BIOLOGY 3: Answers to Italicized Questions

1. Fix carbon. The ability to “fix” carbon is the ability to capture carbon dioxide and integrate that carbon into larger macromolecules. Plants, algae and some bacteria can do this, humans and animals generally cannot. We must eat the carbon we need to build macromolecules.

2. The liver, gallbladder and pancreas play vital roles in digestion and are considered accessory organs of the digestive system. The liver manufactures bile. The gall bladder concentrates and stores bile (but does NOT manufacture it). The pancreas secretes bicarbonate into the duodenum to neutralize the acidic chyme coming from the stomach. The pancreas also secretes six pancreatic digestive enzymes.

3. Carbohydrates; alpha-amylase

4. The breakdown of all nutrient macromolecules into their monomers is accomplished via hydrolysis.

5. Hydrolysis; pepsin; pepsinogen

6. Gastrin is a peptide hormone. Therefore, we would expect it to be soluble in blood without a carrier molecule and to require a membrane receptor because it cannot dissolve through the non-polar interior of the bi-layer membrane.

7. The acid in the stomach denatures proteins. Recall from the Biology 1 lesson that acid is a protein denaturing agent.

8. The lining cells of the stomach are protected by a thick layer of mucus secreted by the mucus cells that line the gastric pits, one of four cell types present.


10. Trypsin and chymotrypsin are both proteases that cleave peptide bonds at specific amino acid sequences. Pancreatic amylase catalyzes the hydrolysis of carbohydrates. Lipase catalyzes the hydrolysis of fats. Ribonuclease and deoxyribonuclease catalyze the hydrolysis of RNA and DNA respectively. Some students find this odd, thinking “Who eats DNA and RNA?” While it’s true we don’t think of either as a food group, anything made of living cells—plant, fungi, animal, etc.—will contain both of these polynucleotides.

11. Bile emulsifies fats, but it does not break any bonds—therefore it is an example of physical rather than chemical digestion.
12. The villi are finger-like projections of the wall of the small intestine. They are hollow and contain both blood vessels and a single lymphatic vessel called a lacteal. Fats are absorbed into the lymph system via the lacteals and carbohydrates and proteins are absorbed into the blood. The villi dramatically increase the surface area available for absorption. Further, each epithelial cell lining a villus contains fingerlike projections of the cell membrane called microvilli. To be clear, a villus is an undulation of the lining of the small intestine, while a microvillus is an undulation of the cell membrane of a single cell. The brush border is a name given to the microvilli and the collection of mucus and digestive enzymes intermingled within them. The name was chosen because under a light microscope individual microvilli are not easily discernible and they appear instead as a fuzzy line along the apical surface of the epithelial cells.

13. Mutualism; Recall that mutualism is a form of symbiosis in which both participants benefit. The bacteria benefit by consuming the food in our intestines and we benefit because the bacteria produce vitamins that we absorb.

14. Either a vitamin deficiency or problems with water balance—either too little water absorption (diarrhea), or too much water absorption (constipation). These are logical assumptions because the two primary functions of the large intestine are water absorption and vitamin absorption.

15. Note to Tutors: Ensure that your students can tell the entire story of digestion—from memory—in at least the level of detail provided below:

The most important roles of the mouth in digestion are to break up food into small pieces by chewing and to mix it with saliva, which contains the enzyme alpha-amylase and some specific classes of antibodies. The saliva lubricates the food, which aids its passage down the esophagus. Amylase initiates carbohydrate digestion. The pharynx ensures the bolus is delivered to the esophagus without entering the nasal cavities or the larynx, but no digestion of any kind occurs here and nothing is added to the bolus. The epiglottis is an upward-oriented cartilaginous flap that folds down over the opening to the larynx during swallowing to prevent food from entering the larynx. The esophagus utilizes peristalsis to push the bolus down and into the stomach. Peristalsis is the rhythmic contraction of smooth muscle in the wall of the gastrointestinal track that moves food forward. Once again, no digestion occurs in the esophagus and nothing is added. Food enters the stomach by passing through the cardiac sphincter, which is located at the junction of the esophagus and the stomach. The churning of the stomach continues physical digestion. The stomach is lined with gastric pits. Chief cells are one of four cell types lining these pits, which are, in turn, lined with four cell types. Chief cells, one of these cell types, release pepsinogen, a zymogen that will be converted to its active form, pepsin, by the low pH of the stomach lumen. Pepsin will hydrolyze proteins. Another of these cell types lining the gastric pits, the parietal cells, secrete the HCl that lowers the pH of the stomach to about 2. The partially digested food mix, now referred to as chyme, passes through the pyloric sphincter and into the upper portion of the small intestine, called the duodenum. The common bile duct and the pancreatic duct both release products into the duodenum. As a result, the duodenum receives bile from the liver and gallbladder, and, from the pancreas, a bicarbonate-rich solution and six digestive enzymes: trypsin and chymotrypsin digest protein, pancreatic amylase digests carbohydrates, lipase digests fats, and ribo- and deoxynuclease digest RNA and DNA. The bicarbonate ions are important because they raise the pH of the chyme to around 6—a necessary step because the enzymes just listed could not function at the much lower pH of the mixture arriving from the stomach. The chyme progresses through the small intestine to its middle section, the jejunum, and then to the final section, the ileum. There are no distinct
boundaries marking these three sections. Most digestion occurs in the duodenum and most absorption (of food molecules, not water) occurs in the jejunum and ileum. The lining of the small intestine features finger-like projections called villi that increase the surface area for absorption. Individual epithelial cells along each villus have microvilli—long fingerlike projections of the cell membrane on their apical surface. Each villus’ center is filled with blood vessels and a single lymph vessel called a lacteal. Fats are absorbed into the lacteal, NOT the blood vessels. Carbohydrates and proteins are absorbed into the blood vessels. The ileum empties into the large intestine on the right side of the abdomen (anatomical right) slightly above a blind (dead-end) pouch called the cecum. The appendix is attached to the cecum. The colon rises upward along the right wall of the abdomen (ascending colon), traverses across the abdomen (transverse colon) and then descends along the left wall (descending colon). The final segment of the colon is somewhat twisted and is therefore appropriately named the sigmoid colon. The primary function of the colon is the absorption of water and vitamins. The colon contains resident commensal bacteria that secrete vitamin K, thiamin, riboflavin, and vitamin B_{12}. The rectum is the final segment of the large intestine. It connects to the anus and stores feces.

16. Monocytes, a type of white blood cell, mature into macrophages, which phagocytize pathogens and cellular debris. Phagocytosis by macrophages is non-specific and a type of innate immunity, but macrophages also present antigens from pathogens they consume for recognition by B and T cells, an aspect of acquired immunity. Neutrophils are one of three kinds of granulocytes—the other two being basophils and eosinophils. The three cells get their names from how they appear when stained and viewed under a light microscope. Commonly used laboratory preparations stain basophils a dark blue (due to the basic nature of the granules), eosinophils a bright red (due to the acidic nature of the granules), and neutrophils a “neutral” pale pink. Similarly, the term “granulocyte” comes from the fact that all three cells contain large cellular granules easily visible with a microscope. Neutrophils are phagocytes that are recruited to areas of infection and inflammation by chemotaxis. They live for only about 5 days, but are the most abundant of all white blood cells. The pus created at a wound is mostly dead neutrophils. Basophils are the least common white blood cell. Their granules contain mostly histamine, which they release along with other chemicals when activated. These chemicals promote inflammation and are integral in the allergic response, so many associate basophils with allergies. Eosinophils are recruited to areas of parasitic invasion, particularly multicellular parasites, where they release their granules containing peroxidases and other enzymes that digest tissue. This would destroy the pathogen but could also destroy host tissue. Note that all granulocytes are short-lived, do not reside permanently in the tissues, circulate in the blood, and are recruited to areas of infection or inflammation. In contrast, mast cells are permanent resident cells within many tissues. They are activated by allergens and other antigens to release histamine and other chemical mediators. They are usually associated with severe allergic reactions, including anaphylactic shock. Dendritic cells are professional antigen-presenting cells. They efficiently phagocytize pathogens and present those antigens on their surface to stimulate other immune cells. Dendritic cells are white blood cells (leukocytes), but are not lymphocytes. They can form from monocytes (which also differentiate into macrophages) or independently in their own cell line from a blood cell precursor. There are three kinds of lymphocytes: T cells, B cells, and natural killer cells. Natural killer cells recognize infected or cancerous cells and release cytotoxic granules that destroy the cell. T cells are lymphocytes that mature in the thymus and participate in cell-mediated immunity. B-cells are lymphocytes that mature in the bone marrow and lymph tissues and participate in humoral immunity. B-cells produce antibodies, T-cells do not.
recognize and bind antigens via a “T-cell Receptor” (TCR) not found on B-cells. Plasma cells are formed when a B-cell binds its matching antigen and is activated (with the help of helper T-cells) to undergo mitosis. The division of the B-cells produces mostly plasma cells—clones of the original B-cell that act as “antibody factories,” making and secreting soluble copies of that antibody. A few cells will differentiate into memory B cells that remain in the body, allowing the immune system to mount a more efficient secondary immune response if there is a later infection by the same pathogen. Helper T-cells are T-cells that “help” other immune system cells, such as B-cells and cytotoxic T-cells, to perform their function. The way they “help” other cells is usually to secrete chemicals, such as cytokines, that activate (i.e., “turn-on”) functions or activities in the cell that is being “helped” Suppressor T-cells (a.k.a., regulatory T-cells) suppress the body’s own immune system—which helps prevent severe allergic reactions or autoimmune disease and aids in turning off an immune response once an infection has been eliminated. Killer (or cytotoxic) T-cells target infected and cancerous versions of the body’s own cells and destroy them. Memory T-cells are just what they sound like—analognes to memory B-cells that have previous experience with a pathogen that allows them to mount a more effective response during a subsequent infection. However, we strongly suggest you forget about memory T-cells for the MCAT! As far as the MCAT is concerned, the concept of immunological “memory” and a “secondary immune response” are so intricately associated with humoral immunity that the wisest choice would be to always associate such concepts with B-cells and humoral immunity only. The algorithm below can help you put together a mental picture of where all of these cells come from and how they relate. You should NOT concern yourself with the progenitor cells. Just focus on the final step of each pathway and perhaps the precursor just before it. For example, it is helpful to observe things such as: a) multiple non-nucleated RBCs form from a single parent cell, b) the three granulocytes are related because they all differentiate from one parent cell, c) platelets (thrombocytes) bud from megakaryocytes, or d) monocytes differentiate into macrophages. Not shown on this diagram are dendritic cells, which can form from either a monocyte or from another cell that is a precursor to lymphocytes.

FIGURE 1
17. The respiratory and gastrointestinal tracts could be considered the “front line” in the battle against foreign invaders, given their position at the interface of the internal and external environments. Clearly, this is an ideal location for lymph tissue and its associated immune cells.

18. See the labeled diagram. We like this diagram because it shows the N-terminus and C-terminus of each chain—emphasizing that these are protein chains. Antigens bind to the ends of the hypervariable regions. An antigen would contact both the end of the heavy chain and the end of the light chain.

19. Shivering is an involuntary response to cold. At sufficiently low temperatures, the hypothalamus receives signals from receptors in the skin. The hypothalamus sends signals to core muscle groups to undergo rapid contractions that generate heat.

20. See labeled diagram.
21. The basic component of the **thick filaments** is **myosin**, a motor protein. Myosin subunits form myosin fibers, which have two moieties: a globular head and a tail. Two of these fibers intertwine to make up a myosin molecule, a dimer. Many myosin molecules form the long myosin filaments of the sarcomere. The heads protrude from the myosin filament at an angle in the relaxed conformation, referred to as “bent” in the sliding filament model. Myosin heads have a high affinity for actin and bind it unless the actin binding sites are blocked by tropomyosin. The **thin filaments** are microfilaments and are polymers of the protein **actin**. They feature troponin and tropomyosin.

![Diagram of myosin and thin filaments](image)

**FIGURE 4**

All of the following terms refer to portions of the sarcomere. The **A band** is the length of the myosin filaments and does NOT change during contraction. The **I band** is the distance between the ends of the myosin filaments in one sarcomere to the ends in the next sarcomere. It is also the lightest band when viewed under a microscope because only the thin actin filaments are present in this region. The I band will shorten during a contraction. The **H zone** is the distance between the ends of the actin filaments. The H zone will also shorten during a contraction. The **Z lines** (a.k.a. Z discs) appear as zigzag lines that define the edges of each individual sarcomere unit. The actin filaments are anchored here by the protein connection and stretch out in both directions. During a contraction the distance between Z lines decreases as the sarcomere shortens. The **M line** is the center of the myosin filaments. The distance between M lines between two sarcomeres will decrease during a contraction.

22. See the diagram that follows. Verify visually each of the distances/changes described in the previous question. Some students have difficulty visualizing how the distance between M lines decreases during contraction. The sarcomere depicted below is only one of many sarcomere units aligned in a chain-like formation. Remember that there will be many sarcomeres directly attached on either side of the structure shown. With each sarcomere becoming shorter, by definition the distance between the centers of each sarcomere must decrease during a contraction.
23. Contraction occurs when calcium is present. After contraction is complete, calcium must be actively transported back into the sarcoplasmic reticulum and sequestered there until the next contraction. The myofibrils are NOT located inside the sarcoplasmic reticulum. Some students seem to the idea that they are inside, perhaps based on the statement that the SR surrounds each myofibril. The confusion may arise because the SR is a membrane compartment and its whole structure does wrap around the myofibril so that the myofibril is adjacent to its outer membrane, but it is not IN the compartment. Compare this to wrapping your gloved hand around a ball. The glove could be said to be “around” the ball, but the ball is clearly not INSIDE of the glove. It can be said that the myofibrils are inside of the sarcolemma (i.e., muscle cell membrane) and surrounded by sarcoplasm.

24. Acetylcholine is used at the ganglionic synapses in the sympathetic nervous system. Norepinephrine is used at almost all the synapse with the target/effector.

25. The SA node acts like a natural pacemaker for the heart. The action potential for each heart beat originates in the SA node, not with a signal from the nervous system. Nerves do innervate the heart, but they only regulate its rhythm up or down—they do not initiate that rhythm. The vagus nerve (parasympathetic) slows the heart rate, and sympathetic nerves increase heart rate.

26. Unitary, or single-unit, smooth muscle is a group of smooth muscle fibers that are innervated by a single neuron and contract simultaneously as a single group. These are the most common smooth muscle unit and are found in most organs, around most blood vessels, the digestive track, etc. A multi-unit smooth muscle is innervated by multiple neurons and does not act as a single unit. This allows for more precise control (remember, however, that all smooth muscle is involuntary, so it is not conscious control). Multi-unit smooth muscle is quite rare. It is found in some of the larger vessels such as the aorta, and in the retina of the eye.
27. The two hormones that regulate bone maintenance and blood calcium levels are parathyroid hormone (PTH) and calcitonin. Remember that “calcitonin tones your bones.” When blood levels are above normal, calcitonin inhibits osteoclast activity. Osteoblast activity continues and thereby a net increase in bone structure results. The calcium used by osteoblasts to build new bone matrix comes from the blood and therefore blood calcium levels decrease. Parathyroid hormone has the opposite effect. Parathyroid hormone stimulates osteoclast activity, resulting in the breakdown of bone matrix and release of the associated calcium into the blood. As a result, blood calcium levels rise. The two hormones also have predictable effects on the absorption of calcium at the gut and the reabsorption of calcium in the kidney.

28. **Hematopoiesis** is the name given to the formation and differentiation of blood cells in the bone marrow. The flowchart given previously to illustrate the source of immune system cells demonstrates hematopoiesis. This process occurs in the red bone marrow that fills the pockets of spongy bone. Hematopoiesis does NOT occur in the yellow bone marrow that fills the medullary cavity of long bones. Yellow bone marrow consists mostly of fat. **Compact bone** is the dense bone that surrounds the outside of all bones and constitutes the shafts of long bones. The interiors of flat and irregular bones, as well as the bulbous ends of the long bones, are filled with spongy bone. **Spongy bone** contains many open spaces, formed by the interwoven trabeculae. These spaces are filled with red bone marrow. Compact bone is many times more compact. It is organized into orderly units called osteons and the only spaces it contains are Haversian canals, perforating canals, and canaliculi.

29. In humans, the **penis** is the male copulatory organ. It can also be thought of as playing a dual role in excretion and ejaculation because the urethra runs through it. The **testicles** serve the primary functions of making, nurturing and storing sperm. The **scrotum** is the thin sack of skin in which the testes are located. The external location of the scrotum allows the testicles to exist at a temperature a few degrees lower than the normal human body temperature of 37°C. The optimum temperature for spermatogenesis is 35°C. **Sperm** cells are the male haploid gametes. They are produced in the **seminiferous tubules** of the testes and move to the **epididymis**, where they are nurtured, fully matured, and stored until ejaculation. The **vas deferens** is a duct that connects each testicle with the urethra. Beginning at the epididymis, it leads up the inside of the scrotum, into the pelvic cavity, past the **se seminal vesicles**, through the **prostate gland**, and empties into the urethra before the urethra enters the penis. The diagram on the following page shows each of the structures just described relative to other common anatomical structures:
30. The acrosome is a membrane-bound structure on the tip of the head of each sperm. The acrosome contains hydrolytic enzymes that break down the otherwise impenetrable coating around the ovum.

31. During ejaculation, the first addition to the ejaculate comes from the seminal vesicles. They release the majority of the fluids that make up semen, including fructose and alkaline fluids that make the semen basic. The alkaline nature of semen helps neutralize the acidic environment of the vagina and the fructose provides nutrients for the sperm. The vas deferens continues into the prostate gland, which secretes a milky white fluid that is slightly acidic and contains proteases. The prostate gland secretions play a protective role, as sperm have been shown to have longer survival rates and better protection of their genetic material in the presence of prostate secretions as compared to without them. The vas deferens then releases its contents into the urethra where it passes the bulbourethral glands (a.k.a., Cowper’s glands). The bulbourethral glands do not add fluids to the ejaculate at this point. They secrete a fluid called pre-ejaculate that lubricates and neutralizes any acidic urine in the urethra prior to the arrival of the other semen components. The term semen refers to the entire ejaculate with all contributed fluids plus the sperm.

32. The vagina serves as the female copulatory organ, as the birth canal, and as an exit route for menstrual fluid. The cervix is the conical-shaped bottom portion of the uterus that projects into the rear, upper wall of the vaginal canal. It contains a small opening that allows for exchange of fluids, but must dilate significantly during child birth to allow for delivery. The uterus is an elastic, muscular pouch that receives a fertilized egg via implantation and provides nourishment for the developing fetus. Muscle contractions of the uterine wall, stimulated by oxytocin, facilitate the process of childbirth. The fallopian tubes are ducts that utilize ciliated epithelium to transport the egg from the ovary to the uterus. Fertilization usually occurs in one of the two fallopian tubes. The ovaries are the female gonads, homologous to the testes in males. The ovaries develop and release ova (i.e., eggs) on a regular 28-day cycle (on average). They also function as endocrine glands that secrete estrogen and progesterone. The diagram that follows illustrates all of the structures discussed relative to other common anatomical structures.
33. On approximately day 14 of the menstrual cycle, high estrogen levels stimulate a rapid increase in luteinizing hormone (LH), a good example of a positive feedback mechanism. This does not happen during other stages of the cycle where LH stimulates estrogen, and estrogen provides negative feedback to the hypothalamus inhibiting further LH secretion (i.e., classic negative feedback loop). However, as mid-cycle approaches, estrogen levels provide positive feedback to the hypothalamus, stimulating it to secrete more LH, which in turn stimulates the production of more estrogen. This causes the “LH surge,” which results in ovulation.
FIGURE CREDITS

2. Source: Altius image.
7. Source: Altius image.