The National Medical Series for Independent Study

biochemistry

Ian D. K. Halkerston, Ph.D.

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Ian D. K. Halkerston, Ph.D.

Associate Professor of Biochemistry
Department of Biochemistry
University of Massachusetts
Medical Center
Worcester, Massachusetts

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Preface

This review of biochemistry was developed from the medical biochemistry course taught to first-year medical students at the University of Massachusetts Medical School. It is presented in two parts: the first gives the essentials of information transfer, protein structure-function, and enzymes, and the second deals with the metabolism of carbohydrates, fats, and proteins (and other nitrogen-containing compounds) together with major mechanisms of integration and control of metabolism.

Ian D. K. Halkerston

Acknowledgments

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Introduction

Biochemistry is one of seven basic science review books in a series entitled, *The National Medical Series for Independent Study*. This series has been designed to provide students, house officers, as well as physicians, with a concise but comprehensive instrument for self-evaluation and review within the basic sciences. Although *Biochemistry* would be most useful for students preparing for the National Board of Medical Examiners examinations (Part I, FLEX, VQE, and ECFMG), it should also be useful for students studying for course examinations. These books are not intended to replace the standard basic science texts, but, rather, to complement them.

The books in this series present the core content of each basic science area, using an outline format and featuring a total of 300 study questions. The questions are distributed throughout the book at the end of each chapter and in a pretest and posttest. In addition, each question is accompanied by the correct answer, a paragraph-length explanation of the correct answer, and specific reference to the outline points under which the information necessary to answer the question can be found.

We have chosen an outline format to allow maximum ease in retrieving information, assuming that the time available to the reader is limited. Considerable editorial time has been spent to ensure that the information required by all medical school curricula has been included and that each question parallels the format of the questions on the National Board examinations. We feel that the combination of the outline format and board-type study questions provides a unique teaching device.

We hope you will find this series interesting, relevant, and challenging. The authors, as well as the John Wiley and Harwal staffs, welcome your comments and suggestions.

Contents

Pretest

QUESTIONS

Directions: Each question below contains five suggested answers. Choose the **one best** response to each question.

1. Which of the following statements explains how galactose is used for glycolysis?

(A) It is phosphorylated to galactose 1-phosphate, which interacts with uridine diphosphoglucose (UDP-glucose) to form UDP-galactose and glucose 1-phosphate. An epimerase converts UDP-galactose to UDP-glucose
(B) It is phosphorylated to galactose 6-phosphate, which is converted to glucose 6-phosphate by an epimerase
(C) It is converted to glucose by an epimerase, and the latter is phosphorylated by hexokinase to glucose 6-phosphate
(D) It is converted by an isomerase to fructose, which is phosphorylated by fructokinase to fructose 1-phosphate. The latter is converted to dihydroxyacetone phosphate and D-glyceraldehyde by aldolase B
(E) It cannot serve as a source of pyruvate

2. Some of the free energy released in the mitochondrial electron transport chain can be harnessed to the formation of adenosine triphosphate (ATP). How many moles of ATP can be formed per mole-pair of electrons transferred from reduced nicotinamide adenine dinucleotide (NADH) to oxygen?

(A) 0
(B) 1
(C) 2
(D) 3
(E) 4

3. A segment of a DNA chain with the base sequence TCAGAT would be transcribed by RNA polymerase to an RNA chain with which of the following base sequences?

(A) CUAAGU
(B) AGUCUA
(C) AGTCTA
(D) AUCUGA
(E) ATCTGA

4. The glycolytic pathway requires which of the following as allosteric regulatory enzymes?

(A) Glucokinase, phosphofructokinase, and pyruvate kinase
(B) Hexokinase, aldolase, and pyruvate kinase
(C) Hexokinase, glyceraldehyde 3-phosphate dehydrogenase, and enolase
(D) Phosphofructokinase, enolase, and pyruvate kinase
(E) Hexokinase, phosphofructokinase, and pyruvate kinase

5. Xeroderma pigmentosum is an autosomal recessive mutation which affects the mechanism for repair of ultraviolet light–induced thymine dimer formation in DNA. Which one of the following enzymes is most likely to be defective?

(A) DNA polymerase I
(B) DNA polymerase III
(C) Endonuclease
(D) Exonuclease
(E) DNA ligase

6. The pK'_a of carbonic acid in plasma is 6.1. The pH of a sample of plasma was found to be 7.1. What is the ratio of HCO_3^- to H_2CO_3?

(A) 100:1
(B) 50:1
(C) 20:1
(D) 10:1
(E) 5:1

7. All of the following statements concerning the actions of transaminases are true EXCEPT that they do not

(A) catalyze readily reversible reactions with an equilibrium constant (K_e) between 1 and 10
(B) interact with four substrates
(C) all require pyridoxal phosphate as a cofactor
(D) all require adenosine triphosphate (ATP) as an energy source
(E) appear in both cytosolic and mitochondrial compartments

8. D-Ribose 5-phosphate is formed in the pentose phosphate pathway from

(A) ribulose 5-phosphate by an isomerase
(B) xylulose 5-phosphate by an epimerase
(C) the interaction of sedoheptulose 7-phosphate and erythrose 4-phosphate
(D) the interaction of fructose 6-phosphate and glyceraldehyde 3-phosphate
(E) the interaction of xylulose 5-phosphate and erythrose 4-phosphate

9. Which of the following statements best describes the DNA polymerase activity within eukaryote cells?

(A) It is of only one kind
(B) It does not have an associated nuclease activity
(C) It uses nucleoside diphosphates as substrates
(D) It does not require a primer
(E) It carries out elongation of DNA chains in a 3′ to 5′ direction

10. If the cytosine content of duplex DNA is 20 percent of the total bases, the adenine content would be

(A) 10 percent
(B) 20 percent
(C) 30 percent
(D) 40 percent
(E) 50 percent

11. State III respiration in a mitochondrial preparation describes the rate of oxygen uptake

(A) when the ratio of adenosine di- to triphosphate (ADP to ATP) is 1:3
(B) in the presence of Mg^{2+}, substrate, inorganic phosphate (P_i), and ADP
(C) in the presence of an uncoupler of oxidative phosphorylation only
(D) in the presence of ADP but in the absence of substrate
(E) in the presence of Mg^{2+} and substrate only

12. A sample of urine from a patient with ketosis contained 30 millimoles of total acetoacetic acid–acetoacetate (pK'_a = 4.8). The pH of the urine was 4.8. How many millimoles of sodium ion were excreted with this keto acid?

(A) 5
(B) 10
(C) 15
(D) 20
(E) 25

13. How many carbons of the purine ring are contributed by the folate one-carbon pool during purine biosynthesis?

(A) 0
(B) 1
(C) 2
(D) 3
(E) 4

14. All of the following statements characterize DNA replication EXCEPT that

(A) RNA and DNA chains are linked covalently
(B) growth of the new DNA chain occurs in the 5′ to 3′ direction
(C) growth of the DNA chain is discontinuous
(D) overall growth of the DNA chain is bidirectional
(E) DNA is synthesized in a 3′ to 5′ direction on one parental strand and in a 5′ to 3′ direction on the other

15. The greatest amount of body glycogen can be found in which of the following human tissues?

(A) Liver
(B) Kidney
(C) Skeletal muscle
(D) Cardiac muscle
(E) Adipose tissue

16. Muscle glycogen cannot be used as a direct source of blood glucose because muscle

(A) uses all of its glucose 6-phosphate for glycolysis
(B) lacks glucose 6-phosphatase
(C) cell membranes transport glucose unidirectionally into the cell
(D) lacks phosphoglucomutase
(E) lacks aldolase

17. Which of the following enzymes catalyzes reactions in the biosynthesis of *both* catecholamines and indoleamines (serotonin)?

(A) Dopamine β-hydroxylase
(B) Phenylethanolamine N-methyl transferase
(C) Aromatic amino acid decarboxylase
(D) Tryptophan hydroxylase
(E) Tyrosine hydroxylase

18. Which of the following statements does not characterize lipoprotein lipase?

(A) It is localized in endothelial cell membranes
(B) It has phospholipase activity
(C) It is activated by phospholipids and apolipoprotein C-II
(D) It hydrolyzes off fatty acids from the sn-2 carbon of the glycerol backbone
(E) It is missing, or deficient, in patients with type 1 hyperlipidemia

19. What proportion of the carbon in tripalmitoyl glycerol can give rise to a net increase in blood glucose?

(A) 6 percent
(B) 16 percent
(C) 84 percent
(D) 94 percent
(E) 100 percent

20. Which of the following cofactors derived from a vitamin is involved in the formation of hydroxyproline during collagen synthesis?

(A) Pyridoxal phosphate (vitamin B_6)
(B) Biotin
(C) Thiamine pyrophosphate (vitamin B_1)
(D) Ascorbic acid (vitamin C)
(E) Methylcobalamin (vitamin B_{12})

21. An enzyme that catalyzes the conversion of an aldose sugar to a ketose sugar would be classified as one of the

(A) oxidoreductases
(B) transferases
(C) hydrolases
(D) isomerases
(E) lyases

22. The transformation of serine to glycine is dependent upon adequate absorption of which of the following pairs of vitamins from the gut?

(A) Niacin and B_{12}
(B) Folic acid and B_{12}
(C) B_6 and B_{12}
(D) NAD^+ and B_{12}
(E) Thiamine and B_{12}

23. The translation of mRNA into the amino acid sequence of a polypeptide is terminated at the end of the message by one of three chain termination codons in the mRNA. The stop codon is recognized by

(A) a specific uncharged tRNA
(B) a specific aminoacyl tRNA
(C) a specific ribosomal RNA
(D) a specific protein
(E) none of the above substances

24. All of the following statements regarding insulin are correct EXCEPT

(A) it is produced by the β cells of the islets of Langerhans in the pancreas
(B) preproinsulin is clipped to form proinsulin in the cisterna of the endoplasmic reticulum
(C) proinsulin is converted to insulin in storage vesicles in the β cell
(D) the active peptide contains 51 amino acids
(E) the active hormone is made up of one B chain linked by disulfide bonds to a C chain

25. Fructose in seminal fluid is the major energy source for spermatozoa and is formed by

(A) isomerization of glucose 6-phosphate to fructose 6-phosphate and dephosphorylation of the latter
(B) reduction of D-glucose to sorbitol and oxidation of the latter to D-fructose
(C) reduction of D-glucose 6-phosphate to sorbitol 6-phosphate and oxidation and dephosphorylation of the latter to D-fructose
(D) dephosphorylation of fructose 1-phosphate
(E) none of the above reactions

26. It is possible for a variety of substrates to use a common pathway for the transfer of electrons to oxygen because

(A) the substrates are oxidized in the mitochondria
(B) many of the substrates are oxidized by enzymes linked to oxidized nicotinamide or flavin adenine dinucleotide (NAD^+ or FAD)
(C) the substrates are all oxidized by the same enzymes
(D) the electrons from all substrates are transferred to the common acceptor, adenosine triphosphate (ATP)
(E) protons from all substrates are used to form water

27. The values of $\Delta G^{o'}$ for the hydrolysis of adenosine triphosphate (ATP) and creatine phosphate are -7.4 kcal/mole and -10.2 kcal/mole, respectively. How then can you account for the formation of creatine phosphate from ATP and creatine, catalyzed by creatine kinase?

(A) Two molecules of ATP are necessary to form one molecule of creatine phosphate
(B) Because ATP contains two high-energy phosphate bonds, there is sufficient free energy available to drive the reaction
(C) The reaction involves the use of another high-energy phosphate compound
(D) The formation of creatine phosphate from ATP and creatine will proceed if the concentration of creatine kinase is high enough
(E) The ΔG of the reaction is dependent upon the concentration of reactants as well as on the $\Delta G^{o'}$ values of hydrolysis

28. The two nitrogen atoms in urea arise from

(A) ammonia and glutamine
(B) ammonia and aspartic acid
(C) glutamine and aspartic acid
(D) glutamine and glutamic acid
(E) glutamic acid and alanine

29. The essential amino acids are best described as

(A) major sources of carbon for gluconeogenesis
(B) ingested in the form of protein
(C) synthesized only in the liver
(D) all basic amino acids
(E) none of the above

30. All of the following statements regarding the DNA of mitochondria are correct EXCEPT that

(A) it is double-stranded
(B) it is circular
(C) it is small compared to nuclear DNA
(D) it codes for all of the mitochondrial proteins
(E) it is *not* associated with histones

31. Epinephrine is formed from norepinephrine by

(A) hydroxylation
(B) decarboxylation
(C) oxidative deamination
(D) O-methylation
(E) N-methylation

32. If a reaction is at equilibrium, the free energy change is

(A) equal to $-RT \times \ln K_{eq}$
(B) equal to $-nF \times \Delta E_0'$
(C) equal to the free energy change under standard conditions
(D) equal to zero
(E) none of the above

33. Cholesterol can act as a precursor for each of the following compounds EXCEPT for

(A) chenodeoxycholic acid
(B) 1,25-dihydroxycholecalciferol
(C) testosterone
(D) glycocholic acid
(E) cholecystokinin

34. All of the following compounds are intermediates of the tricarboxylic acid (TCA) cycle EXCEPT for

(A) isocitrate
(B) malate
(C) oxaloacetate
(D) pyruvate
(E) succinate

35. Which of the following groups of amino acids are catabolized along common pathways?

(A) Alanine, leucine, isoleucine, and methionine
(B) Glycine, serine, glutamine, and asparagine
(C) Lysine, leucine, serine, and cysteine
(D) Proline, glutamate, glutamine, and arginine
(E) Tryptophan, tyrosine, phenylalanine, and histidine

36. All of the following statements describe phosphoglycerides EXCEPT that they

(A) are both amphipathic and amphoteric
(B) arise from phosphatidic acid
(C) are found in cell membranes
(D) are a major store of metabolic energy
(E) contain two fatty acid moieties

37. Which of the following electrophoretic analytical procedures does not depend on the charge of the protein?

(A) Moving boundary electrophoresis
(B) Zone electrophoresis
(C) Sodium dodecyl sulfate (SDS)–polyacrylamide gel electrophoresis
(D) Isoelectric focusing
(E) None of the above

38. Glycogen is stored in the cells as

(A) a component of endoplasmic reticulum membranes
(B) granules which also contain the enzymes that catalyze its formation and degradation
(C) granules adhering to the inner side of the plasma membrane
(D) a component of the Golgi apparatus, where it is formed
(E) free glycogen in solution in the cytosol

39. The acetyl groups required for cytoplasmic fatty acid synthesis appear in the cytoplasm as a result of the activity of

(A) citrate synthetase
(B) isocitrate dehydrogenase
(C) citrate lyase
(D) thiolase
(E) none of the above enzymes

40. Which of the following regulatory actions involves a reversible covalent modification of an enzyme?

(A) Allosteric modulation
(B) Competitive inhibition
(C) Conversion of zymogen to active enzyme
(D) Association of apoenzyme with a cofactor
(E) Phosphorylation of a serine hydroxyl on the enzyme

41. At pH 7.0, the net charge on the peptide Ala-Gly-Glu-Pro would be

(A) −2
(B) −1
(C) 0
(D) +1
(E) +2

42. In biological membranes, proteins and lipids interact mainly by

(A) hydrophobic interactions
(B) hydrogen bonding
(C) covalent bonds
(D) ionic bonds
(E) both hydrophobic and covalent bonds

Directions: Each question below contains four suggested answers of which **one or more** is correct. Choose the answer

A if **1, 2, and 3** are correct
B if **1 and 3** are correct
C if **2 and 4** are correct
D if **4** is correct
E if **1, 2, 3, and 4** are correct

43. Characteristics of peripheral membrane proteins include

(1) extractability using relatively gentle procedures
(2) location on the cytoplasmic or inner face of the red cell membrane
(3) interaction with polar ends of membrane phospholipids
(4) an invariable association with carbohydrate groups which are covalently bound

44. Epinephrine acts on the liver to

(1) increase blood sugar levels
(2) decrease glycogen synthesis
(3) activate glycogen phosphorylase
(4) activate adenylate cyclase

45. Peptide bond synthesis requires an input of energy during

(1) amino acid activation
(2) the formation of the 70S initiation complex of prokaryotes
(3) the binding of the aminoacyl-tRNA to the A site on the ribosome
(4) the movement of the peptide-tRNA to the P site and the associated movement of the mRNA

46. Which of the following fatty acids *could* be a precursor of prostaglandins in humans?

(1) Linoleic acid
(2) Δ^8, Δ^{11}, Δ^{14}-Eicosatrienoic acid
(3) Linolenic acid
(4) Δ^5, Δ^8, Δ^{11}-Eicosatrienoic acid

47. The release of CO_2 results from which of the following reactions in the tricarboxylic acid (TCA) cycle?

(1) Isocitrate to α-ketoglutarate
(2) Malate to oxaloacetate
(3) α-Ketoglutarate to succinyl CoA
(4) Succinate to fumarate

48. Which of the following enzymes require biotin as a cofactor?

(1) Acetyl CoA carboxylase
(2) Pyruvate carboxylase
(3) Propionyl CoA carboxylase
(4) Carbamoyl phosphate synthetase I (mitochondrial)

49. Correct statements regarding the structure of polysaccharides include which of the following?

(1) Amylose is a linear unbranched polymer of D-glucose in a repeating sequence of α-1,4 glycosidic linkages
(2) Amylopectin is a branched polymer of D-glucose with α-1,4 glycosidic linkages and with α-1,6 branching points every 25 to 30 D-glucose residues
(3) Glycogen is a branched polymer of D-glucose with α-1,4 glycosidic linkages and with α-1,6 branching points every 8 to 10 D-glucose residues
(4) Cellulose is composed of linear chains of D-glucose units joined by α-1,4 glycosidic linkages

50. Correct statements describing the biosynthesis of deoxythymidylate include which of the following?

(1) Deoxythymidylate (dTMP) is formed by methylation of deoxyuridylate (dUMP)
(2) The donor of the methyl group is 5,10-methylene tetrahydrofolate
(3) The tetrahydrofolate coenzyme is oxidized to dihydrofolate in the reaction
(4) Blockade of the reduction of dihydrofolate to tetrahydrofolate is the basis of action of the antitumor agent methotrexate

51. Correct statements regarding pancreatic lipase include which of the following?

(1) The substrates for pancreatic lipase are triacylglycerols in micellar form
(2) The products of pancreatic lipase action are fatty acids and 2-acylglycerols
(3) Pancreatic lipase secretion is stimulated by pancreozymin-cholecystokinin
(4) Pancreatic lipase zymogen is activated by bile acids and neutral pH

52. Correct statements regarding the cytoplasmic fatty acid synthetase system of mammals include which of the following?

(1) The major product is a C-16 fatty acid
(2) The chain grows by addition of 2-carbon fragments donated by a 3-carbon compound
(3) The electron donor for the reductive synthesis of fatty acids is reduced nicotinamide adenine dinucleotide phosphate (NADPH)
(4) The NADPH required by the system is produced by the glycolytic pathway

53. Correct statements regarding glucokinase include which of the following?

(1) It has a much higher Michaelis constant (K_m) for glucose than hexokinase
(2) It phosphorylates most hexoses
(3) It is an inducible enzyme
(4) It is found in most cells

54. Which of the following substances can interact with target cells by binding to a receptor on the outer side of the plasma membrane?

(1) Triiodothyronine
(2) Glucagon
(3) 17β-Estradiol
(4) Epinephrine

55. True statements about myoglobin include which of the following?

(1) It is a monomeric protein
(2) It contains four protoheme IX prosthetic groups
(3) The molecule has eight major helical segments
(4) Oxygen binding exhibits cooperative kinetics

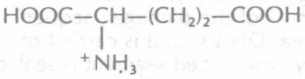
56. Long-chain fatty acid moieties are found in which of the following complex lipids?

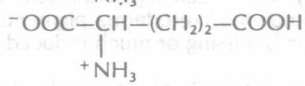
(1) G_{M2} Gangliosides
(2) Phosphatidyl serine
(3) Galactocerebroside
(4) Sphingomyelin

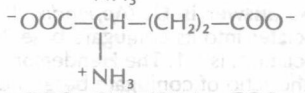
57. Correct statements regarding γ-aminobutyric acid include which of the following?

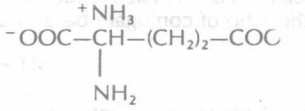
(1) γ-Aminobutyric acid (GABA) is an inhibitory neurotransmitter in the brain and spinal cord
(2) GABA is formed from L-glutamate by decarboxylation
(3) GABA is metabolized within the neurons to succinate
(4) GABA is a five-carbon amino acid

58. Which of the following ionic species of glutamic acid would be the most prevalent at pH 7?

(1) 

(2) 

(3) 

(4) 

59. Correct statements regarding the interconversion of purine nucleotides include which of the following?

(1) Adenosine monophosphate (AMP) can be formed by reduction of guanosine monophosphate (GMP)
(2) Inosine monophosphate (IMP) can be formed by deamination of AMP
(3) GMP can be formed by deamination of IMP
(4) IMP can be formed by reduction of GMP

60. Cells capable of gluconeogenesis include

(1) hepatocytes
(2) kidney tubule cells
(3) small intestine mucosal cells
(4) pancreatic islet β cells

ANSWERS AND EXPLANATIONS

1. The answer is A. *(Chapter 19, IV D 2, 3)* Galactose is phosphorylated by galactokinase to form galactose 1-phosphate. Hexose 1-phosphate uridyl transferase catalyzes the transfer of the uridine diphosphoryl moiety from uridine diphosphoglucose (UDP-glucose) to galactose 1-phosphate to form uridine diphosphogalactose and glucose 1-phosphate. An epimerase converts UDP-galactose to UDP-glucose, which can be metabolized in the glycolytic pathway.

2. The answer is D. *(Chapter 16, V B)* The free energy released in the transfer of electrons from reduced nicotinamide adenine dinucleotide (NADH) to oxygen by the mitochondrial electron transport chain (ETC) is sufficient to support the phosphorylation of adenosine diphosphate (ADP) to the triphosphate (ATP) at three sites. Thus, for every pair of electrons that pass down the chain, 3 molecules of ATP are formed, or for every mole-pair of electrons transferred, 3 moles of ATP are formed.

3. The answer is D. *(Chapter 1, II B; IV A 3)* The complementary strand of RNA formed from the DNA template TCAGAT would be AGUCUA written in the 3′ to 5′ direction with uracil in place of thymine. By convention the sequence should be written 5′ to 3′, to give AUCUGA.

4. The answer is E. *(Chapter 14, V)* There are three allosteric regulatory enzymes in the glycolytic pathway. Hexokinase is inhibited by glucose 6-phosphate, but the main liver enzyme with the same function, glucokinase, is not a regulatory enzyme. Phosphofructokinase is allosterically inhibited by adenosine triphosphate (ATP), citrate, or H^+ ions, and activated by ADP, AMP, or inorganic phosphate. Pyruvate kinase is activated by fructose 1,6-diphosphate.

5. The answer is C. *(Chapter 2, IV B)* Thymine dimers in DNA chains can form on irradiation with ultraviolet (UV) light. A specific repair system depends upon a UV-specific endonuclease which recognizes the thymine dimer and makes a nick in the DNA strand, usually on the 5′ side of the dimer. Removal of the damaged sequence and its replacement by bases which are complementary to the parental DNA strand is carried out by DNA polymerase I. The gap between the main chain and the newly synthesized segment is sealed by DNA ligase. In the genetic abnormality underlying the condition known as xeroderma pigmentosum, the UV-specific endonuclease that recognizes the thymine dimers is missing or much reduced in activity. Thus, the excision repair process does not function.

6. The answer is D. *(Appendix, II D 2 c)* Carbonic acid (H_2CO_3), which is a weak acid, partially dissociates into its conjugate base (HCO_3^-) and a proton. In plasma the pK_a or the pH at 50 percent dissociation, is 6.1. The Henderson–Hasselbalch equation describes the relationship between pH, pK_a', and the ratio of conjugate base to conjugate acid:

$$pH = pK_a' + \log \frac{[base]}{[acid]}$$

At pH 7.1 the log of the ratio of base to acid is 7.1 − 6.1, which is 1. Therefore, since 1 is the log of 10, the ratio is 10:1.

7. The answer is D. *(Chapter 27, I A 1)* Transaminases catalyze the transfer of an amino group from an amino acid to an α-keto group to form a new amino acid and a new α-keto acid. The reactions are readily reversible when the equilibrium constant (K_e) is between 1 and 10. Each transaminase accepts two amino acids and two α-keto acids as substrates, and all require pyridoxal phosphate as a cofactor in the transfer of amino groups from amino acids to the α-keto acids. They are found within the inner mitochondrial membrane (in the matrix space) and in the cytosol. The transamination reaction is not coupled to the hydrolysis of a high-energy phosphate bond of adenosine triphosphate (ATP).

8. The answer is A. *(Chapter 19, I B 4)* Ribose 5-phosphate, required for the synthesis of nucleotides, is formed from ribulose 5-phosphate by an isomerization. Ribulose 5-phosphate arises from glucose 6-phosphate by the sequential action of glucose 6-phosphate dehydrogenase and 6-phosphogluconate dehydrogenase. The interaction of sedoheptulose 7-phosphate and glyceraldehyde 3-phosphate, catalyzed by transaldolase, produces erythrose 4-phosphate and fructose 6-phosphate. The interaction of fructose 6-phosphate and glyceraldehyde 3-phosphate, catalyzed by transketolase, produces xylulose 5-phosphate and erythrose 4-phosphate.

9. The answer is B. *(Chapter 7, III C)* There are three kinds of DNA polymerase in eukaryote cells DNA pol_α functions in the replication of nuclear DNA, DNA pol_β in the repair of nuclear DNA, and DNA pol_γ in the replication of mitochondrial DNA. They all require a primer, use nucleoside triphosphates as substrates, and synthesize new DNA chains in a 5′ to 3′ direction. There is no nuclease activity associated with any of the eukaryote DNA polymerases.

10. The answer is C. *(Chapter 1, IV A 3)* Since the mole fraction of C equals the mole fraction of G in duplex DNA, G + C = 40 percent. The remaining 60 percent must be divided equally between A and T because the mole fraction of A equals the mole fraction of T in duplex DNA (Chargaff's rules). Thus, the adenine content must be 30 percent of the total bases.

11. The answer is B. *(Chapter 17, III B)* A preparation of mitochondria incubated in the presence of Mg^{2+}, substrate, inorganic phosphate (P_i), and adenosine diphosphate (ADP) shows an oxygen utilization rate that is limited by the rate of phosphorylation of ADP to ATP. This is called state III respiration. When all of the ADP has been phosphorylated, the respiration rate will decline to a state IV level.

12. The answer is C. *(Appendix, II D 2 a)* The pH of the urine is the same as the pK_a' of the acetoacetic acid conjugate acid-base pair; that is, 4.8. At this pH 50 percent of the acetoacetic acid is present as acetoacetate ion, which carries a single negative charge. Sodium will be excreted as the positively charged counter-ion in equivalent amount; that is, 50 percent of 30 millimoles, or 15 millimoles.

13. The answer is C. *(Chapter 29, I B 1)* Two carbons from the folate one-carbon pool are used in the formation of the purine nucleotides. The first reaction to use a one-carbon group from the folate pool transfers a formyl group from 5 ,10-methylidyne tetrahydrofolate to 5′-phosphoribosylglycinamide to form 5′-phosphoribosyl-N-formylglycinamide. Another one-carbon group is transferred from 10-formyl tetrahydrofolate to form 5′-phosphoribosyl-5-formamidoimidazole-4-carboxamide, the immediate precursor of inosine monophosphate.

14. The answer is E. *(Chapter 2, III)* DNA is replicated by a polymerase complex, which adds deoxyribonucleotide triphosphates to an RNA primer chain, selecting for insertion only the base-pairing nucleotide complementary to that in the parental DNA chain. The first deoxyribonucleotide inserted is bonded covalently to the primer nucleotide by a phosphodiester link. Growth of the chain is always in the 5′ to 3′ direction on both strands. Replication starts at a specific point and proceeds bidirectionally.

15. The answer is C. *(Chapter 18, II B)* Muscle and liver are major sites for glycogen storage, and although the concentration of glycogen is higher in liver than in muscle, the much greater mass of skeletal muscle stores a greater total amount of glycogen. It is important to recognize that liver glycogen can be mobilized for the release of glucose to the rest of the body, but muscle glycogen can only be used to support muscle glycolysis.

16. The answer is B. *(Chapter 13, IV A, B; Chapter 32, III B 3 e)* The glycogen that is stored in muscle cannot be used to increase blood glucose directly because muscle lacks glucose 6-phosphatase. However, muscle glycogen can provide glucose indirectly by forming lactate, which is released from muscle and forms a gluconeogenic substrate for liver. This is known as the Cori cycle.

17. The answer is C. *(Chapter 28, I D 3)* The neurotransmitter dopamine is formed from 3,4-dihydroxy-L-phenylalanine (dopa) by the action of aromatic amino acid decarboxylase. The same enzyme decarboxylates 5-hydroxytryptophan to yield 5-hydroxytryptamine (serotonin), an indoleamine. The three hydroxylases listed are specific for their substrates, and phenylethanolamine N-methyl transferase is responsible for the conversion of norepinephrine to epinephrine.

18. The answer is D. *(Chapter 24, III A 2; Table 24-1)* Lipoprotein lipase is localized in the plasma membrane of endothelial cells. It hydrolyzes triacylglycerols in chylomicrons and in very low density lipoproteins (VLDLs), removing fatty acids from either the sn-1 or sn-3 carbon of the glycerol moiety. A 2-acyl hydrolase completes the hydrolysis of triacylglycerols. Lipoprotein lipase is activated by phospholipids and apolipoprotein C-II, which is obtained by chylomicrons from high-density lipoprotein particles (HDLs) synthesized in the liver. Lipoprotein lipase also exhibits intrinsic phospholipase activity. It is missing, or deficient, in type I hyperlipidemia (familial lipoprotein lipase deficiency).

19. The answer is A. *(Chapter 13, IV C; Chapter 20 VI B; Chapter 32, I C 1 d)* A triacylglycerol (triglyceride) containing long-chain fatty acids with an even number of carbons can only provide substrate for gluconeogenesis from the three carbons of the glycerol backbone. The carbons from the fatty acids end up as acetyl CoA, which cannot be a substrate for gluconeogenesis. Tripalmitoyl glycerol contains 51 carbons, of which 3 are gluconeogenic, or 6 percent of the total.

20. The answer is D. *(Chapter 9, III C 1 b)* The enzyme prolyl hydroxylase forms hydroxyproline from proline residues in procollagen molecules as they pass through the cisternae of the endoplasmic reticulum during synthesis. Ascorbic acid (vitamin C) is required by this hydroxylase, possibly to keep the essential iron component of the system in the reduced state. The reaction also requires molecular oxygen and α-ketoglutarate, but none of the other vitamin-derived cofactors listed as choices are involved.

21. The answer is D. *(Chapter 10, II B; Chapter 12, III A;)* The choices listed are five of the six groups used by the International Union of Biochemistry to classify all enzymes; the missing group is the ligases. The aldose and ketose sugars are isomers and an enzyme catalyzing their interconversion would thus be classified as an isomerase.

22. The answer is B. *(Chapter 27, III C 4 b; Chapter 31, IV E 3 a, b)* The reversible transformation of serine and glycine requires tetrahydrofolate as cofactor. This is a derivative of the vitamin folic acid. However, with inadequate vitamin B_{12} uptake from the gut, the metabolism of the folate coenzymes is impaired. In particular, there is an accumulation of the inactive form 5-methyl tetrahydrofolate. This is because the only way in which 5-methyl tetrahydrofolate can be utilized is in the reaction converting homocysteine to methionine, which requires methylcobalamin as a cofactor, and this is derived from vitamin B_{12}.

23. The answer is D. *(Chapter 4, III C; Chapter 5, VI C)* The three chain termination codons, UAA, UAG, and UGA do not specify amino acids and there are no tRNAs whose anticodon recognizes them. They are recognized by the protein release factors, RF 1 and RF 2, which bind to the termination codons. RF 1 recognizes UAA or UAG, and RF 2 recognizes UAA or UGA. The binding of the release factors initiates the hydrolysis of the link between the polypeptide and the tRNA.

24. The answer is E. *(Chapter 30, IV)* Because it is a protein that the β cells of the islets of Langerhans in the pancreas are going to secrete, insulin is first formed by ribosomes bound to the endoplasmic reticulum as preproinsulin, which contains a leader, or signal, sequence of 23 amino acids at its amino end. This signal sequence directs the protein to the cisterna of the endoplasmic reticulum. In the cisterna the signal sequence is clipped off to give proinsulin (81 residues), which is stored in vesicles in the β cell. Prior to secretion two peptidases clip out a sequence of 30 residues, which is called the C peptide, leaving active insulin (51 residues), which is secreted. Insulin contains two chains, a B chain and an A chain, linked by disulfide bonds. The inactive C peptide is also secreted.

25. The answer is B. *(Chapter 19, III C 1 b)* Fructose in the seminal vesicle is formed from glucose by reduction to D-sorbitol followed by oxidation of the latter to D-fructose. The fructose is used for an energy supply by its conversion to lactate via the glycolytic pathway in spermatozoa, and by oxidation of the lactate to CO_2 and water by spermatozoal mitochondria, which are unique in their complement of the enzyme lactate dehydrogenase.

26. The answer is B. *(Chapter 16, I B)* The tricarboxylic acid (TCA) cycle and the electron transport chain (ETC) act as a common pathway for the transfer of electrons from a variety of substrates to oxygen because many of the enzymes involved in the oxidation of metabolic fuels are linked to oxidized nicotinamide or flavin adenine dinucleotide (NAD^+ or FAD). These electron carriers pass on their electrons to oxygen via the ETC.

27. The answer is E. *(Chapter 11, II E)* The standard free energy change ($\Delta G^{0\prime}$) associated with the formation of adenosine triphosphate (ATP) from creatine phosphate and ADP is -3.0 kcal/mole, a value which could be predicted from the greater $\Delta G^{\circ\prime}$ for the hydrolysis of creatine phosphate in relation to that for ATP. Thus the $\Delta G^{\circ\prime}$ for the reverse reaction, that is, the formation of creatine phosphate from ATP and creatine, is $+3.0$ kcal/mole. However, the spontaneity of a reaction is indicated by the value for ΔG, which depends not only upon the $\Delta G^{\circ\prime}$ but also on the concentration of reactants and products. The actual ΔG for the formation of creatine phosphate from creatine and ATP, catalyzed by creatine kinase, is given by

$$\Delta G = +3.0 + RT \ln \frac{[\text{creatine P}][\text{ADP}]}{[\text{creatine}][\text{ATP}]}$$

If the concentrations of ATP and creatine are high enough, creatine phosphate will be formed.

28. The answer is B. *(Chapter 27, I C 3)* Mitochondrial carbamoyl phosphate synthetase uses ammonia as the nitrogen source in the formation of carbamoyl phosphate. The cytosolic carbamoyl phosphate synthetase involved in pyrimidine synthesis uses glutamine as the nitrogen source (see Chapter 29, I C 2). The other nitrogen in urea arises from aspartate when citrulline is released from the mitochondria into the cytosol and combines with aspartate to form argininosuccinate. The latter is cleaved to arginine and fumarate, and urea arises from the hydrolysis of arginine by arginase.

29. The answer is B. *(Chapter 8, II C 5; Chapter 26, I A 3)* Humans cannot synthesize the carbon skeletons of 9 out of the 20 amino acids required for protein synthesis. These 9 amino acids must be present in the diet and are ingested mainly in the form of protein. Some of their carbon can be used for gluconeogenesis, after deamination, but they do not constitute a major substrate for this process. Only two of the essential amino acids are basic, namely histidine and lysine.