Topic 1: The Chemistry of Life

ANSWERS AND EXPLANATIONS

Level 1: Knowledge/Comprehension Questions

1. **(B) is correct.** RNA is made up of a phosphate group, a ribose sugar, and one of the following four nitrogenous bases: cytosine, guanine, uracil, and adenine. The phosphate group of RNA contains a phosphate atom and three atoms of oxygen, not two. DNA is similar to RNA in many ways but different in two important ones: It contains deoxyribose instead of ribose as its sugar and it contains the base thymine instead of uracil.
2. **(C) is correct.** The answer is water, H_2O. Polar covalent bonds are those in which valence electrons are shared between atoms, but unequally. (The more electronegative atom will attract the electrons more strongly, and that end of the molecule will have a slightly negative charge, whereas the less electronegative atom will attract the electron less strongly and be slightly positive.) The two atoms involved in the bond must differ in electronegativity in order to form a polar covalent bond.
3. **(E) is correct.** Use this question to review the unique properties of carbon. Since it has 4 valence electrons, carbon will form 4 covalent bonds. It does not form polar bonds.
4. **(D) is correct.** The three terms you should keep in mind as you think of water traveling up through the xylem of a plant are transpiration (in which water evaporates from the plant's leaves); cohesion, in which the water molecules stick together due to the hydrogen bonds; and adhesion, whereby the water molecules stick to plant cell walls and resist the downward pull of gravity.
5. **(D) is correct.** Unsaturated fatty acids contain one or more carbon-carbon double bonds, whereas saturated fatty acids contain no double bonds.
6. **(A) is correct.** Lipids are the only one of the four major classes of biological molecules that are not polymers. They are grouped together because they are hydrophobic. Nucleic acids are polymers of nucleotide monomers, proteins are polymers of amino acid monomers, and carbohydrates are polymers of monosaccharide monomers.
7. **(B) is correct.** The linkages between the amino acids of proteins are peptide bonds. Peptide bonds are covalent bonds formed in dehydration reactions. The carboxyl group of one amino acid is joined to the amino group of an adjacent amino acid, resulting in the loss of one molecule of water.
8. **(C) is correct.** One common secondary structure of proteins is the alpha (α) helix; another is the beta (β) pleated sheet. The secondary structure of a protein refers to hydrogen bonding along the backbone (not the side chains) of the amino acid chain.
9. **(E) is correct.** Cellulose is the polysaccharide that forms the strong cell walls of plant cells. It is a polymer of glucose.

10. **(C) is correct.** Denaturation is the process by which proteins lose their overall structure, or conformation, as a result of changes in pH, temperature, or salt concentration. Denatured proteins have reduced biological activity.
11. **(B) is correct.** The ratio of carbon, hydrogen, and oxygen atoms in carbohydrates is 1:2:1. For example, glucose is $C_6H_{12}O_6$.
12. **(C) is correct.** To get this correct, you should first add up all the C, H, and O in three fatty acid chains plus one glycerol. This would be 51 C, 74 H, and 9 O. Then, recall that to join to molecules by dehydration synthesis, one molecule of water must be removed. Since three fatty acid chains will be attached to one glycerol, three water molecules will be removed. Subtract 6 H and 3 O to arrive at the answer.
13. **(B) is correct.** Proteins have many functions, which encompass most of a cell's metabolic activity.
14. **(B) is correct.** Phospholipids are unique macromolecules. Their hydrophilic heads and hydrophobic tails contribute to the semipermeability of cell membranes.
15. **(D) is correct.** The negative charge comes from the electronegative oxygen of one water molecule attracted to the partial positive charge of hydrogen of another water molecule.
16. **(C) is correct.** The monomers in macromolecules are joined when a molecule of water is removed during dehydration, or condensation reactions.
17. **(B) is correct.** Since the pH scale is logarithmic, each unit change is by a factor of 10. A drop of pH means the solution is more acidic and has 10 times more H^+ ions.
18. **(B) is correct.** Transpiration refers to the evaporation of water from pores in leaves. Transpiration is possible because of cohesion and adhesion, but it is not an emergent property of water.
19. **(C) is correct.** An amino acid is composed of a central carbon, bonded to a hydrogen, with a variable (R) group, and with a carboxyl (the acid part) at one end, an amino group at the other end (the amino part). Aldehydes and ketones are found in sugars; the sulfhydryl group is found in one amino acid.
20. **(E) is correct.** Recall that hydrolysis means to use water to split a molecule, so look for a large molecule reduced to its monomers. Maltose is a disaccharide; glucose is a monosaccharide.

Level 2: Application/Analysis/Synthesis Questions

1. **(D) is correct.** Hydrogen bonds occur when a slightly positive hydrogen atom of a polar covalent bond in one molecule is attracted to a slightly negative atom of a polar covalent bond in another molecule. In living systems hydrogens are often attracted to the highly electronegative elements oxygen (as in this question with water) or nitrogen.
2. **(D) is correct.** Structural isomers have the same molecular formula, but differ in the covalent arrangement of their atoms. Answers A, B, and C would all change the molecular formula; thus, they would not be isomers. The location of the double-bonded oxygen is a change in covalent arrangement.
3. **(B) is correct.** Peptide bonds occur between the carboxyl group of one amino acid and the amino group of another amino acid. All that is required

in this question is for you to carefully examine the information given in the diagram. Take a look at every question, even if you may think the content area is a hard one; often the answers are easier than you might expect.

- **4. (D) is correct.** Hydrolysis is a chemical process that splits molecules by the addition of water. Digestive enzymes work by hydrolysis. Water is removed to join the molecules; water is added to separate the molecules.
- **5. (D) is correct.** Recall that enzymes are proteins and proteins are made of amino acids.
- **6. (D) is correct.** Two environmental factors that affect the three-dimensional structure of enzymes are temperature and pH. As the structure of the enzyme is altered the enzyme will become less effective.
- **7. (C) is correct.** Ten glucose molecules would have a combined molecular formula of $C_{60}H_{120}O_{60}$. To form a polymer, a molecule of water would have to be removed as each glucose is added to the chain. Since ten glucose molecules are bonded together, nine H_2O must be removed, 18 hydrogen atoms and 9 oxygen atoms. This leaves a formula of $C_{60}H_{102}O_{51}$.
- **8. (D) is correct.** This conceptual question is based on your knowledge of the structure of DNA. Recall that the molecule is antiparallel, meaning one strand runs 5′ to 3′ while the opposite strand of the double helix runs 3′ to 5′. All of the answers are given with both strands running 3′ to 3′. To get the proper answer convert the second strand given in the answer to 3′ to 5′ and see which one has the proper, matching base-pair sequence.

Free-Response Questions

(a) A phospholipid molecule contains a hydrophilic "head" (containing a glycerol molecule and a phosphate group) and two hydrophobic fatty acid tails. In cell membrane surfaces, phospholipids are arranged in a bilayer, in which the hydrophilic heads are in contact with the cell's watery interior and exterior, while the tails are pointed away from water and toward each other in the interior of the membrane. The fatty acid chains of phospholipids can contain double bonds, which makes them unsaturated. Because of the kinks in the tails, phospholipids aren't packed together tightly, which contributes to the fluidity of the membrane. The fluidity of the cell membrane is very important in its function; the less fluid the membrane is, the more impermeable it is. There is an optimum permeability for the cell membrane, at which all the substances necessary for metabolism can pass into and out of the cell.

The fluidity of cell membranes enables hydrophobic molecules such as hydrocarbons, carbon dioxide, and oxygen to dissolve in the bilayer and easily cross the membrane. However, ions and polar molecules (including water, glucose, and other sugars) cannot pass through because of the hydrophobic interior. Protein channels and transport proteins allow these required substances to cross membranes.

(b) Proteins function as cell membrane transporters because they act as channels; substances that bind to them can help alter their conformation to permit the passage of molecules through them, and into the cell interior.

There are many different ways by which proteins can permit the passage of ionic and polar molecules through the lipid bilayer. Proteins associated with the membrane are either integral proteins, which actually penetrate the lipid bilayer (ones that completely go through the bilayer are called transmembrane proteins), or they are "peripheral proteins" that are associated with the outside of the membrane. Transmembrane proteins can form hydrophilic channels that permit the passage of certain hydrophilic substances that otherwise would not be able to cross the membrane. Other functions that membrane proteins serve are to attach the cell to the extracellular matrix, to stabilize it, and to function in cell-cell recognition. Membrane proteins are also important in cell-cell signaling; some have enzyme function and carry out important metabolic reactions, and they aid in joining adjacent cells.

This response shows thorough knowledge of the processes of the structure of phospholipids, cell membrane structure and components, and movement across membranes. A strong response to this item requires an understanding of topics from Units 1 and 2 of the textbook. Note that the response includes the following key terms in context, showing the writer's knowledge of their meanings and relatedness:

phospholipids
hydrophilic head
glycerol
phosphate
hydrophobic tails
lipid bilayer
double bonds
unsaturated
permeability
metabolism
protein channels
transporters
conformation
integral proteins
transmembrane proteins
extracellular matrix
cell-cell signaling

The student's response would have been strengthened by a more explicit correlation of structure and function, especially by using protein functions other than transport. Specific examples of cell-cell signaling, enzymatic function, and others listed would have demonstrated a deeper knowledge of the topic.

Topic 2: The Cell

ANSWERS AND EXPLANATIONS

Level 1: Knowledge/Comprehension Questions

1. (C) is correct. Light microscopes are good for viewing objects that are 0.2 μm or larger. With a light microscope, you can observe animal and plant cells, some bacterial cells, and some larger organelles such as nuclei mitochondria, and chloroplasts. To see the other organelles in the list of choices, you would need an electron microscope.

2. (C) is correct. The nucleoid region is the only cell structure on this list not found in both prokaryotes and eukaryotes. Eukaryotic cells have a true nucleus, which is surrounded by a double membrane called a nuclear envelope. The genetic material of prokaryotes is localized in a clump in one particular region of the cell that is not enclosed by a membrane.

3. (D) is correct. The endoplasmic reticulum (ER) is an organelle characterized by extensive, folded membranes, and it is often associated with ribosomes.

4. (B) is correct. The Golgi apparatus is the organelle that has a *cis* and *trans* face, and it acts as the packaging and secreting center of the cell. It consists of a series of flattened sacs of membranes called cisternae.

5. (E) is correct. Mitochondria are the powerhouses of the cell; cellular respiration takes place in the mitochondria, forming ATP, the cell's energy currency. Mitochondria are bound by double membranes, and the proteins involved in ATP production are embedded in the inner membranes of the mitochondria.

6. (A) is correct. Peroxisomes perform many metabolic functions in the cell, including the production of hydrogen peroxide in the process. The hydrogen peroxide, a poison, is immediately broken down in the peroxisome by the enzyme catalase. You may recall that catalase was the enzyme used in AP Lab 2.

7. (C) is correct. Lysosomes are characteristic of animal cells but not most plant cells. They are large membrane-bound structures that contain hydrolytic enzymes, and they are responsible for the breakdown of proteins, polysaccharides, fats, and nucleic acids. They function best at a low pH (around 5), so they pump hydrogen ions from the cytosol into their lumen to achieve this acidic pH.

8. (D) is correct. The only answer choice listed that names a molecule typically found in the plasma membranes of animal cells is D, carbohydrates. The major components of animal cell membranes are phospholipids, integral and peripheral proteins, and carbohydrates. One of the main functions of carbohydrates in the cell membrane is cell-cell recognition, which means carbohydrates are an important component of the immune system. Cell-surface carbohydrates are unique to each organism.

9. (D) is correct. Substances will move down their concentration gradient until their concentration is equal on either side of a membrane. For this reason, because the concentration of glucose on side B of the tube is 2.0 *M*, while the concentration of glucose on the A side of the tube is 1.0 *M*, glucose will move to side A.

10. (D) is correct. The only substance listed that can passively diffuse through the cell membrane unaided by proteins is carbon dioxide. Remember that passive diffusion occurs without the cell doing any work. Other choices need the processes of facilitated diffusion and transport proteins to cross the membrane. This is true of all of the answer choices listed except for D.

11. (A) is correct. This figure illustrates the process of cotransport. In cotransport, a pump that is powered by ATP transports a specific solute, protons in this case, out of the cell. The protons then travel down their concentration gradient back into the cell, passing through another transport protein and indirectly providing energy for the movement of another substance (sucrose in this case) against its concentration gradient.

12. (E) is correct. Large molecules are moved out of the cell by exocytosis. In exocytosis, vesicles that are to be exported from the cell (often coming from

the Golgi apparatus) fuse with the plasma membrane, and their contents are expelled into the extracellular matrix. Pinocytosis, phagocytosis, and receptor-mediated endocytosis are types of endocytosis; cytokinesis is the division of the cytoplasm after mitosis.

13. (D) is correct. The shape of the curve in the art shown most closely depicts an exergonic reaction. The free energy of the products is lower than that of the reactants—meaning that in the course of the reaction, energy is given off. This is characteristic of exergonic reactions. Conversely, in an endergonic reaction, energy is taken in during the course of the reaction.

14. (C) is correct. The second law of thermodynamics states that every energy transfer that occurs increases the amount of entropy in the universe. The first law of thermodynamics states that the amount of energy in the universe is constant, and therefore energy can be neither created nor destroyed. Evolutionary theory refers to the myriad changes that have taken place to transform living organisms from the beginning of life on Earth until today.

15. (D) is correct. Catalysts speed up chemical reactions by providing an alternate reaction pathway that lowers the activation energy of the reaction. Less energy is required to start the reaction, so it runs more quickly.

16. (A) is correct. In allosteric regulation, the enzyme is usually composed of more than one polypeptide chain with more than one allosteric site remote from the active site, which is not part of the active site. When an allosteric activator binds to the allosteric site, the protein assumes a stable conformation with a functional active site, and the reaction can proceed. When an allosteric inhibitor binds, this stabilizes the inactive conformation of the protein.

17. (C) is correct. Competitive inhibitors compete for the active site of the enzyme. They are able to bind because they closely resemble the normal substrate. One way to overcome the effects of competitive inhibitors is to increase the amount of substrate so that chances are greater that a substrate molecule (rather than the competitive inhibitor) will bind.

18. (E) is correct. In cooperativity, the enzyme in question has more than one subunit with more than one active site, and it is able to bind more than one substrate—so multiple reactions can be taking place at once in the enzyme. The binding of one substrate molecule to the enzyme causes a conformation change that makes the binding of other substrate molecules, at the other active sites, more favorable.

19. (B) is correct. In feedback inhibition, the product of a metabolic pathway switches off the pathway by binding to and inhibiting an enzyme involved somewhere along the pathway.

20. (D) is correct. In noncompetitive inhibition, the inhibitor binds to a site other than the active site of the enzyme, and this causes the enzyme to change shape. The change in conformation makes the substrate unable to bind to the active site of the enzyme, and this prevents the action from taking place.

21. (A) is correct. Since the substance is being moved against the concentration gradient, energy is required. All the other choices are modes of passive transport and require no energy.

22. (D) is correct. The question requires you to know the structure and action of receptor tyrosine kinases. Recall that they exist as two proteins that come

together when bound by ligands to form a dimer. The tyrosine kinases of each original monomer phosphorylate the tyrosine kinases of the other.

23. **(A) is correct.** When a signal molecule binds to the receptor protein, the gate of the ion channel opens or closes, allowing or blocking the flow of specific ions.
24. **(B) is correct.** Answer A is a reference to a G protein-coupled receptor, but is a quick pick if the question is not read carefully. The G protein is activated by the G protein-coupled receptor, which is a protein and eliminates E as a possible answer.
25. **(D) is correct.** Kinase enzymes are involved with ATP. Protein kinase enzymes are used to amplify the signal during the transduction phase of cell signaling by activating cell proteins with a phosphate from ATP.
26. **(C) is correct.** Many signaling pathways involve small, nonprotein water-soluble molecules or ions called second messengers. Calcium ions and cyclic AMP are two common second messengers. The second messengers, once activated (and always found on the inside of the membrane), can initiate a phosphorylation cascade resulting in a cellular response.
27. **(D) is correct.** Intracellular receptors work with signal molecules that are hydrophobic compounds and are therefore able to cross the plasma membrane. Testosterone, as indicated in the question, is a steroid hormone and thus hydrophobic. Intracellular receptors often act as transcription factors.
28. **(A) is correct.** In telophase, nuclear envelopes begin to form around the sets of chromosomes, which are now located at opposite ends of the cell. The chromatin becomes less condensed, and cytokinesis begins—the cytoplasm of the cell is divided.
29. **(C) is correct.** During cytokinesis, the cytoplasm of the cell is divided approximately equally as the cell membrane pinches off (in animal cells), forming two daughter cells; a cell plate forms in plant cells.
30. **(E) is correct.** In anaphase, the sister chromatids, which were lined up along the equator of the cell, begin to separate, pulled apart by the retracting microtubules. By the end of anaphase, the opposite ends of the cell contain complete and equal sets of chromosomes.
31. **(B) is correct.** Interphase is not a part of mitosis; rather it is the part of the cell cycle when the cell gets ready to divide by replicating its DNA. There are three stages in interphase: G_1 phase, S phase, and G_2 phase. The genetic material is replicated in S phase.
32. **(D) is correct.** Prometaphase is the phase of mitosis in which the nuclear envelope begins to fragment so that the microtubules can begin to attach to the kinetochores of the chromatids, which by this time are very condensed.
33. **(B) is correct.** The depicted cell is in prometaphase. As you can see, the nuclear envelope is fragmenting, and the microtubules have already attached to some of the kinetochores at the centromeres of the chromosomes. The chromosomes are condensed and beginning to line up along the cell's equator.
34. **(D) is correct.** The most crucial checkpoint of the cell cycle is the G_1 checkpoint. In the cell cycle, a checkpoint is a point at which there can be a signal to stop or to go ahead with division. If a cell receives the signal to go ahead at the G_1 checkpoint, it will usually complete the cycle and divide. If it does not receive the go-ahead signal, it will enter the (nondividing) G_0 phase for an indeterminate period of time.

Level 2: Application/Analysis/Synthesis Questions

1. **(D) is correct.** The radioactive tracking starts with the formation of the protein, which occurs on the ER. The protein then moves to the Golgi and out of the cell via vesicles that will fuse with the membrane. Answer C is the proper pathway, but the radioactive amino acids will not be used in the nucleus, and would therefore not be tracked with this system.
2. **(A) is correct.** During S phase of interphase, DNA is replicated. If this did not occur, the daughter cells would have half the genetic material found in the parent cell.
3. **(A) is correct.** Water moves in a hypotonic to hypertonic direction. Cells A, B, and C are all animal cells (red blood cells) and lack a cell wall. Cell D is a plant cell with a cell wall. Cell A is in a hypotonic solution, cell B an isotonic solution, and cell C is in an hypertonic solution. When answering this type of question, pay close attention to whether the solution or the cell is referenced as being hypertonic or hypotonic. In A the solution is hypotonic, while the cell is hypertonic.
4. **(C) is correct.** In plant cells the relatively inelastic cell wall exerts a back pressure on the cells, called turgor pressure. In cell D the plant cell is immersed in a hypotonic solution, causing the cell to uptake water, thus creating the highest levels of turgor pressure. The animal cell A lyses ("pops") because it has only a thin, flexible membrane.
5. **(C) is correct.** The solution in Tank A started with more solutes, then as the water is purified its concentration of solutes increases through the process of reverse osmosis. Tank A becomes increasingly hypertonic over the course of the purification treatment.
6. **(B) is correct.** Tank A with the tap water is hypertonic to the purified water. Since water flows from hypotonic to hypertonic, water would move from Tank B into Tank A.
7. **(C) is correct.** Epinephrine is the ligand that activates the G protein-coupled receptor responsible for glycogen breakdown. Epinephrine does not enter the cell, suggesting a second messenger. Only in intact cells could the first messenger (epinephrine) be translated to a cellular response–glycogen breakdown.
8. **(C) is correct.** G protein-coupled receptors are activated by their specific ligand, not by a phosphorylation event.

Free-Response Questions

(a) Some eukaryotic cell organelles might have evolved from free-living prokaryotic organisms. First of all, prokaryotic cells are much smaller than eukaryotic cells—they range from 100 nm to 10 μm, compared to the average size of eukaryotic cells: 10 to 100 μm. However, mitochondria (organelles unique to eukaryotic cells, and functioning in the creation of ATP in cellular respiration) and eukaryotic cell nuclei are comparable in size to prokaryotic cells, ranging from about 1 to 10 μm.

Another interesting characteristic of organelles that may tie them to prokaryotes is their structure and cell contents. To illustrate this, let's consider the structure of mitochondria. With few exceptions, mitochondria are found in all animal cells, plant cells, fungi, and protists. They can exist in great numbers

in these cells, or cells can contain just one mitochondrion (depending on the metabolic activity of the cell). It has been observed that mitochondria can move around, alter their shape, and even divide in two—all of which are characteristic of living cells. Their structure consists of a double membrane exterior (the membrane is a typical combination of phospholipids and proteins, like the membrane of the cell itself); the outer membrane is relatively smooth, but the interior membrane has infoldings called cristae. This creates two different compartments in mitochondria: The inner compartment is the mitochondrial matrix, and the compartment in between the two membranes is called the intermembrane space. Mitochondria also contain mitochondrial DNA. Not very much DNA is contained in mitochondria, but the presence of DNA could be evidence that they were independent organisms at some time. Also similar to prokaryotes, mitochondria do not contain many interior structures other than their genetic material (which is not enclosed in a nucleus) and their cell membranes. All of the above indicates a close evolutionary relationship between prokaryotic cells and mitochondria.

(b) In order to trace the path of proteins in the cell from their creation to their expulsion, we must start in the nucleus. In the nucleus, mRNA is transcribed from DNA, and mRNA travels out of the nucleus through a nuclear pore to the cytoplasm, ending up at ribosomes, some of which are associated with the endoplasmic reticulum (called rough endoplasmic reticulum because of this association). Within the lumen of the ER, the mRNA is translated into protein, which then undergoes folding to assume its final shape, or conformation.

Secretory proteins travel from the endoplasmic reticulum to the series of flattened membranous sacs known as the Golgi apparatus. They enter at the *cis* face and eventually bud from the *trans* face, after undergoing a series of modifications to prepare them for secretion. The vesicles may then fuse with the cell membrane, and the contents are released from the cell in a process called exocytosis.

This response shows that the writer used the following key terms in context, showing the writer's knowledge of their meanings and relatedness:

organelles
prokaryote
eukaryote
mitochondria
phospholipids
proteins
crista
mitochondrial matrix
DNA
mRNA
ribosomes
endoplasmic reticulum
conformation
enzymes
secretory proteins
Golgi apparatus
cis/trans face
vesicle

The student response in (a) would be improved by including the chloroplast with the discussion on mitochondria. Specific sizes of cells and organelles is not expected. An additional argument for endosymbiosis could have been the presence of ribosomes in mitochondria and chloroplasts that translate genes unique to the organelles.

Additional points would probably be awarded in (b) if the student included a discussion of signal peptides and signal recognition particles. (This is covered in Chapter 17.)

Topic 3: Respiration and Photosynthesis

ANSWERS AND EXPLANATIONS

Level 1: Knowledge/Comprehension Questions

- **1. (C) is correct.** The purpose of cellular respiration in eukaryotes is to produce energy for cellular work in the form of ATP. Respiration is an aerobic process, meaning that it requires oxygen. Answer choices A and B are incorrect because respiration involves the breakdown (not the synthesis) of carbohydrates, fats, and proteins. Choice D is wrong because ADP is the product of the dephosphorylation of ATP—it is left over after the energy from ATP has been released. Choice E is wrong because oxygen is required for cellular respiration.
- **2. (B) is correct.** In the course of the reaction shown, potassium (K) is oxidized. Oxidation involves the loss of an electron, whereas reduction is the gain of an electron by an atom or molecule. In this reaction, potassium is oxidized and bromine is reduced. Both cellular respiration and photosynthesis involve numerous oxidation-reduction (redox) reactions.
- **3. (D) is correct.** The net energy result of glycolysis is the production of two molecules of ATP and two molecules of NADH. Glycolysis is the first of the three stages of respiration—the second being the citric acid cycle and the third being oxidative phosphorylation. During glycolysis, glucose is oxidized to form two molecules of pyruvate. Glycolysis occurs in the cytosol, and the pyruvate it produces travels to the mitochondria, where it is used in the citric acid cycle.
- **4. (B) is correct.** Note that this question is framed per glucose, not per single turn of the citric acid cycle. In the breakdown of glucose in the citric acid cycle, 2 ATP are produced. The citric acid cycle takes in a molecule called acetyl CoA (pyruvate is converted into acetyl CoA before it enters the citric acid cycle), and this is joined to a four-carbon molecule of oxaloacetate to form a six-carbon compound citrate that is then broken down again to produce oxaloacetate; the oxaloacetate reenters the cycle. In the course of the citric acid cycle, the following are produced *per glucose*: 4 CO_2, 2 ATP, 6 NADH, and 2 $FADH_2$.
- **5. (D) is correct.** The process that produces the most ATP during cellular respiration is oxidative phosphorylation. $FADH_2$ and NADH donate electrons to the electron transport chain, which is coupled to ATP synthesis by chemiosmosis. The movement of electrons down the electron transport chain creates an H^+ gradient across the mitochondrial membrane, which drives the synthesis of ATP from ADP. A maximum of 26 to 28 ATP can be produced in oxidative phosphorylation per glucose molecule.
- **6. (D) is correct.** In glycolysis, glucose is oxidized to two molecules of pyruvate. This is the first step in cellular respiration, showing a net production of 2 ATP and 2 NADH.

7. **(A) is correct.** In chemiosmosis, the hydrogen ion gradient created by the transfer of electrons in the electron transport chain provides the power to synthesize ATP from ADP.

8. **(E) is correct.** Fermentation is a way of harvesting chemical energy without using either oxygen or an electron transport chain. It consists of glycolysis and several reactions that serve to regenerate NAD^+. Electrons are transferred from NADH to pyruvate or its derivatives; then NAD^+ can return to glycolysis to once again accept electrons, continuing the production of small amounts of ATP. There are two main types of fermentation: alcohol fermentation (which creates ethanol as a product) and lactic acid fermentation (which creates lactate).

9. **(B) is correct.** The electron transport chain is a series of inner mitochondrial matrix membrane-embedded molecules that are capable of being oxidized and reduced as they pass along electrons. The energy produced from the passage of these electrons down the chain is used to create an H^+ gradient across the membrane, and the flow of H^+ down the gradient and back across the membrane powers the phosphorylation reaction of ADP to form ATP.

10. **(C) is correct.** The citric acid cycle includes the final reactions for the breakdown of glucose that began in glycolysis. The pyruvate from glycolysis is converted into acetyl CoA, which enters the cycle and is joined to oxaloacetate to create citrate, which is then converted to oxaloacetate again and reused. This cycle gives off CO_2 and forms 1 ATP, 3 NADH, and 1 $FADH_2$. The cycle goes through one rotation to break down each of the molecules of pyruvate produced in glycolysis (which of course is first converted to acetyl CoA), so the net result of the breakdown of one glucose molecule is 2 ATP, 6 NADH, and 2 $FADH_2$.

11. **(A) is correct.** Groups of photosynthetic pigment molecules in the thylakoid membrane are called photosystems. The two photosystems involved in photosynthesis are photosystem I and photosystem II. Both contain chlorophyll molecules and many proteins and other organic molecules, and both have a light-harvesting complex that harnesses incoming light. Each of these photosystems contains a reaction center, where chlorophyll *a* and the primary electron acceptor are located.

12. **(B) is correct.** The main products of the light reactions of photosynthesis are NADPH and ATP. NADPH and ATP are used to convert CO_2 to sugar in the Calvin cycle. The enzyme rubisco combines CO_2 with ribulose bisphosphate (RuBP), and electrons from NADPH and energy from ATP to synthesize a three-carbon molecule called glyceraldehyde 3-phosphate.

13. **(B) is correct.** The process in photosynthesis that bears the closest resemblance to chemiosmosis and oxidative phosphorylation in cellular respiration is linear electron flow. In this process, energy from the transfer of electrons down the electron transport chain is used to create a hydrogen ion gradient used in the making of ATP. Later, the energy stored in this ATP is used during the formation of carbohydrates in the Calvin cycle.

14. **(E) is correct.** The organic product of the Calvin cycle, which may be used later to build large carbohydrates in the cell, is glyceraldehyde 3-phosphate, or G3P. This molecule is created as a result of the fixation of three molecules of

CO_2, which costs the cell ATP and NADPH that were created in the light reactions of photosynthesis.

15. (E) is correct. C_4 and CAM plants both grow better than do C_3 plants under conditions of increased median air temperature and decreased relative humidity. Both C_4 and CAM plants use an alternative method of carbon fixation that enables them to fix carbon into an acid intermediate for later deposit into the Calvin cycle.

16. (D) is correct. The electron transport chains pump protons across membranes from regions of low H^+ concentrations to regions of high H^+ concentrations. This proton pumping occurs in both mitochondria and chloroplasts, and the protons then diffuse (with the concentration gradient) back across the membrane through ATP synthases. This drives the synthesis of ATP.

17. (D) is correct. ATP synthase is located in the thylakoid membrane. Notice the direction of flow of protons through ATP synthase in photosynthesis: The protons flow from the thylakoid space to the stroma. ATP is produced in the stroma, where it will be used by the Calvin cycle.

18. (C) is correct. When water is split, three products are formed: two protons, an oxygen atom that immediately bonds with another oxygen to form O_2, and two electrons. The electrons immediately feed the P680 chlorophyll *a* in the reaction center of photosystem II. The ultimate electron donor in photosynthesis is water.

19. (A) is correct. CAM plants separate the two stages of photosynthesis temporally to reduce photorespiration. This is accomplished by fixing CO_2 at night using PEP carboxylase and storing the carbon in organic acids. During the day when CAM plants have their stomata closed to conserve water, the carbon from the organic acids is chemically released and used in the Calvin cycle. Choice C would be correct for C_4 plants, but not for CAM plants.

20. (D) is correct. Each turn of the Calvin cycle involves the enzyme rubisco fixing one atom of carbon. It follows that it would take six turns to produce the six-carbon sugar glucose. Students sometimes miss this question by confusing the Calvin cycle with the Krebs or citric acid cycle of cellular respiration. Read these questions carefully, being disciplined enough to carefully identify what the question is asking.

21. (E) is correct. The light reactions of photosynthesis move electrons from their low-energy state in water to a higher energy level when the electrons are donated to $NADP^+$ to make NADPH. In cellular respiration electrons pass down the electron transport chain from high to low potential energy, ultimately combining with O_2 and hydrogen ions to form water.

Level 2: Application/Analysis/Synthesis Questions

1. (D) is correct. Plant leaves are green because they reflect and refract green light, which is not utilized in photosynthesis. Red light is used in photosynthesis, meaning the plant would absorb CO_2 for photosynthesis. Check the action spectrum for photosynthesis in your text and be prepared to explain the peaks and valleys shown in the graph.

2. (A) is correct. The light reactions convert solar energy to the chemical energy of ATP and NADPH, which are utilized in the Calvin cycle to reduce CO_2 to sugar.

3. (A) is correct. The Calvin cycle occurs in the stroma.

4. **(C) is correct.** In step 3 the five-carbon α-ketoglutarate is converted to the lower energy four-carbon compound succinate. The drop in energy allows for the production of 1 ATP and the reduction of NAD^+ to NADH. No other step in the citric acid cycle accomplishes this.
5. **(D) is correct.** Normally the potential energy of the H^+ gradient across the inner mitochondrial membrane is coupled with ATP synthase in the production of ATP. The drug allows for the leaking of H^+ across the membrane, effectively uncoupling ATP synthesis from the H^+ gradient.
6. **(A) is correct.** With the uncoupling of ATP synthase from the H^+ gradient, the inner membrane no longer has a sufficient electrochemical gradient to generate normal ATP production.

Free-Response Questions

(a) Although plants have two photosystems, they both work in the same way. Both photosystems have two components: the light-harvesting complexes and the reaction center. The light-harvesting complex is made up of many chlorophyll and accessory pigment molecules. When one of the pigment molecules absorbs light energy in the form of photons, one of the molecule's electrons is raised to an orbital of higher potential energy. The pigment molecule is then said to be in an "excited" state. The increase in potential energy is transferred to the reaction center of the photosystem. The reaction center consists of two chlorophyll *a* molecules, which use the increased potential energy passed to them by the photosynthetic pigments to donate electrons to the primary electron acceptor. The solar-powered transfer of an electron from the reaction-center chlorophyll *a* pair to the primary electron acceptor is the first step of the light reactions. This is the conversion of light energy to chemical energy.

(b) Glycolysis is the first stage of cellular respiration and occurs in the cytoplasm. Glycolysis involves the breakdown of glucose to two pyruvate molecules. To accomplish this, 2 ATP molecules are invested, which helps to destabilize glucose, making it more reactive and allowing glucose to break into two three-carbon molecules. By the time the pathway has produced pyruvate, 4 ATP molecules have been produced along with 2 NADH molecules. This gives a net energy gain of 2 ATP and 2 NADH. Thus, one important role of glucose is to produce energy molecules for the cell to use in its life processes. The second role is to produce pyruvate, which can feed into the citric acid cycle in the mitochondria and ultimately into the electron transport chain, where most of the ATP in cellular respiration is produced.

(c) In cellular respiration water is a product of the reaction, whereas in photosynthesis water is a reactant. In cellular respiration water is formed when the electrons at the end of the electron transport chain in the cristae membrane of the mitochondria combine with hydrogen ions and an atom of oxygen to form water. Water is the ultimate electron acceptor in cellular respiration. In photosynthesis an enzyme splits a water molecule into two electrons, two hydrogen ions, and an oxygen atom. The electrons are supplied as needed directly to the chlorophyll molecules in the reaction center of photosystem II. In photosynthesis water is the ultimate electron donor.

This response shows that the writer used the following key terms in context, showing the writer's knowledge of their meanings and relatedness:

photosystems
reaction center
glycolysis
electron donor
accessory pigments
ATP
light-harvesting complexes
chlorophyll
net energy production
electron acceptor
primary electron donor
NADPH

This response also contains an explanation of the following subjects and processes:

—role of photosystems in photosynthesis
—how light energy becomes transformed to chemical energy
—function of glycolysis in overall scheme of cellular respiration
—ATP and NADPH as important energy molecules in the cell
—role of water as an electron sink or an electron donor

This student has written a particularly clear essay. Notice how carefully sequenced the responses are. Also note the clarity of each sentence and the absence of third-person pronouns. Avoiding pronouns may require a little more time and patience, but it pays off in added clarity and higher scores.

Topic 4: Mendelian Genetics

ANSWERS AND EXPLANATIONS

Level 1: Knowledge/Comprehension Questions

- **1. (E) is correct.** The probability that the woman will have a seventh child who is a daughter is 1/2. Since the probability that a sperm carrying an X chromosome and the probability that a sperm carrying a Y chromosome will fertilize an egg is equal—both 50%—fertilization is considered an independent event. The outcome of independent events is unaffected by what events occurred before or will occur after. Therefore, the probability that this woman's next child will be a girl is 1/2. Likewise, the probability that she will have a child that is a boy is also 1/2.
- **2. (A) is correct.** If the probability of allele *R* segregating into a gamete is 1/4, and that of *S* segregating is 1/2, you can calculate the probability of two independent events occurring in a specific combination, order, or sequence by multiplying their probabilities. So in this case, you need to multiply 1/4 by 1/2.
- **3. (D) is correct.** Note that this cross involves incomplete dominance because there are phenotypes in the offspring. Let's say that the yellow coat parent is *CYCY*, and the homozygous brown coat parent is *CBCB*. Because the yellow coat parent can produce only gametes *CY*, and the brown coat parent can produce only gametes *CB*, the F_1 generation will all have genotype *CYCB*. Crossing

two members of this generation would give you a ratio of 1 yellow coat: 2 gray coats: 1 brown coat. This means that 25% of the offspring would have brown coats, 25% would have yellow coats, and 50% would have gray coats.

4. (A) is correct. All of the statements about meiosis are true except A. The spindle fibers attach during prophase, not metaphase.

5. (D) is correct. To find the answer to this problem, first look at the ratio of the offspring. It's 6:2, which can be reduced to 3:1. Next, you can quickly work through the crosses listed. You can immediately rule out answers A and B, because A would give you only offspring that exhibited the dominant traits—short hair and green eyes—and B would give you all offspring that had the recessive traits—long hair and blue eyes. If you look carefully at the remaining answers, you will want to choose the one that will give you all short-haired offspring, so you will need the dominant allele to be present in both parents. This rules out answer E. If you still cannot choose between C and D, write out what gametes the parents could produce, and then use a Punnett square to determine their offspring. By doing this, you can see that D is correct: the ratio of offspring is 12:4, or 3:1, which matches the ratio in the original question.

6. (A) is correct. If the boy is afflicted with hemophilia, then he must have inherited the recessive hemophilia gene from his mother. Sex-linked genes are usually located on the X chromosome. In order for the child to be a boy, he must have inherited a Y chromosome from his father. Because the gene causing hemophilia is located on the X chromosome, you can rule out answers B and C (it would not matter if the father possessed the allele for hemophilia because he can't pass on his X to a son). Therefore, you need to look for an answer choice that shows that the source of his X chromosome was a carrier of the allele—afflicted or not. This is answer A.

7. (E) is correct. While genes that are on the same chromosome tend to be inherited together, the process of crossing over enables "linked" genes to sort independently. Those that are linked but located farther apart on the chromosome will undergo crossing over more frequently than those located very close together on a chromosome simply because there are more sites between the two genes at which crossing over can take place.

8. (D) is correct. Autosomal dominant traits appear with equal frequency in both sexes, and they do not skip generations. These qualities are all exhibited by the trait that is illustrated in the pedigree. All three generations are affected with the trait, and both sexes are affected.

9. (A) is correct. The father either has type A, B, or O blood. The mother, who has the phenotype for type A blood, has the genotype I^Ai. In order to produce a son with genotype *ii* (the genotype of people with type O blood), she would need to reproduce with a man who had genotype I^Ai, genotype I^BI, or genotype *ii*. Try writing out the Punnett square if you aren't confident of this.

10. (C) is correct. If the individual with type O blood were to mate with an individual who has type AB blood, since I^A and I^B are both dominant over *i*, the genotype would be 1 I^A:1 I^B, and the phenotype would be a ratio of 1:1 offspring with type A blood or type B blood.

11. (B) is correct. The most likely reason for this 2:1 ratio in the offspring is that *Y* is lethal in homozygous form, and this caused the death of all of the *YY*

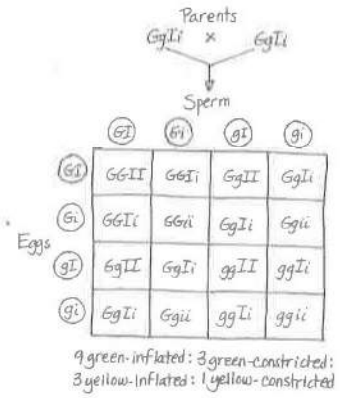
individuals in the litter. The expected ratio of this cross would be 1 *YY*:2 *Yy*: 1 *yy*. If you remove the *YY*, you get a ratio of 2 *Yy* (yellow mice, since the gene for yellow, *Y*, is dominant) to 1 *yy* (nonyellow mouse).

- **12. (D) is correct.** The only process listed that does not lead directly to genetic recombination, or the recombining (scrambling) of genes in the offspring, is gene linkage. If genes are linked, they are located on the same chromosome and are more likely to segregate together into the same cell, reducing genetic recombination
- **13. (C) is correct.** Recall that a dihybrid cross between two heterozygotes produces a 9:3:3:1 offspring ratio. The question is asking for one of the heterozygotes (which would be one of the 3s in the above ratio). To come up with the answer, you could complete a Punnett square and see that the ratio of offspring produced is 9 warty green, 3 warty orange, 3 dull green, and 1 dull orange. The total number of offspring produced is 144, and 3/16 of 144 is 27; the closest answer choice to 27 is 28.
- **14. (B) is correct.** Fertilization restores the diploid number in a sexually reproducing organism. The two major events in the life cycle of sexually reproducing organisms are meiosis and fertilization.
- **15. (E) is correct.** All of the responses are correct. Homologous chromosomes are a key conceptual point in Mendelian genetics. If you missed this question, review more thoroughly the concept of homologous chromosomes.
- **16. (B) is correct.** The number of possible gametes can be determined by using the formula $2n$ where n equals the haploid number. With a diploid number of 6, thus a haploid number of 3, the answer is $2 \times 2 \times 2 \times 8$.
- **17. (A) is correct.** Recall that in G_1 the chromosomes have not replicated. After meiosis I the chromosomes have replicated, which doubles the amount of DNA. Next, the homologs separate in meiosis I. This separation reduces the amount of DNA by one-half and back to the original amount.
- **18. (A) is correct.** The synaptonemal complex forms during prophase I and is the platform from which crossing over occurs.
- **19. (A) is correct.** In meiosis II the most important event is the separation of sister chromatids. Mitosis involves only the separation of sister chromatids; homologs do not form in mitosis.
- **20. (B) is correct.** Synapsis is the process of homologs moving to the tetrad position. This occurs in prophase I, not S phase as indicated in the question.
- **21. (E) is correct.** Begin by drawing a straight line to represent a chromosome, and then place genes A and B 8 units apart. Note that A and C are 28 units apart with B and C 20 units apart. This means the genes are found in order A, B, C. Next, consider the map distances between A and D and B and D. Since map distance represents the frequency of crossing over, it will only work if D precedes A on the chromosome. The correct gene sequence must be D-A-B-C.
- **22. (B) is correct.** Since there are regions of the X chromosome that have no corresponding region on the Y, alleles that are found on this unmatched area of the X in males may be expressed, even though the male has a single copy of the gene.

Level 2: Application/Analysis/Synthesis Questions

- **1.** Albino (*b*) is a recessive trait; black (*B*) is dominant. First cross: parents *BB* × *bb*; gametes *B* and *b*; offspring all *Bb* (black coat). Second cross: parents *Bb* × *bb*; gametes 1/2 *B* and 1/2 *b* (heterozygous parent) and *b*; offspring 1/2 *Bb* and 1/2 *bb*.

2.



3. Parental cross is $AAC^RC^R \times aaC^WC^W$. F_1 genotype is AaC^RC^W, phenotype is all axial-pink. F_2 phenotypes are 3 axial-red : 6 axial-pink : 3 axial-white : 1 terminal-red : 2 terminal-pink : 1 terminal-white.

4. **(D) is correct.** Given that the diploid ($2n$) number is four and the cells in the diagram with an (n) or haploid number show two chromosomes, this must be meiosis. Nondisjunction in meiosis I would involve homologs not separating, whereas nondisjunction in meiosis II would involve sister chromatids not separating. The diagram shows sister chromatids not separating, thus leaving one cell $n + 1$ and the other cell $n - 1$.

5. **(B) is correct.** Type O blood is recessive. This means that the woman could be heterozygous for blood type A (I^Ai) and the father heterozygous for type B blood (I^Bi). If each parent donates their recessive allele, the baby would be ii, type O blood.

6. **(C) is correct.** It appears the mother has inherited the color-blind gene from her father and passed it to her son. This is a typical inheritance pattern seen in sex-linked genes.

7. **(C) is correct.** The question and correct answer describe independent assortment as it occurs in meiosis. Independent assortment increases variability, or as phrased in the question, increases the possible combinations of characteristics.

Answer from page 100: The karyotype in Figure 4.1 is that of a male. Note the unpaired X and Y in the bottom right corner.

Topic 5: Molecular Genetics

ANSWERS AND EXPLANATIONS

Level 1: Knowledge/Comprehension Questions

1. **(C) is correct.** Operons are gene expression mechanisms of bacteria. They are not found in eukaryotic cells.

2. **(B) is correct.** Viruses are made up of nucleic acid surrounded by a protein coat. The answer cannot be A because retroviruses consist of RNA. Viruses reproduce by injecting their genetic material into a host cell and using the cell's replicative machinery to replicate their DNA and proteins. The new viruses leave the cell to infect more cells, sometimes killing the host cell in the process.
3. **(D) is correct.** The process of genetic engineering is possible because the processes of transcription and translation are so similar in all eukaryotic cells. Once the spider gene or genes that were responsible for coding for the silk proteins were isolated and then inserted into a bacterial plasmid (which would serve as the vector), the cloning vector would be taken up by the goat's cells, and the goat's cells' transcription/translation machinery would begin the process of producing the spider protein, along with its own proteins.
4. **(D) is correct.** Restriction enzymes can be used to cut DNA at specific locations, and this enables researchers to perform recombinant DNA techniques. When specific restriction enzymes are added to the DNA, they produce cuts in the sugar-phosphate backbone and create "sticky ends," which can bind to DNA fragments from a different source to produce recombinant DNA. DNA ligase is then added to seal the strands together permanently.
5. **(C) is correct.** Transposons are also called transposable genetic elements, and they are pieces of DNA that can move from location to location in a chromosome—or a genome. Transposons are also called "jumping genes," and most of them are capable of moving to many different target sites in the genome.
6. **(D) is correct.** One of the two important ways that the cell has of controlling gene expression is through DNA methylation. In DNA methylation, methyl groups are attached to certain DNA bases after DNA is synthesized. This appears to be responsible for the long-term inactivation of genes.
7. **(B) is correct.** The process by which genetic information flows from mRNA to protein is called translation. Translation occurs in the cytoplasm of the cell, at ribosomes. A molecule of mRNA is moved through the ribosome, and codons are translated into amino acids one at a time. Transfer RNAs add their associated amino acids onto a growing polypeptide as its anticodon pairs with a codon on the mRNA and then departs from the ribosome to bind more free amino acids.
8. **(A) is correct.** In transcription, RNA is synthesized using the genetic information encoded by DNA. Transcription occurs in the nucleus of the cell. The double-stranded DNA helix unwinds, allowing enzymes and proteins to synthesize a new complementary single-stranded mRNA molecule from the template strand of DNA.
9. **(E) is correct.** In histone acetylation, acetyl groups are attached to certain amino acids of histones. Deacetylation is the process by which they are removed. Acetylation makes the histones change shape so they are less tightly bound to DNA, and this allows the proteins involved in transcription to move in and begin the process. Therefore, acetylation is one way for the cell to initiate transcription and to control the expression of its genes.
10. **(A) is correct.** This art portrays the lytic cycle of phage reproduction. In the lytic cycle, the phage first attaches to the cell surface and injects its DNA into the cell. It then hydrolyzes the host cell's DNA and uses the cell's machinery

to produce phage proteins and to replicate its genome. The phage proteins are then assembled in the cell until the host cell lyses (breaks open), and the new phages are released to infect other cells. In the lysogenic cycle, the phage genome becomes incorporated into the host cell's DNA without destroying the host cell.

11. (A) is correct. In eukaryotic cells the enzyme telomerase catalyzes the lengthening of telomeres in selected cells, such as the germ cells that produce gametes.

12. (D) is correct. PCR, the polymerase chain reaction, is a technique by which any piece of DNA can be copied many times without the use of cells. The DNA is heated to separate its strands and then cooled to allow primers to attach to the single strands. DNA polymerase is added, which begins to add nucleotides to the 3′ end of each primer on the two strands. With each turn of the cycle, the amount of DNA is multiplied by two.

13. (C) is correct. The fragments of DNA separated out from one another along the gel once the electric field was applied because they differ in size. For DNA in gel electrophoresis, how far a molecule travels through a gel (while the current is applied) is inversely proportional to its size. The larger a fragment is, the more slowly it will migrate.

14. (D) is correct. The restriction enzyme used to cut the DNA that was placed into the first well of the gel must have cut the DNA at eight sites, because it produced nine DNA fragments. The number of fragments produced is always one more than the number of restriction sites cut.

15. (D) is correct. You should recall that a T4 phage injects its DNA, which is used to assemble new protein coats and viral DNA. The protein coat of the infecting T4 phage is left outside the bacterium.

16. (B) is correct. Reverse transcriptase is an example of an enzyme that is required to produce DNA from the RNA of a retrovirus.

17. (C) is correct. In genetic engineering (the manipulation of genes for practical purposes), DNA ligase is an enzyme that is used to seal the strands of newly recombinant DNA (DNA that is spliced together from two different sources) by catalyzing the formation of phosphodiester bonds.

18. (C) is correct. The addition of a poly-A tail after transcription is one example of posttranscriptional modifications that the mRNA undergoes. This poly-A tail inhibits the degradation of the newly synthesized mRNA strand and is thought also to help ribosomes attach to it. Another important modification that mRNA undergoes is the addition of a 5′ cap. The 5′ cap helps protect mRNA from degradation and also acts as the point of attachment for the ribosomes, just prior to translation.

19. (D) is correct. RNA polymerase is the most prominent enzyme involved in the transcription of DNA to make mRNA. It is responsible for binding to the promoter sequence on the template DNA, prying the two DNA strands apart, and hooking the RNA nucleotides together as they base-pair along the DNA template. RNA polymerases add nucleotides to the 3′ end of the growing chain until a terminator sequence is reached—it transcribes entire transcription units.

20. (E) is correct. Ribosomal RNA (rRNA), together with proteins, makes up ribosomes. Ribosomes, the sites of protein synthesis, are composed of two

subunits, the large and the small subunit. The large subunit of the ribosome contains the A, P, and E sites, which shuttle through the tRNA and mRNA during translation.

21. (A) is correct. tRNA, or transfer RNA, interprets the genetic message coded in mRNA. It transfers amino acids taken from the cytoplasmic pool to a ribosome, which adds the specific amino acid brought to it by tRNA to the end of a growing polypeptide chain. Each type of tRNA binds to a specific amino acid at one end; its other end contains an anticodon, which base-pairs with a complementary codon on the mRNA strand.

22. (B) is correct. mRNA, also known as messenger RNA, is a type of RNA that is synthesized from DNA and attaches to ribosomes in the cytoplasm to specify the primary structure of a protein. Since mRNA is the product of transcription, which occurs in the nucleus, it must travel out of the nucleus and into the cytoplasm in order to participate in translation.

23. (E) is correct. Acetylation occurs as a mechanism of gene regulation when histones are acetylated, not DNA. Histone acetylation causes the histone tails to no longer bind to neighboring nucleosomes, allowing the transcription proteins to have easier access to genes in the acetylated area.

24. (B) is correct. In the modification of mRNA that occurs after transcription, a process called RNA splicing occurs. In this process, noncoding regions of nucleic acid that are situated between coding regions are cut out. These noncoding regions are called introns. The remaining regions are called exons, and these are spliced together to form the final mRNA product. When you think of exons, think expressed—because they are actually translated into proteins, whereas introns are not.

25. (E) is correct. Wobble refers to the relaxing of base pairing between the third base of a codon and the corresponding base of a tRNA anticodon. For example, the base U in the third position of the anticodon can pair with either A or G in the third position of the mRNA codon. This is why only 45 tRNAs are needed to translate the 61 codons that specify an amino acid. (Recall that 3 of the 64 codons specify stop, instead of an amino acid.)

26. (E) is correct. A missense mutation is a base-pair substitution (the replacement of a nucleotide and its partner in the cDNA strand with a different pair of nucleotides) that still enables the codon to code for an amino acid. The amino acid may or may not ultimately contribute to a functional protein, but a missense mutation is one where an amino acid is still chosen to be added to the polypeptide chain, and translation will continue.

27. (B) is correct. The amount of adenine in DNA will equal the amount of thymine; guanine will equal cytosine, which leads to the mathematical equality A + G = C + T. Try this: If a certain species has 15% adenine in its DNA, what would be the percentage of guanine? (It would be 35%. A + T = 30%, so G + C = 70%, and G = 35%.)

28. (D) is correct. DNA replication is semiconservative. Each new daughter molecule contains one newly synthesized strand, and one strand that used to belong to the parent double helix DNA.

29. **(B) is correct.** In gel electrophoresis the smallest fragments travel farthest; the largest fragments are closest to the well. Fragment b is shortest, followed by a and c. We would expect a gel with c closest to the well, then a, with b at the far end.
30. **(A) is correct.** Several of the other possible answers have errors that would be instructive to note. Answer B is false because the genetic code is near universal; answer C is false because introns are not part of the inserted gene, as they have been removed; answer D is false because ribosomes are not governed by the length of the gene; answer E is false because prokaryotes do not have splicing enzymes to take out introns. Answer A is correct because the signals that control gene expressions and promoter regions are different between prokaryotes and eukaryotes.
31. **(A) is correct.** Retrotransposons move by means of an RNA intermediate that is a transcript of the retrotransposon DNA. They always leave a copy at the original site during transposition, since they are initially transcribed into an RNA intermediate. Sometimes this mechanism is called "copy and paste." Choice C refers to the general action of transposons, "cut and paste," in which the original segment is moved, but not copied.
32. **(B) is correct.** In order to be a probe, it would have to contain complementary nucleotides, not amino acids. It is a common error to confuse the matching of nucleotides with nucleic acids (DNA or RNA) and amino acids with proteins.
33. **(B) is correct.** The number of genes in the human genome has been revised sharply downward since the Human Genome Project. Less than a decade ago the number of human genes was at 100,000; now it is about 20,000! How can only 20,000 genes be enough for a human? The answer is alternative gene splicing yielding multiple proteins per gene.
34. **(E) is correct.** An example of a multigene family is seen with the various forms of hemoglobin; the α-globin gene family is on chromosome 16, whereas the β-globin gene family is on chromosome 11.
35. **(A) is correct.** Homeotic genes are "master control genes" and when activated will in turn activate numerous other genes important in development.

Level 2: Application/Analysis/Synthesis Questions

1. **(D) is correct.** In HIV (the virus that causes AIDS) the envelope glycoprotein enables the virus to bind to specific receptors on certain white blood cells. After binding, the virus fuses with the cell's plasma membrane, entering the cell. The mutated gene CCR5 prevents binding and subsequent entering of the cell by HIV.
2. **(D) is correct.** In HIV infections, recall that the infectious agent is a retrovirus with RNA as the genetic material. In the cytoplasm of the host cell the viral RNA is converted to DNA, which then enters the nucleus and incorporates as a provirus into the cell's DNA. The provirus can direct the production of new viral particles.
3. **(D) is correct.** Bacteria do not perform mitosis, meiosis, or sexual reproduction. However, the processes of transformation, transduction, and conjugation are processes that bacteria use to increase their genetic diversity. Be sure to review all three processes.

- **4. (B) is correct.** These profiles were done using short tandem repeats as genetic markers. All 13 sites must match as this shows the highest degree of certainty between the pilot's DNA and the DNA from the three families.
- **5. (D) is correct.** Family 3 matches in all 13 sites. This is a good time to review the principles of gel electrophoresis, making sure you understand which poles on the gel are positive and negative, how the bands are arranged by size on the gel, and the role of restriction enzymes in preparing the DNA.
- **6. (D) is correct.** A nucleotide insertion downstream and close to the start of the coding sequence creates a frameshift mutation, causing the regrouping of codons and a completely new list of amino acids, leading to a nonfunctional protein. If the amino acids sequence is changed after the insertion, a *missense mutation* occurs. If the regrouping leads to the formation of a stop codon, a *nonsense mutation* occurs, which terminates the forming protein. Types of mutations are common questions on the exam, but you should give emphasis to the *effect* of a mutation, and be able to predict which type in a particular location would cause the greatest change in nucleotide sequence.
- **7. (A) is correct.** Introns, not exons, are removed before mRNA leaves the nucleus. The rest of the choices in this question are true and worthy of your perusal and understanding. RNA editing is a fundamental concept in molecular genetics.
- **8. (C) is correct.** The polymerase enzymes, both DNA and RNA, can only add nucleotides to the 3' end of a growing strand. This is the underlying reason for the leading strand, where DNA polymerase is adding a continuous, unbroken new strand of nucleotides and the lagging strand where DNA polymerase is moving away from the unwinding replication fork forming new nucleotides in Okazaki fragments. Knowing all the enzymes of replication is not required for the exam, but understanding how DNA polymerase works and the formation of leading and lagging strands is fundamental and worth your time investment.

Free-Response Questions

(a) There are many ways by which chromosomes can be altered to cause problems for the cell. Among these is nondisjunction—when during mitosis or meiosis the chromosomes fail to separate properly, and one cell ends up with two copies of a chromosome while the other gets no copies. This results in a condition called aneuploidy. Smaller chromosomal mutations are deletions (in which part of the chromosome breaks off and is lost), inversions (in which a chromosome segment is reversed within a chromosome), duplications (in which a chromosome segment is repeated in a chromosome), and translocation (in which part of a chromosome is moved from one chromosome to another).

The reason that it is detrimental to an organism to have an abnormal chromosome number is that genes, which are located on chromosomes, code for proteins, which have specific functions in the cell. If an organism has extra copies of a particular gene, then this gene will be transcribed in excess, creating more of the usual gene product. This alters the relative amounts, or doses, of interacting products in the cell, and this can cause serious developmental problems. Likewise, if a gene is missing from a chromosome, it will not be transcribed, and its corresponding protein will not be produced. If that protein has an important cellular function, the organism will be seriously affected.

(b) Colorblindness and hemophilia are more common in males than females because males are hemizygous for these traits. These traits are found on the X chromosome, and because males have only one copy of the X chromosome, they will show the phenotype for whatever allele they receive. Females, on the other hand, have two copies of the X chromosome and, if one X chromosome has an allele for colorblindness, for example, and the other X chromosome carries an allele for normal vision, the female will have normal vision. She is a "carrier" for colorblindness because she can pass it on to her sons.

(c) When fertilization occurs and a sperm carrying a Y chromosome penetrates the egg first, a male zygote with one X and one Y chromosome is produced. If a sperm carrying an X chromosome penetrates the egg first, a female zygote with XX is produced. Although it seems as though the female zygote would have twice the cell product as the male, due to its double dose of genes located on the two X chromosomes, this is not the case. The reason for this is that, in every cell of the female human body, one of the X chromosomes is inactivated. The mechanisms for this are not fully understood, but the X chromosome that is inactivated condenses into a structure called a Barr body, which then associates with the nuclear envelope. As a Barr body, most of the X chromosome's genes are not expressed. As a result of this, females are a mosaic consisting of cells with the X chromosome from their mother activated and other cells with the X chromosome from their father activated in about a 50:50 ratio. This is also the reason sex-linked disorders are usually not expressed in females. Though one of the X chromosomes may be incapable of producing a crucial gene product, this mosaic effect ensures that the other half of the somatic cells produce sufficient amounts of the protein in question.

This response demonstrates knowledge of the following terms and processes:

chromosome
gene
gene product
doses
transcription
nondisjunction
aneuploidy
deletion
inversion
duplication
translocation
X and Y chromosomes
zygote
X chromosome inactivation
Barr body
somatic cell