 10^{-3})(298)\ \ln\ (1.25/20)$. Thus, $\Delta G = 15.5 + (0.59)\ \ln\ (0.0625)$. $\Delta G = 15.5 - 1.64 = 13.86$ kcal/mol. As ΔG is a positive number, under these conditions, the reaction is still an unfavorable reaction.

6 **The answer is D: D.** The conversion of A to B is slightly unfavorable, but as soon as B is produced it will be converted to C due to the highly favorable B to C conversion (a high negative ΔG). The conversion of C to D is also highly favorable, which will lead to accumulation of D. The conversion of D to E, however, is highly unfavorable (high positive ΔG), such that D will accumulate under standard conditions.

7 **The answer is B: E transfers to D, which transfers to C, which transfers to B, which transfers to A.** The order of electron flow goes from the lowest standard redox potential (E/EH_2, with a value of −0.47 V) to the highest redox potential (A/AH_2, with a value of +0.55 V). Redox pairs with low redox potentials are good reducing agents (they like to give up their electrons), whereas redox pairs with high redox potentials are good oxidizing agents (they love to accept electrons). Thus, the order of electron transfer would be E to D to C to B and then to A as the terminal electron acceptor.

8 **The answer is C: 47 kcal/mol.** In order to answer this question, one needs to use the Nernst equation, which equates overall changes in redox potential to Gibbs free energy. The Nernst equation is $\Delta G^{o\prime} = -nF\Delta E^{o\prime}$, where n is the number of electrons transferred, F is Faraday's constant, and $\Delta E^{o\prime}$ is the change in redox potential. In this case, $\Delta E^{o\prime}$ is equal to 1.02 V (the difference between −0.47 and +0.55), and $n = 2$ for a pair of electrons traveling through the chain. The equation thus becomes

$$\Delta G^{o\prime} = -(2)(23)(1.02) = -47\ \text{kcal/mol}$$

9 **The answer is B: About 80 g fat, 125 g of protein, and 310 g of carbohydrate.** In order to answer this question, one first needs to calculate the basic daily energy needs of the student. At 175 lb (79.55 kg) one can estimate his BMR as 1,910 cal/day (79.55 kg multiplied by 24 cal/day/kg). Being sedentary, the activity factor is 1.3, for a total daily caloric need of 2,480 cal/day. Current nutritional guidelines indicate that no more than 30% of one's daily calories should be fat, so the maximum caloric intake for fat should be 750 cal, which is about 80 g of fat (fat contains 9 cal/g). These data alone eliminate answers A and C. Answer E has insufficient total calories (450 from fat, 100 from protein, and 900 from carbohydrates, for a total of 1,450) for the needs of the student, and can also be eliminated. Answer D contains too much ethanol (420 cal out of a total of 2,780) and too many calories. Thus, answer B is correct, in which the 80 g of fat provide 720 cal, the 125 g of protein provides 500 cal, and the 310 g of carbohydrates provides 1,240 cal, for a total of 2,460 cal/day.

10 **The answer is D: 150 g protein, 75 g fat, 125 g carbohydrate, 20 g ethanol.** To answer this question, one needs to recall that fat contains 9 cal/g, ethanol 7 cal/g, and protein and carbohydrates 4 cal/g each. Using these numbers, diet A contains 1,875 cal, diet B contains 1,875 cal, diet C contains 1,625 cal, diet D contains 1,915 cal, and diet E contains 1,550 cal.

11 **The answer is C: 3,500 cal.** Mr Applebod's BMR can be approximated as 24 × 111.4, or 2,673 cal/day. Since he is sedentary, his activity factor is 1.3, and has a daily caloric need of 3,475 cal/day.

12 **The answer is C: 2,900 cal/day.** To lose one pound of weight, a reduction in intake of approximately 3,500 cal is required; thus, a loss of 5 lb will require a reduction of 17,500 cal over the next 30 days (one month). Dividing 17,500 by 30 yields 583 cal/day. Since his normal intake (to maintain weight) is 3,475 cal/day, 3,475 – 583 yields 2,892 cal/day.

13 **The answer is B.** The energy required to increase the energy state of the starting material (indicated by A in the diagram) is the Gibbs free energy of Activation. The change in energy states of reactants and products is indicated by E, while D shows the maximal energy change from the energy of activation to the energy level of the products.

14 **The answer is E.** The energy required to increase the energy state of the starting material (indicated by A in the diagram) is the Gibbs free energy of activation. The change in energy states of reactants and products is indicated by E, while D shows the maximal energy change from the energy of activation to the energy level of the products.

15 **The answer is C: <4.3 nM.** Recall, $\Delta G = \Delta G^{o\prime} + RT\ln([C][D]/[A][B])$. In order for the reaction to be favorable,

ΔG must be negative. If one solves for the concentration of D required for $\Delta G = 0$, then any concentration lower than the one calculated will be sufficient to allow for a negative ΔG. Thus, when ΔG is set to zero, $\Delta G^{o\prime} = -RT \ln ([C][D]/[A][B])$. Therefore, $8.65 = -(1.98 \times 10^{-3})(298) \ln ([1.25D]/[12.5])$. This reduces to $-14.66 = \ln (D/10)$, or $(10)(e^{-14.66}) = [D]$ in mM. $[D] = 4.3 \times 10^{-6}$ mM, or 4.3 nM.

16 **The answer is C: 1,200.** Each pound of weight is equivalent to about 3,500 cal. The runner had lost 7 lb, for a total deficit of 24,500 cal. As she lost that weight over 21 days, her daily deficit, if evenly distributed over the course of the three weeks, was 1,167 cal/day.

17 **The answer is B: 150 g of each.** Both proteins and carbohydrates contain 4 cal/g, so to make up approximately 1,200 cal/day the total intake of proteins and carbohydrates would have to be 300 g/day. Since the runner wants to split the calories equally between protein and Carbohydrates, 150 g of each is a better answer than splitting the 300 g into 100 g of one nutrient, and 200 g of another nutrient.

18 **The answer is D: Preponderance of inert adipocytes.** All estimates of the BMR utilize the weight of the individual, however, adipose tissue is primarily metabolically inactive, and if an individual has a lot of adipose tissue, the contribution of the adipose tissue to the overall BMR will lead to an overestimate of the energy needs of the individual. It is not related to the amount of calories consumed, nor does it relate to use of the muscles, since the BMR is estimated for energy use during rest.

19 **The answer is D: A 30-year-old female bodybuilder.** The BMI is an estimate of the "fitness" of an individual, and is calculated by taking the weight, in kilograms, and dividing by the square of the height, in meters. Values between 18.5 and 24.9 are considered the normal range, while values above 24.9 fall into the preobese and obese categories. Body builders, whether male or female, have an increased muscle mass for their height, which adds weight. Thus, body builders will have an inflated BMI which is not indicative of their fat content (it reflects their muscle mass instead). The other individuals listed will mostly fit the criteria for a valid BMI determination.

20 **The answer is C: 180.** With alcohol at 5% wt./vol., 500 mL of beer would contain 25 g of alcohol (5 g/100 mL). Alcohol contains 7 cal/g, so $7 \times 25 = 175$ cal. Beer also contains some carbohydrates, so its total caloric content would be even higher than the 175 due to the ethanol alone. In contrast, 12 ounces of a cola product typically contains 150 cal (none from ethanol).