BIOLOGY

Section I

Time—1 hour and 30 minutes

60 Questions

Directions: Each of the questions or incomplete statements below is followed by four suggested answers or completions. Select the one that is best in each case and then fill in the corresponding circle on the answer sheet.

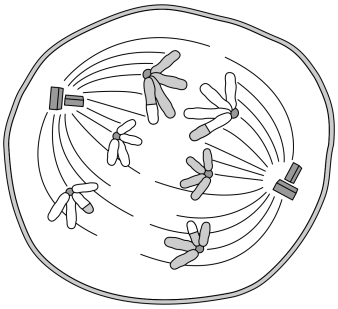


Figure 1. A cellular process

1. Which of the following best describes the cellular process illustrated in Figure 1?

   (A) Sister chromatids separating during anaphase of mitosis

   (B) Chromosomes lining up along the midline of the cell during mitosis

   (C) Reducing the chromosome number during anaphase I of meiosis

   (D) Chromatids failing to separate during meiosis

Bacteria	P M V V G H E Y V G E V V G I G Q
Yeast	P L V G G H E G A G V V V G M G E
Corn	P R I L G H E A G G I V E S V G E
Horses	P V I A G H E A A G I V E S I G E
Sheep	P M V L G H E A S G T V V K V G S

Figure 2. Amino acid sequences of certain dehydrogenase enzymes in different species

2. Portions of the amino acid sequences of some dehydrogenase enzymes found in bacteria, yeast, corn, horses, and sheep are shown in Figure 2. Each letter represents a different amino acid in the sequence.

   Based on Figure 2, which of the following conclusions about the enzymes is most likely correct?

   (A) Corn and horse dehydrogenase enzymes arose separately during each organism's evolution and now exhibit strong sequence similarity as a result of their similar catalytic roles.

   (B) These enzymes all evolved from a common prokaryotic dehydrogenase enzyme, so they exhibit regions of sequence similarity.

   (C) Any evolutionary relationship is unlikely, because there is little sequence similarity between these enzymes.

   (D) No conclusion can be drawn based on amino acid sequence, because there are twenty amino acids and only four nucleotides.

3. In some species of bats, adult females regurgitate (bring up food from the stomach) to feed their young. In addition, adult bats regurgitate to feed other adults that have not recently eaten. The adults receiving the food may be unrelated bats who have previously participated in food sharing and are members of the same social group. Scientists claim that sharing among unrelated adult bats increases the fitness of the species.

   Which of the following best supports the scientists' claim?

   (A) Bats that do not find food over a 24-hour period may die, preventing their alleles from being passed on within the social group.

   (B) Bats that do not find food may adapt to eating other types of food, adding new alleles to the social group.

   (C) Food sharing reduces the number of unrelated animals that cluster in one area, thus increasing the genetic diversity in the social group.

   (D) Food sharing increases the number of unrelated animals that cluster in one area, thus decreasing competition for food among members of the social group.

4. Which one of the following cells is likely to be the most efficient at eliminating waste by diffusion?

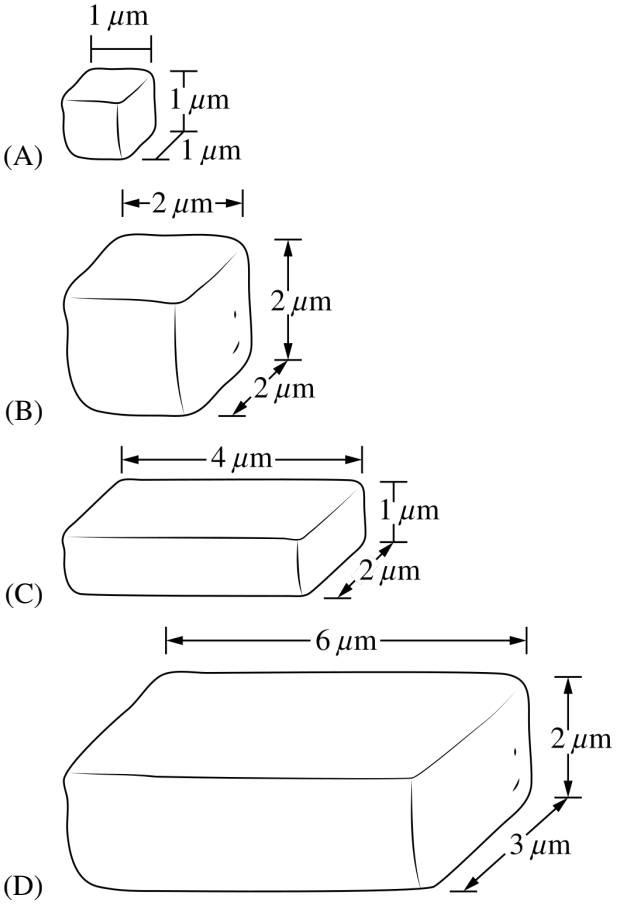


TABLE 1. DIMENSIONS OF SHAPES USED TO MODEL EFFICIENT MATERIAL EXCHANGE

Cell Shape	**Width at Widest Point** (μm)	**Height** (μm)	**Surface Area** (μm)	**Volume** (μm)
Right circular cylinder	30	90	9,896	63,617
Triangular prism	30	90	8,879	35,074
Rectangular prism	30	90	12,600	81,000
Square-based pyramid	30	90	6,374	27,000

5. A scientist is developing a mathematical model of cells of different shapes. To construct the model, the scientist has specified that the width of each cell at its widest point must be 30 μm and the height of each cell must be 90 μm. Table 1 shows the three-dimensional shapes that the scientist is considering for the model cells. Which of the proposed shapes for the model cells will allow the most efficient exchange of materials with the surrounding environment?

   (A) Right circular cylinder

   (B) Triangular prism

   (C) Rectangular prism

   (D) Square-based pyramid

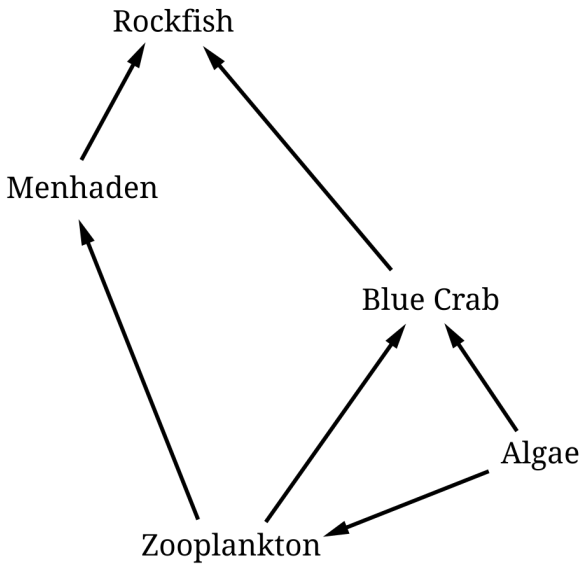


Figure 1. Feeding relationships between selected organisms in the Chesapeake Bay

6. Figure 1 represents the feeding relationships between selected organisms in the Chesapeake Bay. Decades of overharvesting have reduced the populations of both blue crabs and rockfish. However, recent efforts have increased the number of rockfish in the bay. Based on Figure 1, what is the most likely result of the increase in rockfish?

   (A) The population of menhaden will increase because the energy available from zooplankton will increase.

   (B) The population of menhaden will decrease because the energy resources available to them will decrease.

   (C) The population of zooplankton will decrease because the energy available from algae will decrease.

   (D) The population of blue crabs will decrease because predation by rockfish will increase.

TABLE 1. NUMBER OF CHICKENS OF EACH PHENOTYPE

Phenotype	**Number**
Black, solid	47
Black, spotted	12
Gray, solid	16
Gray, spotted	4
Total	79

7. In a certain type of chicken, the allele for gray feathers is recessive to the allele for black feathers, and the allele for a spotted pattern is recessive to the allele for a solid pattern. Chickens that are heterozygous for both traits were crossed and the phenotypes for the offspring were recorded (Table 1).

   To determine whether the data are consistent with the expectations for independent assortment, students performed a chi-square analysis.

   Which of the following is the closest to the calculated chi-square value for the experiment?

   (A) -0.26

   (B) 0.20

   (C) 0.95

   (D) 1.25

8. In fruit flies of the genus *Drosophila*, the allele for vestigial wings is recessive to the allele for round wings, and the allele for brown eye color is recessive to the allele for red eye color. A scientist crossed flies that are heterozygous for both traits and determined the number of offspring with each combination of phenotypes. The scientist performed a chi-square analysis to determine if the data are consistent with the expectations for independent assortment. The chi-square calculated value for the experiment was 6.03.

   Based on the chi-square calculated value, which of the following statements is most accurate?

   (A) The chi-square calculated value is greater than the chi-square critical value; therefore the null hypothesis should be rejected.

   (B) The chi-square calculated value is greater than the chi-square critical value; therefore the null hypothesis should not be rejected.

   (C) The chi-square calculated value is less than the chi-square critical value; therefore the null hypothesis should be rejected.

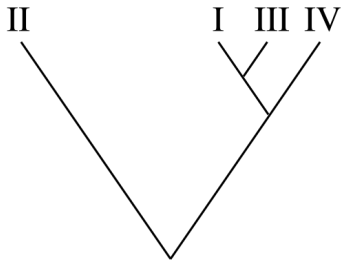
   (D) The chi-square calculated value is less than the chi-square critical value; therefore the null hypothesis should not be rejected.

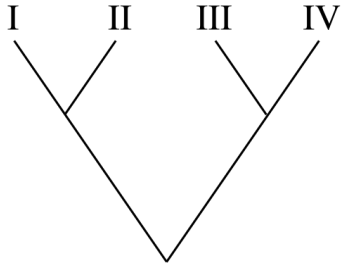
TABLE 1. PERCENT DNA SEQUENCE DIFFERENCES IN THE *MT-CO1* GENE

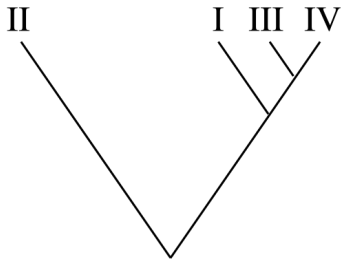
Species	I	II	III	IV
I		13.5	1.5	3.0
II			12.7	12.2
III				3.8
IV				

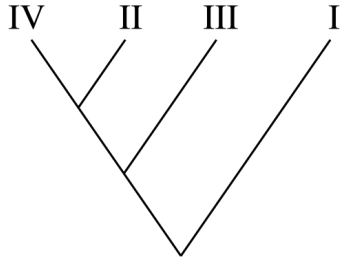
9. The gene encoding the catalytic subunit of cytochrome c oxidase ($MT-CO1$) is found in the mitochondria of all animals. The gene evolves rapidly and is often used to determine evolutionary relationships among species. Table 1 shows DNA sequence differences among four animal species (I, II, III, and IV).

   Which of the following cladograms best represents the evolutionary relationships among the four species?

(A)


(B)


(C)


(D)


Questions 10-13

The coral species *Acropora millepora* is a marine animal that has a symbiotic relationship with algae species in the genus Symbiodinium. An increase in the concentration of dissolved CO_2 in oceans has a negative impact on this relationship and the health of the coral species. Scientists investigated the effect of CO_2 concentrations on the number of algae cells found in the coral (Figure 1) and on both the gross (total) and net rates of photosynthesis of those algae (Figure 2). The net rate of photosynthesis is equal to the gross rate of photosynthesis minus the rate of respiration by the algae.

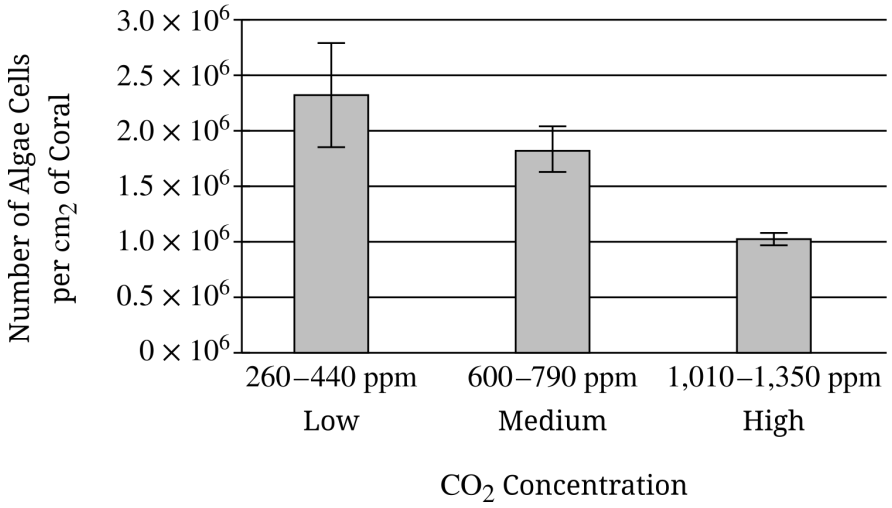


Figure 1. Effect of CO_2 concentration on the number of algae per cm^2 of coral. Error bars represent $\pm 2SE_{\bar{x}}$.

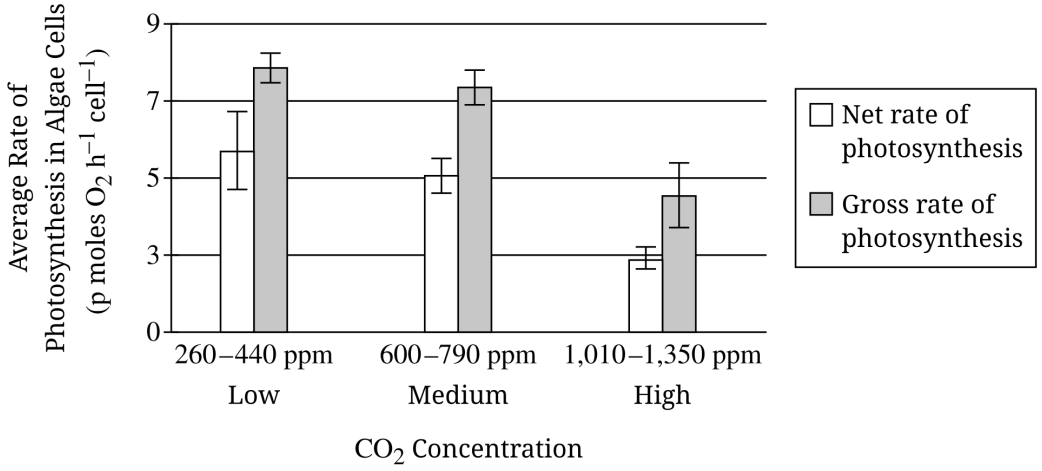


Figure 2. Average gross and net rates of photosynthesis in algae under various concentrations of CO_2. Error bars represent $\pm 2SE_{\bar{x}}$.

10. Which of the following best explains the symbiotic relationship between the coral and the algae?

    (A) The relationship is an example of commensalism because the algae add CO_2 to the oceans and the coral use CO_2.

    (B) The relationship is an example of commensalism because the coral provide shelter for the algae and the algae provide chlorophyll to the coral.

    (C) The relationship is an example of mutualism because the coral use sugars made by the algae and provide shelter for the algae.

    (D) The relationship is an example of mutualism because the algae perform photosynthesis for the coral and the coral perform respiration for the algae.

11. Based on Figure 1, which of the following values best represents the change in the number of algal cells at the high concentration of CO_2 as compared with the number at the low concentration of CO_2?

    (A) 17.4% increase

    (B) 43.5% increase

    (C) 56.5% decrease

    (D) 65.2% decrease

12. Based on Figure 2, which of the following best supports the claim that CO_2 concentration and photosynthetic productivity are inversely related?

    (A) The net rate of photosynthesis is less than the gross rate of photosynthesis at the high concentration of CO_2.

    (B) Both the net and gross rates of photosynthesis at the high concentration of CO_2 are lower than those at the low concentration of CO_2.

    (C) The net rate of photosynthesis at the low concentration of CO_2 is lower than the gross rate of photosynthesis at the high concentration of CO_2.

    (D) The difference between net and gross rates of photosynthesis is greater at the low concentration of CO_2 than it is at the high concentration of CO_2.

13. Researchers observe that the water with the high CO_2 concentration has a lower pH than does the water with the low CO_2 concentration. The researchers claim that lower pH alters the structure of the enzymes of photosynthesis.

    Which of the following most likely explains how a lower pH could alter the structure of photosynthetic enzymes?

    (A) There will not be enough H^+ ions for the ribosome to correctly form peptide bonds between amino acids during synthesis of the enzymes.

    (B) There will not be enough H^+ ions for the necessary hydrogen bonds to form in the secondary, tertiary, and quaternary structures of the enzymes.

    (C) There will be additional H^+ ions that can disrupt peptide bonds in the primary structure of the enzymes.

    (D) There will be additional H^+ ions that can disrupt hydrogen bonds in the secondary, tertiary and quaternary structures of the enzymes.

Questions 14-18

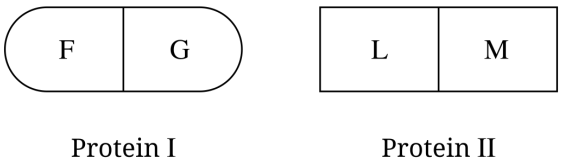


Figure 1. Domain structure of two proteins

Investigators studied the interactions between two different proteins, protein I and protein II. Each protein has two structural domains (Figure 1) that represent different functional parts of the protein. Different combinations of the protein domains were tested for their ability to bind to a known DNA sequence, interact with each other, and activate transcription. The results are shown in Table 1.

TABLE 1. INTERACTION AND FUNCTION OF COMBINATIONS OF STRUCTURAL VARIANTS OF PROTEINS I AND II

Test	**Domain(s) of Protein I Used**	**Domain(s) of Protein II Used**	**DNA Binding**	**Protein-Protein Interaction**	**Transcription Activation**
1	FG	LM	+	+	+
2	FG	None	+	−	−
3	None	LM	−	−	−
4	F	LM	+	−	−
5	G	LM	−	+	−
6	FG	L	+	−	−
7	FG	M	+	+	+

14. Which of the following claims is best supported by the data from test 5 in Table 1?

    (A) Domain L is required for transcription activation.

    (B) Domain F is not required for protein-protein interaction.

    (C) Protein-protein interaction is necessary for DNA binding.

    (D) Protein-protein interaction is sufficient for transcription activation.

15. Based on the data, which structural domain is most likely required for DNA binding?

    (A) Domain F

    (B) Domain G

    (C) Domain L

    (D) Domain M

16. Which of the following claims is best supported by the data in Table 1?

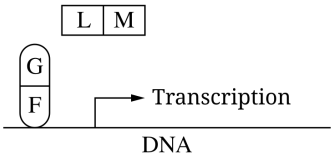
    (A) Protein-protein interaction always results in transcription activation.

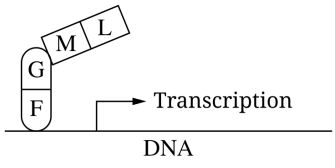
    (B) DNA binding is required for protein-protein interaction.

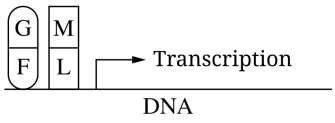
    (C) Protein-protein interaction is necessary for, but not adequate for, transcriptional activation.

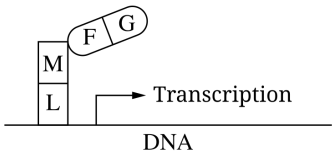
    (D) DNA binding always results in transcription activation.

17. Which of the following best models the interaction of protein I and protein II that results in the transcription of target genes?

(A)


(B)


(C)


(D)


18. Which of the following is the most likely result of testing a combination of domains G and M?

    (A) No functionality

    (B) DNA binding only

    (C) Transcriptional activation only

    (D) Protein-protein interaction only

19. Human epidermal growth factor (EGF) is a protein that stimulates cell division and growth by binding to its receptor, human epidermal growth factor receptor 2 (HER2). Certain types of cancer are caused when the overexpression of EGF activates a cell-signaling pathway, leading to uncontrolled cell division.

Which of the following best explains how a drug can be used to inhibit tumor growth caused by EGF overexpression?

(A) The drug binds to HER2, preventing the activation of the signaling pathway.

(B) The drug acts as a positive regulator of transcription of the gene encoding EGF.

(C) The drug activates the receptor in the absence of EGF, leading to the activation of the signaling pathway.

(D) The drug enables the cells to progress through the S/G_2 checkpoint.

Questions 20-24

Dystrophin is a protein that is expressed in certain muscle cells. In combination with other cellular proteins, dystrophin strengthens protein fibers in muscle cells to allow muscles to contract without injury.

Nucleotide deletions in the gene that encodes dystrophin are associated with the genetic disorder Duchenne Muscular Dystrophy (DMD). Individuals with DMD do not produce functional dystrophin and, as a result, the protein fibers, and then entire muscle cells, become damaged.

The history of DMD for three generations of a family is shown in Figure 1.

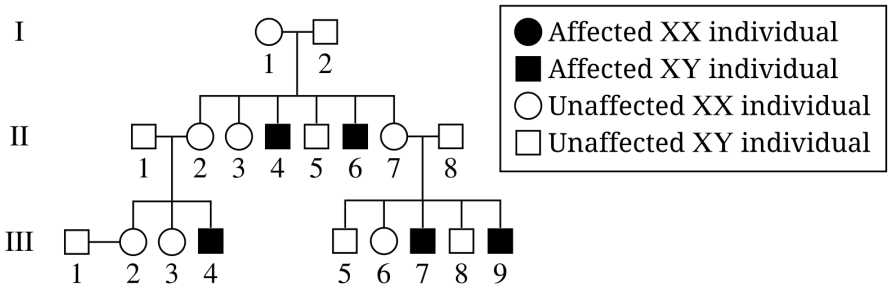


Figure 1. Pedigree showing instances of DMD in a family

Individuals III–1 and III–2 plan to have children and wish to first determine whether individual III–2 is a carrier of DMD. Individual III–2 undergoes genetic testing to determine whether individual III-2 carries a particular allele for the mutated dystrophin that is associated with the disorder in this family. The results of gel electrophoresis analysis of the individual's dystrophin alleles and the alleles of several family members are shown in Figure 2.

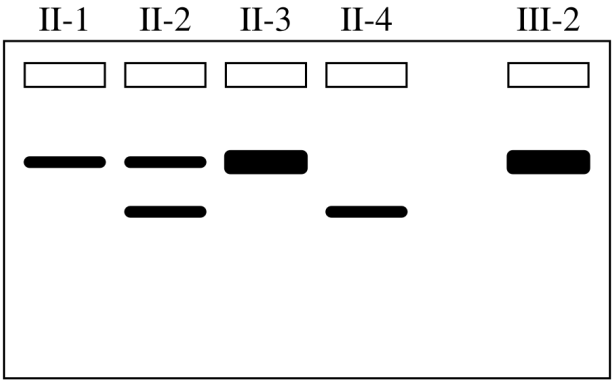


Figure 2. Gel electrophoresis showing the dystrophin alleles present in five members of the family

20. Based on the information provided, which of the following describes the most likely pattern of inheritance for the disorder?

    (A) Autosomal recessive

    (B) Autosomal dominant

    (C) X-linked recessive

    (D) Mitochondrial

21. Based on the information provided in Figures 1 and 2, which of the following best describes the chances of individuals III–1 and III–2 passing on the mutant dystrophin allele and/or DMD disorder to their offspring?

    (A) There is a 50% chance that an XY child will have DMD.

    (B) There is a 25% chance that a child will have DMD.

    (C) There is a 0% chance that any of the children will have the disorder or be carriers of the mutant allele.

    (D) There is a 0% chance that an XY child will have DMD but a 50% chance that an XX child will be a carrier of the mutant allele.

22. Which of the following best explains how the dystrophin protein is synthesized by certain muscle cells of an individual but not by other cell types?

    (A) Each cell has different genes as a result of changes that occur during development and cell specialization.

    (B) The presence of different transcription factors in different cell types results in differential gene expression.

    (C) A cell can only translate mRNA transcripts that have gene-specific sequences that are recognized by the ribosomes.

    (D) The promoter region of the gene is necessary for expression to occur, and this region is only present in certain cell types.

23. Another form of muscular dystrophy, BMD, has a less severe phenotype. Individuals with BMD produce less dystrophin protein or abnormal dystrophin protein with reduced function, whereas individuals with DMD produce no dystrophin protein. Both BMD and DMD are commonly caused by the deletion of a portion of the dystrophin gene.

    Which of the following best explains why there is a difference in phenotype between BMD and DMD?

    (A) BMD can be caused by the deletion of exons, while DMD is caused by the deletion of introns.

    (B) BMD can be caused by a deletion that affects a single amino acid, while DMD is caused by a deletion that alters all the amino acids that follow the mutation.

    (C) BMD can be caused by a deletion that removes the transcription start site, while DMD is caused by a deletion that removes the transcription stop signal.

    (D) BMD can be caused by the inheritance of two alleles containing deletions, while DMD is caused by the inheritance of one allele containing the deletion and one normal allele.

24. Over 2,000 different mutations in the gene encoding dystrophin are associated with different forms of muscular dystrophy. The mutations include deletions of a portion of the gene, duplications of a portion of the gene, and sometimes substitutions of base pairs in certain regions of the gene.

    Which of the following correctly predicts the movement of a mutant allele compared with the movement of the normal allele when analyzed by gel electrophoresis?

    (A) An allele with base pair substitutions in an exon will travel farther than the normal allele does.

    (B) An allele with a duplication in an exon will travel a shorter distance than the normal allele does.

    (C) An allele with base pair deletions in an exon will travel the same distance as the normal allele does.

    (D) An allele with a duplication in an exon will travel a longer distance than the normal allele does.

25. A chemical binds to a protein composed of a single polypeptide chain and prevents the formation of an alpha helix that is typically formed in the absence of the chemical. Which of the following best describes the effect the chemical has on the structure of the protein?

    (A) The primary structure held together by covalent bonds is affected.

    (B) The secondary structure held together by hydrogen bonds is affected.

    (C) The secondary, tertiary, and quaternary structures are affected.

    (D) All levels of protein structure are affected.

26. The drug 5-fluorouracil inhibits thymine production in eukaryotic cells. Which of the following cell cycle stages will be most directly affected by 5-fluorouracil?

    (A) The first growth phase (G_1)

    (B) Synthesis of DNA phase (S)

    (C) Preparation for mitosis (G_2)

    (D) Cytokinesis

Questions 27-30

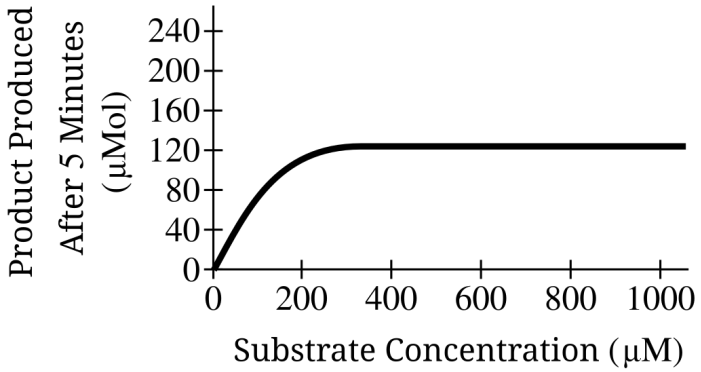


Figure 1. Rate of an enzyme-catalyzed reaction

Researchers investigated the dynamics of a reaction catalyzed by an enzyme. The researchers prepared a series of reactions, each with the same concentration of enzyme but with different concentrations of substrate. The researchers measured the amount of product in each reaction mixture after 5 minutes. The results are shown in Figure 1.

27. Which of the following best describes how an increase in the concentration of substrate in the reaction mixture affected the frequency of enzyme-substrate interactions?

    (A) The frequency of enzyme-substrate interactions decreased over all substrate concentrations.

    (B) The frequency of enzyme-substrate interactions increased exponentially over all substrate concentrations.

    (C) The frequency of enzyme-substrate interactions increased until all of the active sites were interacting with substrate.

    (D) The frequency of enzyme-substrate interactions increased until all of the enzyme was depleted.

28. Which of the following experimental designs would best allow researchers to investigate the effect of pH on the rate of the enzyme-catalyzed reaction?

    (A) Measure reaction rates at different pH levels when the enzyme concentration remains the same and the substrate concentration is 100 μM.

    (B) Measure the pH of the reaction mixture when the enzyme concentration remains the same and substrate concentrations vary between 0 μM and 1,000 μM.

    (C) Measure reaction rates when the enzyme concentration remains the same but the pH of the reaction mixture increases and the substrate concentration increases from 0 μM to 1,000 μM.

    (D) Measure reaction rates when the substrate concentration is 100 μM and both the pH of the reaction mixture and the enzyme concentration are increased.

29. Which of the following questions best addresses whether a particular inhibitor is competitive or non-competitive?

(A) Does the inhibitor bind more tightly to the substrate or to the enzyme?

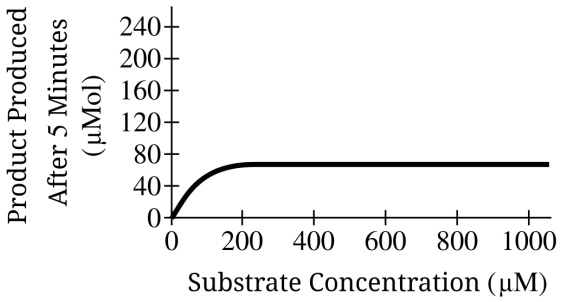
(B) Can the inhibitor be converted to product by the enzyme?

(C) How much inhibitor is necessary to completely inhibit the activity of the enzyme?

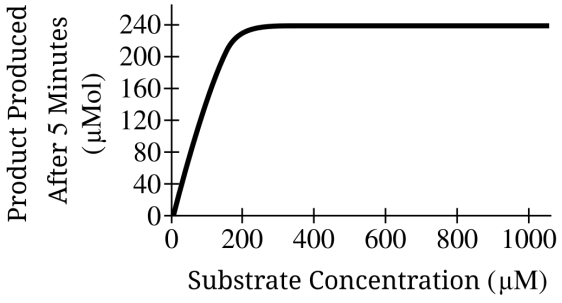
(D) Does the inhibitor bind to an allosteric site or the active site of the enzyme?

30. Which of the following graphs predicts the most likely rate of the enzyme-catalyzed reaction if the concentration of the enzyme in the mixture were doubled?

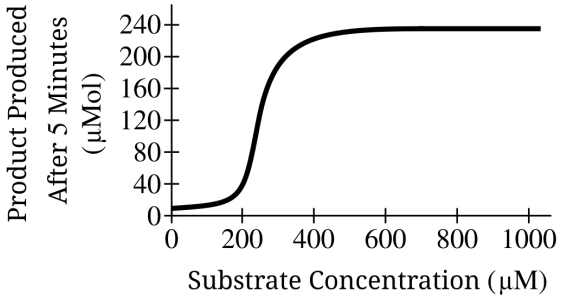
(A)



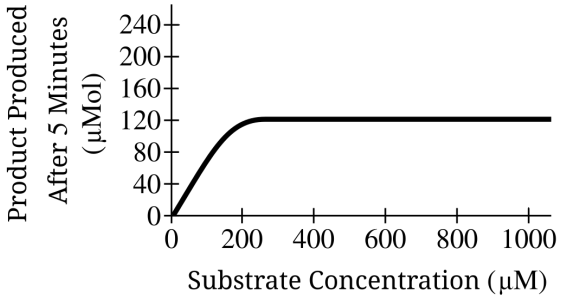
(B)



(C)



(D)



31. Beta cells, a type of cell found in the pancreas, are responsible for producing, storing, and releasing the hormone (chemical signal) insulin. An increase in blood glucose levels stimulates beta cells to produce insulin, which facilitates the uptake of glucose by body cells and reduces the glucose levels in the blood. As the blood glucose levels decrease, beta cells are no longer stimulated and stop producing insulin.

    Which of the following best explains the feedback mechanism that regulates blood glucose levels?

    (A) Regulation of blood glucose levels demonstrates positive feedback, because as the blood glucose levels increase, insulin acts to raise blood glucose levels.

    (B) Regulation of blood glucose levels demonstrates negative feedback, because as the blood glucose levels increase, insulin acts to lower blood glucose levels.

    (C) Regulation of blood glucose levels demonstrates positive feedback, because as the production of insulin by beta cells increases, blood glucose levels increase.

    (D) Regulation of blood glucose levels demonstrates negative feedback, because as the production of insulin by beta cells decreases, blood glucose levels decrease.

32. Over 100 different types of G-protein-linked receptors have been observed in eukaryotes, including scent receptors in animals, mating-signal receptors in yeasts, and light-sensing proteins in vertebrates. The proton pumps of bacteria have protein structures similar to G-protein-linked receptors. Based on this information, which of the following scientific questions will best guide research on the evolution of G-protein-linked signal transduction?

    (A) Did the G-protein-linked signal transduction pathway in eukaryotes arise from a precursor in prokaryotes?

    (B) Are G-protein-linked receptors acquired from the environment as they are needed?

    (C) Do eukaryotes require symbiotic prokaryotes in order to use G-protein-linked receptors?

    (D) Do single-celled organisms have more efficient cell communication than do multicellular organisms?

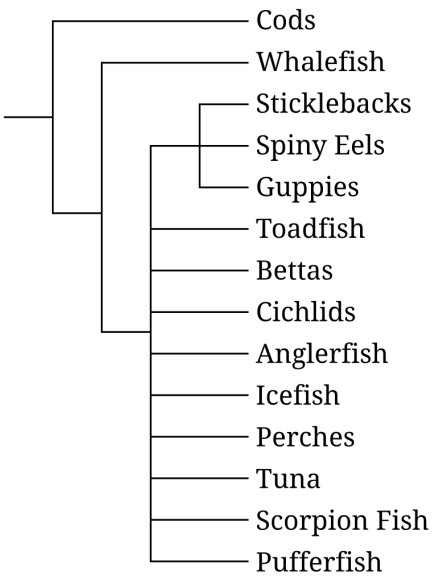


Figure 1. Simplified cladogram of several orders of fish

33. Cods and icefish are the only orders of fish that include species that produce antifreeze proteins in their blood. Based on the cladogram in Figure 1, which of the following scenarios describes the most likely evolutionary history of antifreeze protein synthesis in fish?

    (A) Antifreeze proteins arose twice, once in the cod lineage and once in the icefish lineage.

    (B) Antifreeze proteins arose once in a common ancestor of cods and icefish.

    (C) Antifreeze proteins arose once in the most recent common ancestor of whalefish and icefish.

    (D) Antifreeze proteins were lost repeatedly in fish lineages.

34. Hydrangea flowers differ in color based on interactions between a pigment in the flower cells and aluminum ions dissolved in water absorbed from the soil. When aluminum ions are present, the pigment is blue; when aluminum ions are absent, the pigment is pink. The amount of aluminum ions the plant can absorb is dependent on the pH of the soil.

    Which of the following questions will best help a researcher design an experiment to learn about the relationship between hydrangea flower color, aluminum, and pH?

    (A) How do aluminum-pigment interactions change the structure of the pigment and flower color?

    (B) Can the pigment be used as an indicator of pH, because flower color depends on pH and aluminum?

    (C) Does an increase in hydrogen ion concentration affect the ability of the pigment to dissolve in water?

    (D) What will be the flower color of hydrangeas grown in soils of varying pH with or without aluminum?

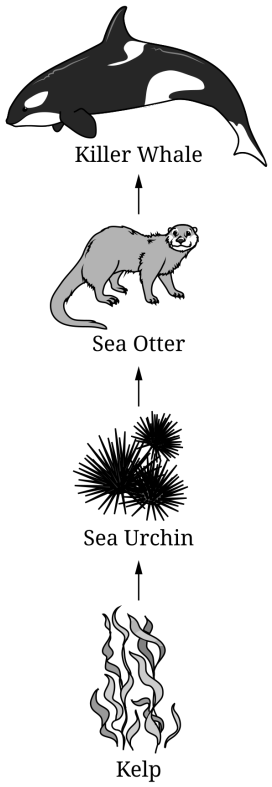


Figure 1. A food chain in the North Pacific Ocean

35. Based on Figure 1, which of the following is the most likely short-term effect of a decrease in the killer whale population?

    (A) The sea otter and kelp populations will increase, while the sea urchin population will decrease.

    (B) The sea otter and sea urchin populations will increase, while the kelp population will decrease.

    (C) The sea otter population will stay the same, while the sea urchin and kelp populations will increase.

    (D) There will be no change to the sea otter, sea urchin, and kelp populations because another predator species will fill the niche previously occupied by the killer whales.

TABLE 1. PERCENT CHEMICAL COMPOSITION OF FOUR MACROMOLECULES

Macromolecule Sample	C (%)	O (%)	H (%)	N (%)	P (%)	S (%)
A	25	25	50	0	0	0
B	15	20	40	20	0	5
C	40	4	45	0	1	0
D	25	20	35	15	5	0

36. A researcher analyzed four different samples of macromolecules, where all macromolecules in each sample are of the same type. The researcher measured the percent of carbon, oxygen, hydrogen, nitrogen, phosphorus, and sulfur atoms in each sample. The results are shown in Table 1.

Which of the following claims is best supported by the data in Table 1?

(A) Sample A contains nucleic acids.

(B) Sample B contains protein.

(C) Sample C contains nucleic acids.

(D) Sample D contains protein.

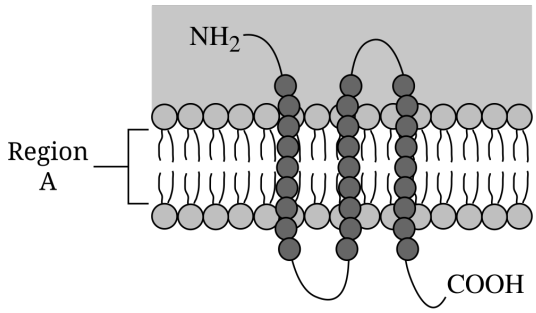


Figure 1. Structure of a membrane protein

37. Based on Figure 1, the amino acids in region A are most likely to have which of the following characteristics?

(A) Most amino acids will be hydrophobic because they interact most favorably with the phospholipid tails.

(B) Most amino acids will be hydrophilic because they interact most favorably with the phospholipid heads.

(C) Most amino acids will be ionic amino acids because they interact most favorably with the phospholipid tails.

(D) Most amino acids will be polar amino acids because they interact most favorably with the phospholipid heads.

38. Which of the following accurately describes a model of active transport?

(A) A membrane channel protein facilitates the movement of molecules from an area of high concentration on the outside of the cell to an area of lower concentration on the inside.

(B) A cell in a hypotonic solution swells as water moves into it.

(C) A membrane protein binds a specific molecule outside of the cell and moves the molecule into the cell where there is already a high concentration of the molecule compared with the outside.

(D) A membrane protein binds a specific molecule on the inside of the cell and moves the molecule to an area of lower concentration on the outside of the cell.

39. Old World vultures are birds that have digestive systems that enable them to feed mainly on carrion (dead animals). They have large wings used to soar as they search for dead animals with their vision. New World vultures have similar digestive systems and wingspans; however, they search for food using their sense of smell. Old World vultures and New World vultures are not closely related.

Which of the following best explains how Old World vultures and New World vultures both evolved to feed mainly on carrion?

(A) Old World vultures and New World vultures had a common ancestor that fed mainly on carrion, and this trait was selected for in populations of New World and Old World vultures.

(B) Old World vultures and New World vultures were exposed to similar selective pressures, which contributed to the independent evolution of carrion feeding in two separate lineages.

(C) Old World vultures were introduced into areas with New World vultures, and the trait for carrion feeding was selected for in the population of New World vultures.

(D) Old World vultures and New World vultures have similar digestive systems, which drove them to consume a food source that was not available to other bird species.

TABLE 1. INTERNAL AND EXTERNAL WATER POTENTIALS OF FOUR DIFFERENT PARAMECIA

Paramecium	**Internal Ψ**	**External Ψ**
1	-1.44 MPa	-0.08 MPa
2	-1.56 MPa	-1.01 MPa
3	-1.33 MPa	-1.76 MPa
4	-0.37 MPa	-1.73 MPa

40. A paramecium is a single-celled organism that contains one or more organelles called contractile vacuoles. In its freshwater environment, water may accumulate inside the paramecium and the contractile vacuoles. Contraction of the vacuoles removes excess water from the organism, thus preventing the paramecium from bursting. Table 1 provides internal and external water potentials (Ψ) for four different paramecia living in four different environments.

In which paramecium in Table 1 will the contractile vacuoles most likely have the highest contraction rate?

(A) Paramecium 1

(B) Paramecium 2

(C) Paramecium 3

(D) Paramecium 4

TABLE 1. OZONE DAMAGE IN SIX PLANT SPECIES

Species	Number of Plants Observed	Number of Damaged Plants	Percent of Plants with Damage
Ash	544	41	7.5
Cherry	30	2	6.7
Dogwood	4	2	4.9
Sassafras	132	3	2.3
Sweet gum	170	2	1.2
Wild grape	124	20	16.1

41. To investigate the effects of ground-level ozone pollution on different species of plants, researchers recorded the number of plants in a certain area that had ozone-induced leaf damage. Based on the results of the survey shown in Table 1, which of the following plant species was most affected by ozone pollution?

    (A) Ash

    (B) Cherry

    (C) Sweet gum

    (D) Wild grape

42. Decades of seal hunting eliminated many fur seal breeding colonies. Since that time, fur seals have recolonized several islands in the Pacific Ocean. Scientists studying the populations of fur seals on three recently colonized islands observed different population growth rates among the three populations.

    Which of the following best explains the different population growth rates on the recently colonized islands?

    (A) The islands differed in the number of predators of seals in the surrounding waters, resulting in lower growth rates on islands with fewer predators nearby.

    (B) The islands differed in the amount of available prey, resulting in a higher population growth rate on the islands with fewer prey.

    (C) The islands differed in the amount of competition for resources, resulting in higher population growth rates on islands with greater competition.

    (D) The islands differed in the amount of available space for breeding, resulting in higher growth rates on islands with more available breeding space.

43. Producers within very deep regions of the ocean most likely introduce energy into ecosystems through which of the following processes?

    (A) Absorbing photons of light energy

    (B) Capturing electrons from inorganic molecules

    (C) Absorbing heat energy from hydrothermal vents on the ocean floor

    (D) Living in other organisms

44. The binding of erythropoietin to the erythropoietin receptor (EPoR) stimulates intracellular signaling in certain cells, which causes them to differentiate to red blood cells. The EPoR is a transmembrane protein with two cytoplasmic domains, each of which is bound by a kinase protein, JAK2. The binding of erythropoietin to the EPoR causes the cytoplasmic domains of the EPoR to undergo conformational changes that activate the bound JAK2 kinases. The JAK2 kinases then phosphorylate several intracellular proteins, including STAT5, whose resulting activity causes the cells to differentiate to red blood cells.

    Which of the following explains how a mutation that removes a portion of each cytoplasmic domain of EPoR most likely affects differentiation of the cells?

    (A) The cells will differentiate more rapidly than they typically do because the JAK2 kinases will always be active.

    (B) The cells will mature to another cell type because the JAK2 kinases will phosphorylate inappropriate cellular proteins.

    (C) STAT5 will not be activated because erythropoietin cannot bind to the EPoR.

    (D) STAT5 will not be activated because it will not be phosphorylated by the JAK2 kinases.

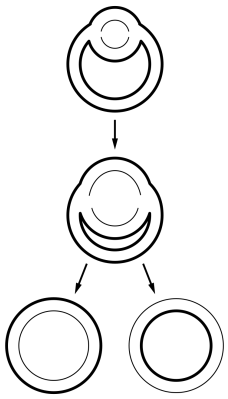


Figure 1. A cellular process

45. Which of the following processes is best represented by Figure 1?

    (A) Cell signaling to increase gene expression

    (B) Translation of an mRNA to produce a protein

    (C) Regulation of gene expression by microRNA

    (D) Replication of a plasmid

46. Retinitis pigmentosa is a rare genetic disorder that causes the breakdown of cells in the eye, resulting in vision loss. Worldwide, the occurrence of retinitis pigmentosa in the population is approximately 1 in 4,000. However, on a small group of islands in the Atlantic Ocean, the occurrence is approximately 1 in 58.

    Which of the following best explains how the occurrence of a rare, genetic disorder can be so much more prevalent on a small group of islands as compared with the rest of the world?

    (A) An unusually high number of individuals with the disease initially colonized the islands, and there has been little immigration to the islands since that time.

    (B) Individuals on the islands evolved adaptations to the vision loss, and because the disorder does not affect an individual's fitness, the disorder remains in the population.

    (C) The population of individuals on the islands has greater genetic diversity compared with the worldwide population, resulting in a larger number of individuals with genetic disorders.

    (D) The mutation rate is greater in the population of individuals on the islands than in the worldwide population, resulting in a greater incidence of rare disorders.

47. Which of the following best describes the role of ATP and NADPH in the process of photosynthesis?

    (A) ATP is required for the chemiosmotic production of NADPH during photosynthesis.

    (B) ATP and NADPH are necessary to initiate the Krebs cycle in photosynthesis.

    (C) ATP and NADPH are carriers of chemical energy that is used in the production of carbohydrates.

    (D) ATP and NADPH are required to boost electrons to a higher energy state in photosystems I and II.

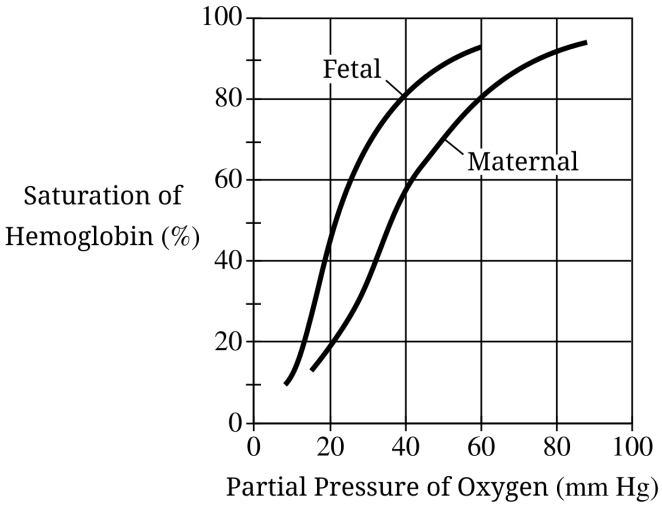


Figure 1. Percent saturation of human hemoglobins as a function of the partial pressure of oxygen

48. The graph in Figure 1 shows the percent saturation of fetal hemoglobin and maternal hemoglobin in humans as a function of the partial pressure of oxygen. Based on the data, which of the following values is closest to the predicted difference in the percent saturation of fetal hemoglobin and maternal hemoglobin at 40 mmHg?

    (A) 10

    (B) 12

    (C) 20

    (D) 40

49. In a region of Africa where malaria is common, 9% of the population is born with a severe form of sickle-cell anemia (*ss*). Carriers of the sickle-cell allele (heterozygotes) are resistant to malaria and display only mild symptoms of malaria if exposed to the malaria parasite. If an effective antimalarial program is instituted in the region, which of the following is most likely to occur over many generations?

    (A) The frequency of the sickle-cell allele will increase, as there will be more heterozygous individuals.

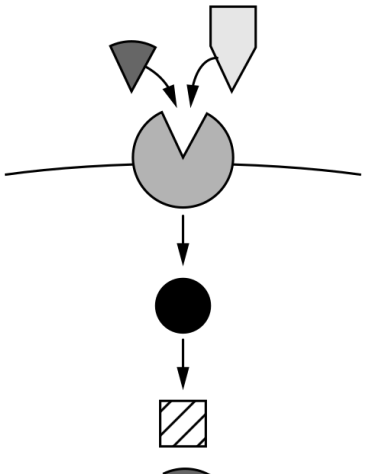
    (B) The incidence of malaria will decrease, but the incidence of sickle-cell anemia will increase.

    (C) The frequency of the sickle-cell allele s will decrease as the incidence of malaria decreases.

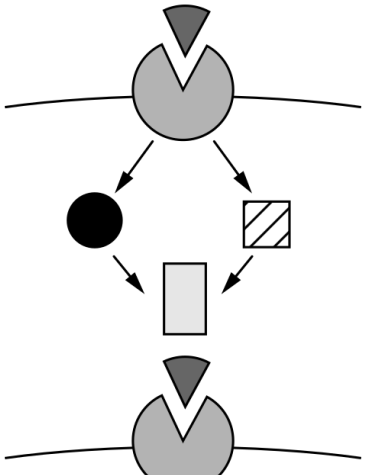
    (D) The frequency of the sickle-cell allele will increase because antimalarial treatments cause mutations.

50. Which of the following best represents a signaling pathway that will lead to multiple responses from the same signaling molecule?

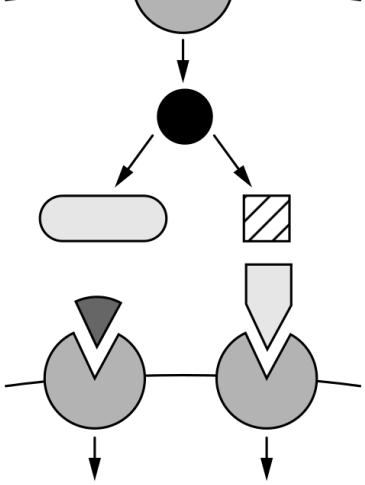
(A)



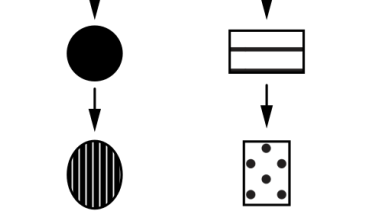
(B)



(C)



(D)



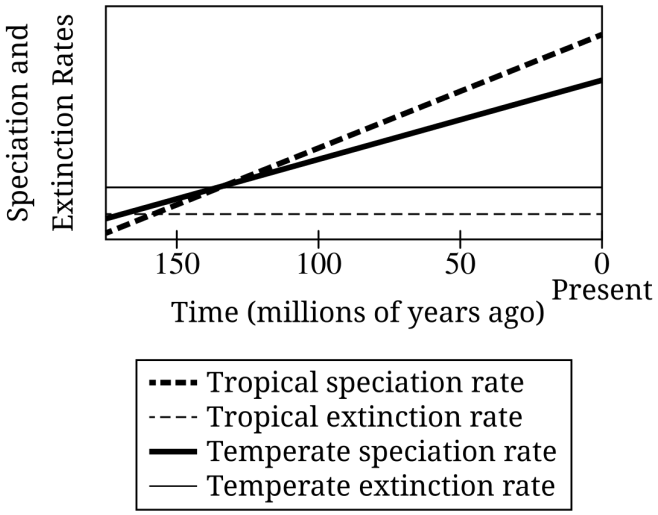


Figure 1. Estimate of rates of speciation and rates of species extinction in temperate and tropical biomes over the last 175 million years

51. Assuming both temperate and tropical biomes had equivalent biodiversity 175 million years ago, which of the following claims is best supported by the data in Figure 1?

    (A) Tropical biomes in the present have less biodiversity than do temperate biomes.

    (B) Tropical biomes in the present have greater biodiversity than do temperate biomes.

    (C) The rate of extinction is lower in temperate biomes than in tropical biomes.

    (D) The rate of speciation in both temperate and tropical biomes has not changed over time.

52. Which of the following best supports the endosymbiotic theory?

    (A) Mitochondria and chloroplasts have their own genomes.

    (B) Enzymes used in photosynthesis differ from those in cellular respiration in all eukaryotes.

    (C) Bacteria and plants both have cell walls.

    (D) Bacterial flagella are structurally different from eukaryotic flagella.

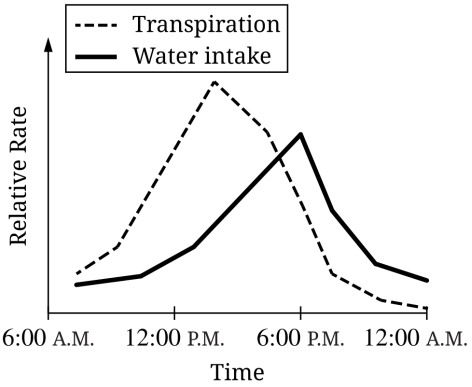


Figure 2. Relative rates of transpiration and water intake for a plant over 18 hours

53. Figure 2 shows the relative rates of transpiration (water loss) and water intake for a plant over an 18-hour period. Which of the following describes the most likely relationship between transpiration and water intake in the plant?

    (A) Transpiration from the leaves of the plant stimulates subsequent water intake by the roots of the plant.

    (B) Transpiration and water intake peak at the same time of day.

    (C) Water intake by the roots of the plant drives transpiration at the leaves of the plant.

    (D) Transpiration and water intake have an inverse relationship.

Questions 54-57

In prokaryotes, the genes of the *trp* operon encode enzymes used in the synthesis of tryptophan. The genes of the *trp* operon are actively expressed (Figure 1A) unless abundant tryptophan is present in the environment. When tryptophan is abundant, some tryptophan binds to the *trp* repressor protein, which in turn causes the repressor to bind to the operator and block transcription of the genes (Figure 1B). The repressor protein is encoded by the *trpR* gene which is not a part of the trp operon.

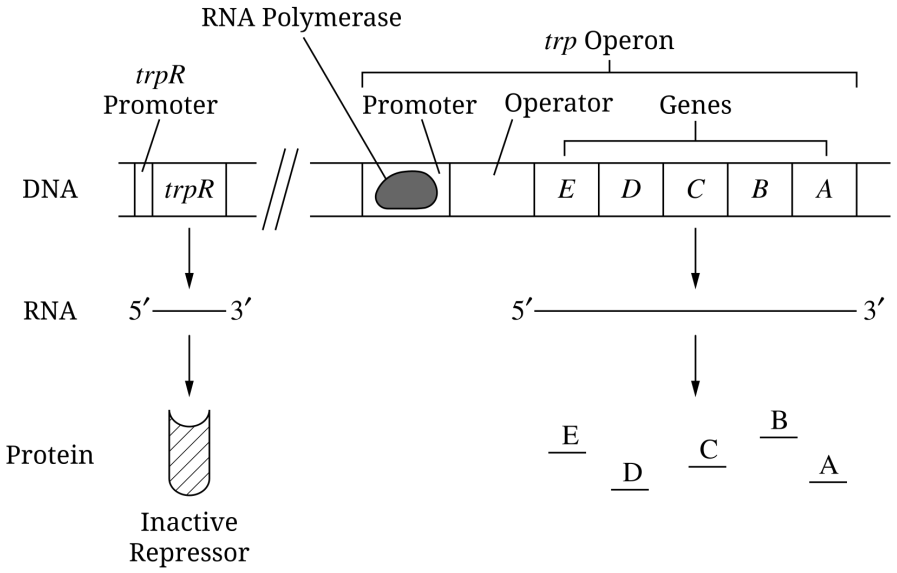


Figure 1A. When tryptophan is absent, the *trp* operon is active.

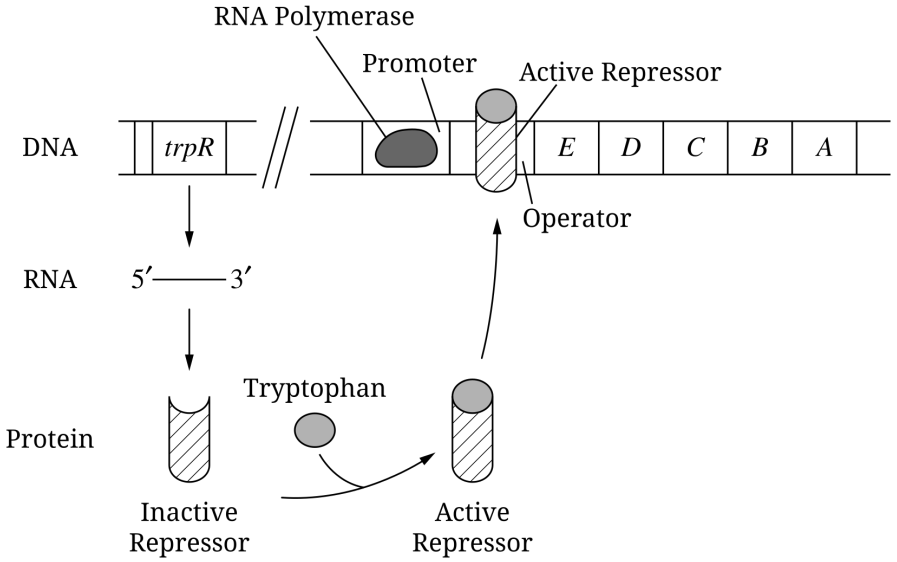


Figure 1B. When tryptophan is abundant, the *trp* operon is inactivated by the binding of the repressor protein to the operator.

54. A scientist claimed that an *E. coli* strain had either a mutated *trpR* gene or a mutated operator. Which of the following observations most likely supports the claim?

(A) Transcription from the operon occurred only in the presence of abundant tryptophan.

(B) The strain of *E. coli* required more tryptophan for its metabolic processes than does a strain of *E. coli* with typical tryptophan regulatory controls.

(C) Enzymes required for the synthesis of tryptophan were continuously produced whether tryptophan was absent or present in large quantities.

(D) The cells died when they were grown in nutrient medium that lacked tryptophan.

55. Which of the following questions will most likely allow the scientist to design an experiment to determine whether unregulated tryptophan synthesis in a strain of *E. coli* is caused by a mutation in the *trpR* gene or in the operator of the *trp* operon?

(A) Is normal regulation of tryptophan synthesis restored when the operator sequence of this strain of *E. coli* is duplicated?

(B) Is normal regulation of tryptophan synthesis restored when a gene encoding a normal repressor protein is introduced into and expressed by this strain of *E. coli*?

(C) Is normal regulation of tryptophan synthesis restored when a plasmid that contains a normal operator sequence is introduced into this strain of *E. coli*?

(D) Is normal regulation of tryptophan synthesis restored when the repressor protein gene is deleted in this strain of *E. coli*?

56. Which of the following best supports a claim that an *E. coli* strain has a mutation in gene *E* that results in the production of a nonfunctional enzyme?

(A) Cells of this strain synthesize very little of the repressor protein and produce a large amount of tryptophan.

(B) RNA polymerase does not bind to the promoter of the operon in cells of this strain unless tryptophan is added to the nutrient medium.

(C) The operator sequence of the operon always has repressor proteins bound to it, independent of the amount of tryptophan in the nutrient medium.

(D) mRNA is continuously transcribed from the operon, but the amount of tryptophan produced from the cells of this strain remains low.

57. Attenuation is another mechanism by which tryptophan synthesis is regulated when tryptophan is abundant in the environment. During attenuation, ribosomes quickly translate the $5'$ end of the mRNA transcript, causing the transcript to fold into a loop that forces RNA polymerase to detach from the DNA.

Which of the following best explains why attenuation is a mechanism that is unique to prokaryotes?

(A) Prokaryotic genes do not contain introns.

(B) Only prokaryotes can translate an mRNA while the mRNA is being transcribed.

(C) Eukaryotes require more amino acids than prokaryotes do and therefore do not shut down production of tryptophan.

(D) Eukaryotes do not have groups of genes that are regulated together.

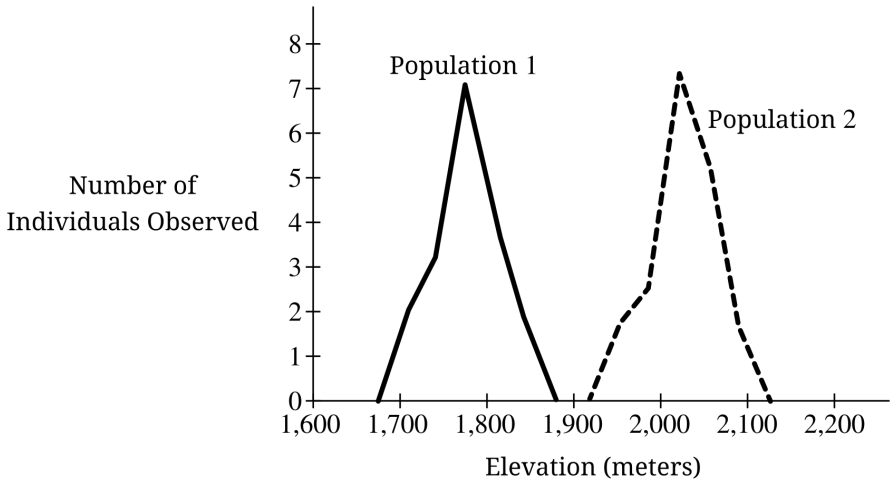


Figure 1. The distribution of individuals from two populations of the same species at different elevations

58. Researchers investigating two populations of the same species recorded the elevation at which individuals from each population were found (Figure 1).

    Which of the following claims is best supported by the data in Figure 1?

    (A) Gene flow is likely to occur between the two populations because they share the same habitat.

    (B) Gene flow is likely to occur between the two populations because they are the same species.

    (C) Gene flow is unlikely to occur between the two populations because they compete for food.

    (D) Gene flow is unlikely to occur between the two populations because they are geographically isolated.

59. In a population of coyotes, there is variation in the size of individual animals. Larger animals are able to bring down larger prey but also require more food to survive. In a particular area, the primary food source for many years had been rabbits, but disease led to a sudden crash in the rabbit population. However, the deer population in the area increased at about the same time. Over time, naturalists noted that the average size of coyotes in the population had increased.

    Which of the following is the best explanation for the increase in average coyote size following the crash in the rabbit population?

    (A) Deer run faster than rabbits, so coyotes needed to get larger to survive.

    (B) Smaller coyotes were at a hunting disadvantage, so fewer survived long enough to reproduce.

    (C) Since the coyotes needed to be larger to bring down the deer, they grew larger.

    (D) Since smaller coyotes struggled to obtain enough food, they produced larger offspring to improve their fitness.

60. Water is transported from the soil into the roots of a plant, and then up the stem to the leaves. A student determines that the water potential of root cells in the plant is -0.2 MPa. Which of the following claims is best supported by this measurement?

(A) The water potential of the soil will be higher than -0.2 MPa, whereas the water potential of the leaf will be lower than -0.2 MPa.

(B) The water potential of the soil will be lower than -0.2 MPa, whereas the water potential of the leaf will be higher than -0.2 MPa.

(C) The water potential of both the soil and the leaf will be higher than -0.2 MPa.

(D) The water potential of both the soil and the leaf will be equal to -0.2 MPa.

STOP
END OF SECTION I

BIOLOGY

Section II

Time—1 hour and 30 minutes

6 Questions

Directions: Questions 1 and 2 are long free-response questions that require about 25 minutes each to answer. Questions 3 through 6 are short free-response questions that require about 10 minutes each to answer.

Read each question carefully and completely. Answers must be written out in paragraph form. Outlines, bulleted lists, or diagrams alone are not acceptable.

You may plan your answers in this orange booklet, but no credit will be given for anything written in this booklet. **You will only earn credit for what you write in the separate Free Response booklet.**

1. Brook trout (*Salvelinus fontinalis*) is a species of fish that lives in freshwater streams. Brook trout are adapted to tolerate wide ranges in several environmental factors, including temperature and water flow. Brook trout are well adapted to water temperatures from near freezing (3°C) to about 18°C.

   A researcher investigated whether the phenotypes of the brook trout are affected by the rate of water flow. The researcher collected a random sample of 5,000 brook trout eggs and incubated the eggs until the embryos matured. Four weeks after hatching, the juvenile fish were randomly divided into two groups of equal numbers. One group was placed in tanks that simulated a freshwater stream with slowly moving water. The other group was placed in tanks that simulated a freshwater stream with rapidly moving water. After 16 weeks, the researcher collected the fish from the tanks and measured several phenotypic traits (Figure 1). Some of the researcher's measurements are shown in Table 1.

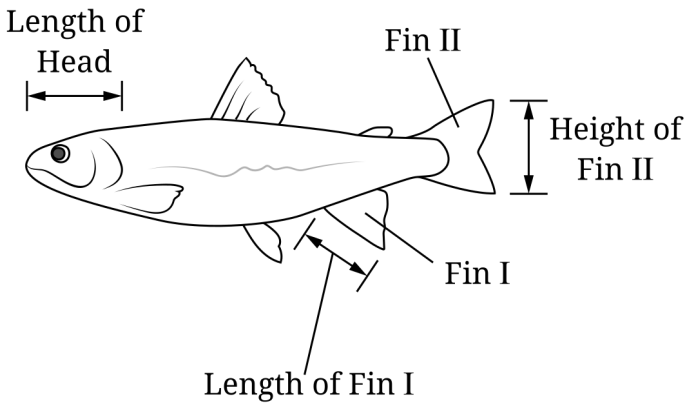


Figure 1. Phenotypic traits of the brook trout measured under different water flow rates

TABLE 1. MEASUREMENTS OF PHENOTYPIC TRAITS OF THE JUVENILE FISH

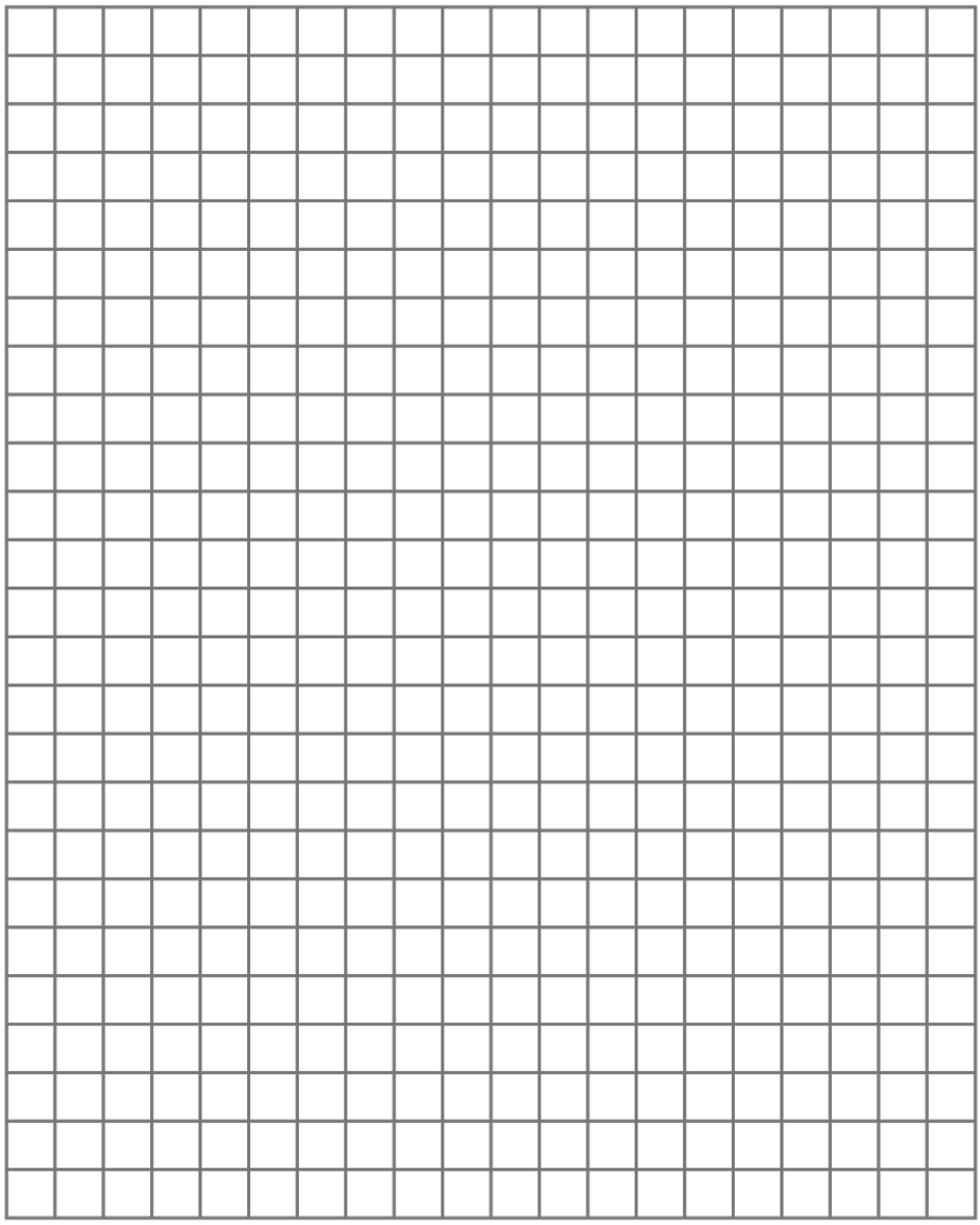
Phenotypic Trait	Juvenile Fish in Slowly Moving Water(mm; mean $\pm 2SE_{\bar{x}}$)	Juvenile Fish in Rapidly Moving Water(mm; mean $\pm 2SE_{\bar{x}}$)
Length of head	20.95 ± 0.20	20.96 ± 0.20
Length of fin I	15.83 ± 0.70	14.98 ± 0.78
Height of fin II	18.08 ± 0.64	19.62 ± 0.34

(a) Brook trout that live in bodies of freshwater with surface temperatures that reach freezing (0°C) can survive in the water under sheets of ice. **Describe** a property of water that allows the ice to float.

(b) Using the template in the space provided for your response, **construct** an appropriately labeled graph that represents the data shown in Table 1. Based on the data, **determine** whether there is a statistical difference in the length of fin I between the groups of fish in slowly moving water and rapidly moving water.

(c) Based on the data, **describe** the effect of the rate of water flow on head length and the height of fin II.

(d) In a follow-up experiment, the researcher collects fertilized eggs produced by fish raised in a tank with rapidly moving water and places the eggs into a tank with slowly moving water. The researcher measures the phenotypic traits when the offspring reach the same age as the fish measured in the original experiment. Assuming no natural selection occurred over the course of the experiments, **predict** the phenotypes of the offspring in comparison with the phenotypes of their parents. **Explain** how the results of the original experiment provide evidence of phenotypic plasticity.



2. Chemical Z blocks the cell cycle of T cells, cells that divide in order to respond to pathogens to prevent infectious diseases. Scientists activated T cells that were in cell cycle phase G_0 to make them reenter the cell cycle. The scientists treated the activated T cells with chemicals A, B, C, or Z. Chemicals A, B, and C are known to block cell cycle progression at certain phases of interphase (Figure 1).

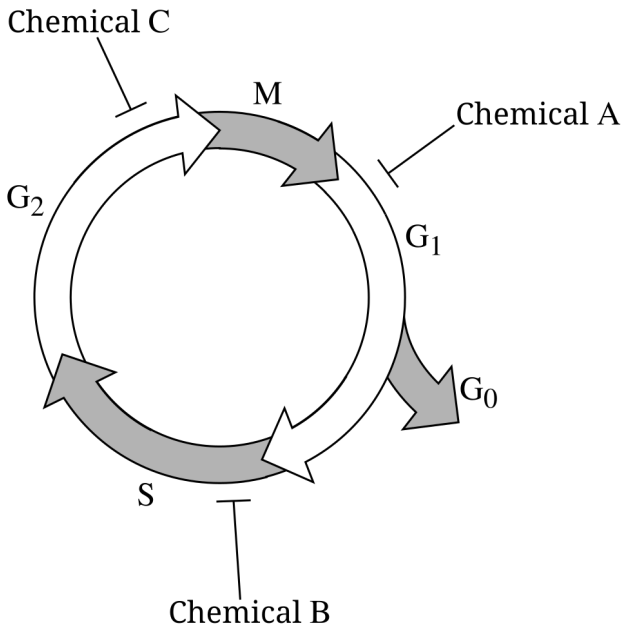


Figure 1. A model of the eukaryotic cell cycle showing the points (marked by bars, $\perp$) at which chemicals A, B, and C block progression through interphase

By measuring the amount of DNA in the T cells in each sample, the scientists were able to determine the percent of cells in each phase of interphase (Figure 2).

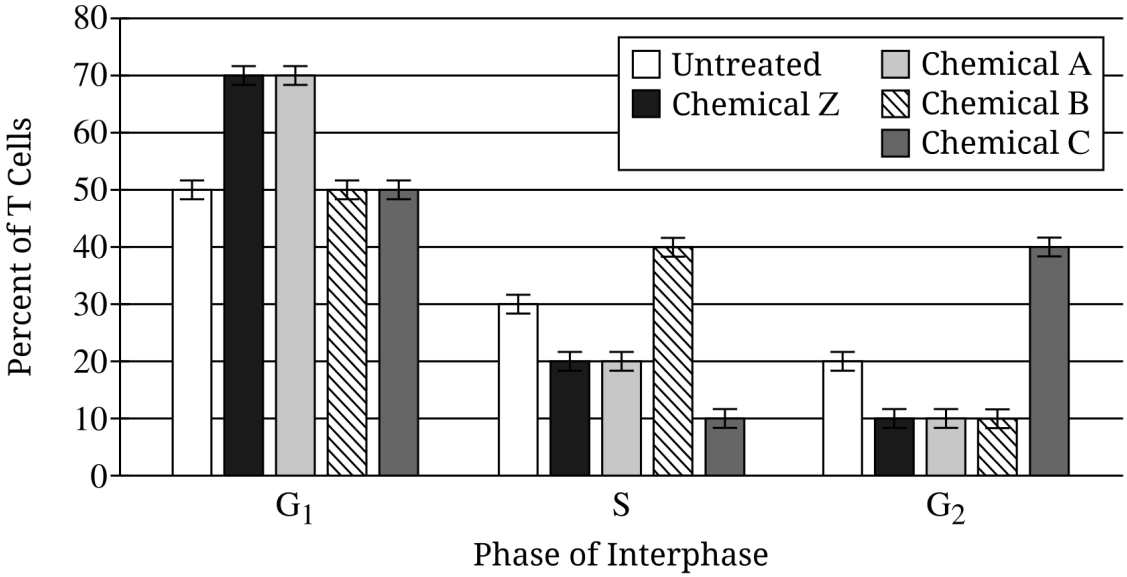


Figure 2. Percent of activated T cells in each phase of interphase in untreated cells and cells treated with chemicals A, B, C, and Z. Error bars represent $\pm 2SE_{\bar{x}}$.

(a) Chemical Z is a large, polar molecule. **Describe** the process by which chemical Z moves across the plasma membrane without an input of cellular energy. **Explain** why the amount of DNA in a cell indicates whether the cell is in G_1, S, or G_2.

(b) **Identify** a dependent variable in the experiment. **Justify** the use of untreated cells in the experiment. **Justify** the use of both chemicals B and C in the experiment.

(c) Based on the data in Figure 2, **identify** the phase in interphase at which chemical Z treatment blocks the cell cycle. **Describe** the trends in the data that support your identification. Based on the mean values shown in Figure 2, **calculate** the difference in the number of cells in G_1 between the sample treated with chemical Z and the untreated sample if a total of 600 cells are counted for each sample.

(d) Cancerous T cells result from genetic mutations and lack normal cell cycle controls. Scientists tested whether chemical Z blocks the cell cycle of cancerous T cells. **State** the null hypothesis for their experiment. Individuals with cancerous T cells also have normal T cells. Scientists find that chemical Z is an effective treatment against cancerous T cells. However, they claim that using chemical Z can have a negative effect on a patient's ability to fight off an infection. Provide reasoning to **justify** their claim.

3. *Saccharomyces cerevisiae*, also known as baker's yeast, is a single-celled eukaryote that can make ATP both aerobically and anaerobically. To obtain a readily accessible form of chemical energy for cellular activities, many strains of yeast convert glucose into ethyl alcohol and carbon dioxide.

   Researchers conducted an experiment to determine the effect of temperature on the rate of glucose conversion to ethyl alcohol and carbon dioxide. They added an equal mass of yeast cells to equal volumes of a glucose solution in a series of sealed test tubes. Groups of tubes were incubated at temperatures ranging from 28°C to 40°C, the optimal range for yeast growth. The researchers measured carbon dioxide production in the tubes.

   (a) **Describe** the importance of fermentation to eukaryotic cells such as yeast.

   (b) **Identify** the independent variable in the experiment.

   (c) **Predict** the relative rates of glucose breakdown at 4°C AND at 56°C compared with the rate at 37°C.

   (d) **Provide reasoning** to support your prediction in part (c).

4. Several studies indicate that a particular forest biome in the Northern Hemisphere will become significantly warmer over the next century. Researchers studying a population of trees in the forest hypothesize that warming will negatively impact the evolutionary fitness of many of the trees. The researchers also hypothesize that warming will shift the range of the population further north to cooler habitats.

   (a) **Describe** the way the evolutionary fitness of an individual tree is measured.

   (b) The range shift of the tree population may result in the fragmentation of the population into several smaller, isolated populations. **Explain** how the fragmentation may result in speciation.

   (c) Recent research suggests that the range in which trees can grow is due in large part to their symbiotic relationships with soil microbes that are sensitive to temperature. **Predict** the effects on a population of microbes if the average temperature in an area increases above the temperature at which most of the microbes are able to successfully reproduce.

   (d) **Justify** your prediction in part (c) using evidence from biological principles.

5. Tuberculosis is an infectious disease caused by the bacterium *Mycobacterium tuberculosis*. Many of the mycobacteria are resistant to the drugs typically used for treatment. As a part of the process of developing new drugs, scientists identified two mycobacterial proteins, L10 and L12, that are part of the ribosome and that must bind to each other to allow ribosomal function. The scientists aimed to identify a compound that blocks the interaction between the two proteins, thereby preventing the survival and reproduction of *Mycobacterium tuberculosi*s.

   As a first step, the scientists performed an *in vitro* (in a test tube) experiment to test the ability of different compounds to block the binding between the L10 and L12 proteins. The scientists measured the amount of binding in the presence of increasing concentrations of three compounds: I, II, and III. Results are shown in Figure 1.

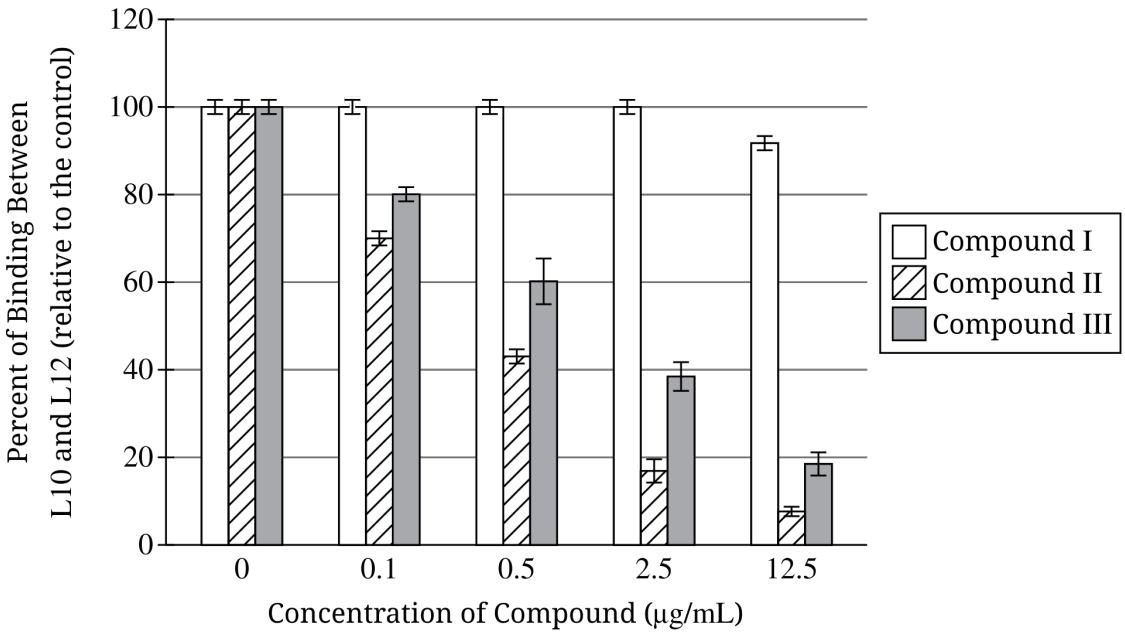


Figure 1. Average percent of binding between L10 and L12 in the presence of increasing concentrations of compounds I, II, and III, relative to the amount of binding in the absence of any compound (0 μg/mL, the control). Error bars represent $\pm 2SE_{\bar{x}}$.

In a second experiment, the scientists performed an *in vitro* experiment to test the amount of inhibition of translation in the presence of compounds I, II, and III. They added the three compounds to test tubes containing molecules needed for translation, including a specific mRNA, and ribosomes from one of three organisms: *Mycobacterium tuberculosis*, the bacterium *Escherichia coli*, or the eukaryote *Oryctolagus cuniculus* (rabbit). They measured the concentration of each compound required to reduce translation by 50% (Table 1).

TABLE 1. CONCENTRATION (μg/mL) REQUIRED TO REDUCE TRANSLATION BY 50% FOR COMPOUNDS I, II, AND III

Compound	*M. tuberculosis* ribosomes	*E. coli* ribosomes	*O. cuniculus* ribosomes
I	162.7	143.1	30.2
II	16.9	117.7	118.1
III	25.9	34.2	60.1

(a) Based on the data in Figure 1, **identify** the concentration in μg/mL of compound III that reduces the amount of binding between L10 and L12 to 60% of the control.

(b) Based on the data in Figure 1, **describe** the specific decrease in L10 and L12 binding in relation to each specific increase in compound III concentration from 0.1 μg/mL to 12.5 μg/mL.

(c) Based on the data in Table 1, the scientists predict that compound II is the best of the three compounds to treat tuberculosis infections. **Evaluate** the data to support or refute their prediction.

(d) One of the compounds becomes routinely used as a drug to treat tuberculosis. Based on the experiments, **explain** how a mutation in *Mycobacterium tuberculosis* would most likely cause resistance to the drug.

6. A population of invasive feral hogs in a wilderness area is approaching carrying capacity. The feral hogs in each age-group of this population are counted once a year. Figure 1 shows the age pyramid of this population in one particular year. Feral hogs reproduce between 1 and 5 years of age. Mothers care for their young until the young are three months old.

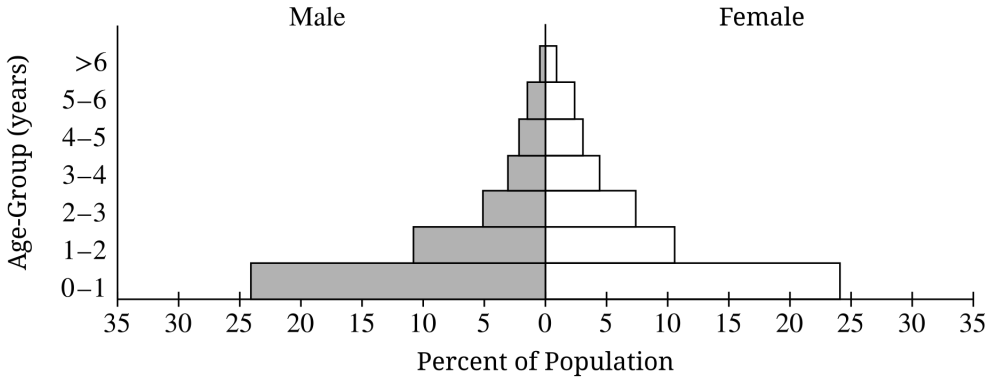


Figure 1. Age pyramid of a feral hog population in a wilderness area

Ten years later a researcher again counts the number of individual feral hogs in each age-group in the same population and produces the age pyramid shown in Figure 2.

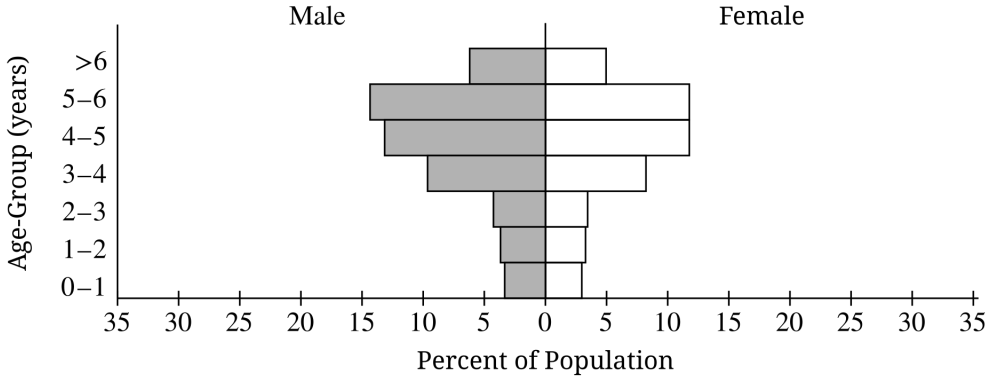
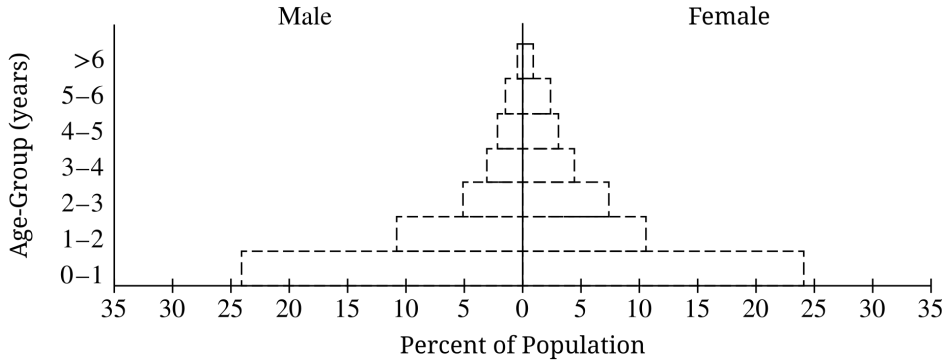


Figure 2. Age pyramid of the feral hog population ten years later

(a) **Describe** a characteristic of an ecosystem that allows an introduced species to become an invasive species.

(b) A population age structure, as shown in Figure 1, is the result of multiple factors affecting birth and death rates of animals of various ages. **Explain** how ecological factors lead to the difference between the numbers of hogs in the 0-1 year age-group and the number of hogs in the 1-2 year age-group shown in Figure 1.

(c) An outbreak of a viral infection causes approximately half of the male hogs in each age-group to die. Using the template in the space provided for your response, **draw** new bars for each age-group to represent the approximate distribution of the entire hog population immediately after the death of the males. The dashed lines of the template represent the original age pyramid (Figure 1) before the viral outbreak.



(d) Using biological principles, **explain** what is likely to have caused the shift from the age structure in Figure 1 to the age structure shown in Figure 2.

STOP
END OF EXAM