

The following information applies to all parts.

1. Molecules known as dinucleoside polyphosphates, a type of nucleotide, are signaling molecules that accumulate in plant cells during dry or stressful conditions.

Part A

Describe the three structural components of a nucleotide.

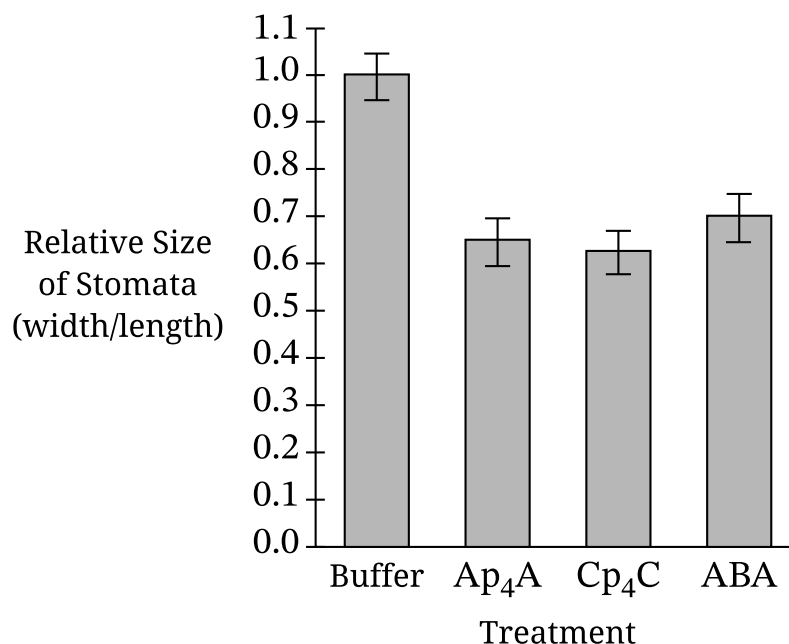
The following information applies to parts B, C, and D.

Stomata are pores on the surface of leaves that open when exposed to light and regulate the flow of carbon dioxide, oxygen, and water vapor in and out of a plant. In response to dry environmental conditions, many plants close their stomata, which reduces water loss.

Scientists hypothesized that the dinucleoside polyphosphates Ap_4A and Cp_4C bind to DORN1 receptors on the plasma membrane of plant cells and initiate signaling cascades that cause stomata to close. The scientists exposed plants to light to open the stomata and then placed samples of the leaves in buffer alone or in buffer containing one of three different compounds: Ap_4A , Cp_4C , or abscisic acid (ABA), a molecule that causes stomata to close.

The scientists measured the size of the stomata in each sample and calculated their sizes relative to the size of the stomata in the sample kept in buffer alone, as shown in Figure 1.

Figure 1. Effect of Ap_4A , Cp_4C , and ABA on Relative Stomatal Size
(Error Bars Represent $\pm \text{SE}_{\bar{x}}$)



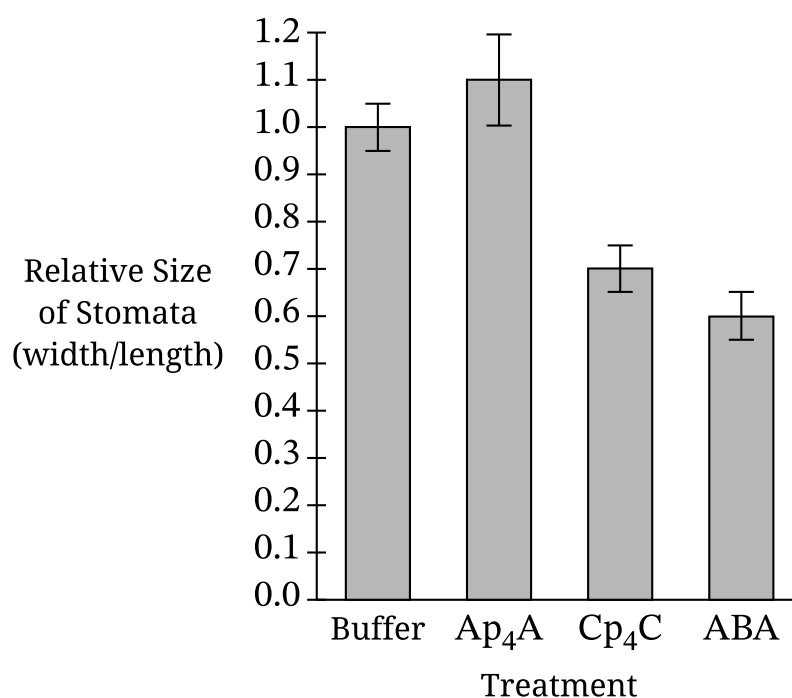
Part B

- i. **Identify** the dependent variable in the scientists' first experiment.
- ii. Based on Figure 1, **describe** the relative size of the stomata in the Cp_4C treatment group as compared with the size of the stomata in the group treated with buffer alone.
- iii. **Justify** the use of buffer alone as a control in the scientists' experiments.

Part C

In a second experiment, the scientists used plants that were identical to those in the first experiment except that the gene encoding the DORN1 receptor was mutated. The scientists repeated the procedure of the first experiment. Their results are shown in Figure 2.

Figure 2. Effect of Ap_4A , Cp_4C , and ABA on Relative Stomatal Size in DORN1 Mutants (Error Bars Represent $\pm \text{SE}_{\bar{x}}$)



- i. **Justify** the scientists' treating one sample of leaves with ABA in the experiments.
- ii. Based on Figure 2, **describe** the difference between the effects of Ap_4A and Cp_4C treatments on the size of stomata in plants with mutated DORN1 receptors.
- iii. Activation of DORN1 receptors induces plant cells to produce certain molecules that cause the stomata to close. Based on the data in Figures 1 and 2 for cells treated with Ap_4A , **predict** the relative production of the molecules by DORN1-mutated cells in comparison to the production by nonmutated cells.

Part D

The DORN1 receptor transmits signals that result in an increase in the transcription of genes involved in plant defenses. The scientists then developed DORN1-mutant plants in which the DORN1 receptor lacked most of its intracellular domain.

- i. In cells homozygous for this mutation, **predict** the effect of Ap_4A treatment on transcription of the genes involved in plant defenses relative to the effect of Ap_4A on nonmutated cells.
- ii. **Justify** your prediction.

AP Biology: 2023

3. Sand lances of the genus *Ammodytes* are small fish that function as keystone organisms in several coastal ecosystems. These sand lances are prey fish that support organisms at higher trophic levels. Scientists performed experiments to examine how sand lance populations are likely to be affected by the rising temperatures and CO_2 levels associated with climate change.

Sand lance embryos typically develop and mature into adult fish at low temperatures (approximately 5°C) and stable, low CO_2 levels (approximately $400\ \mu\text{atm}$). Over the course of two years, the scientists measured the survival rate of sand lance embryos allowed to develop and mature in a laboratory at three different temperatures, 5°C , 7°C , and 10°C , with the level of CO_2 maintained at $400\ \mu\text{atm}$, $1,000\ \mu\text{atm}$, and $2,100\ \mu\text{atm}$ for each temperature.

- (a) **Describe** the effect of increased biodiversity on the resilience of an ecosystem in a changing environment.
- (b) **Justify** the scientists' selecting 5°C as the lowest temperature and $400\ \mu\text{atm}$ as the lowest CO_2 level in their study of sand lance embryo survival.
- (c) **State** a null hypothesis for the experiment.
- (d) The scientists claim that a reduction in the population size of the *Ammodytes* sand lances will affect the stability of the entire coastal ecosystem. Provide reasoning to **support** the scientists' claim.

Write your responses to this question only on the designated pages in the separate Free Response booklet.

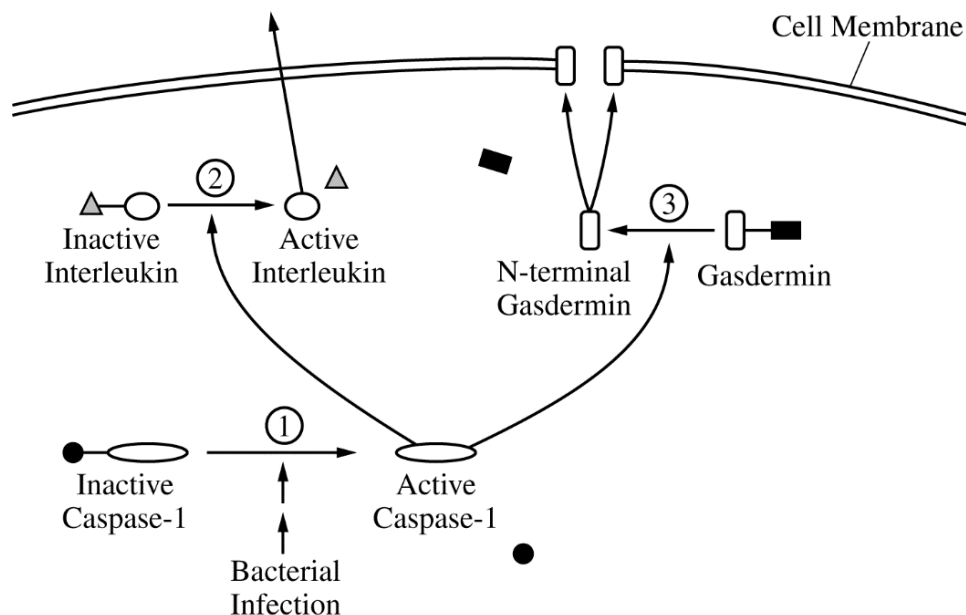


Figure 1. Cellular response to infection by pathogenic bacteria

2. Some pathogenic bacteria enter cells, replicate, and spread to other cells, causing illness in the host organism. Host cells respond to these infections in a number of ways, one of which involves activating particular enzymatic pathways (Figure 1). Cells normally produce a steady supply of inactive caspase-1 protein. In response to intracellular pathogens, the inactive caspase-1 is cleaved and forms an active caspase-1 (step 1). Active caspase-1 can cleave two other proteins. When caspase-1 cleaves an inactive interleukin (step 2), the active portion of the interleukin is released from the cell. An interleukin is a signaling molecule that can activate the immune response. When caspase-1 cleaves gasdermin (step 3), the N-terminal portions of several gasdermin proteins associate in the cell membrane to form large, nonspecific pores.

Researchers created the model in Figure 1 using data from cell fractionation studies. In the experiments, various parts of the cell were separated into fractions by mechanical and chemical methods. Specific proteins known to be located in different parts of the cell were used as markers to determine the location of other proteins. The table below shows the presence of known proteins in specific cellular fractions.

CELL FRACTIONS CONTAINING DIFFERENT CELLULAR PROTEINS

	Aconitase (Krebs cycle protein)	DNA polymerase	GAPDH (glycolytic protein)	Sodium- potassium pump	NF- κ B (Immune response protein)
Whole cell sample	+	+	+	+	+
Fraction 1	+				
Fraction 2		+			+
Fraction 3			+		+
Fraction 4				+	
+ = presence of protein					

- (a) **Describe** the effect of inhibiting step 3 on the formation of pores AND on the release of interleukin from the cell.
- (b) **Make a claim** about how cleaving inactive caspase-1 results in activation of caspase-1. A student claims that preinfection production of inactive precursors shortens the response time of a cell to a bacterial infection. **Provide ONE reason** to support the student's claim.
- (c) A student claims that the NF- κ B protein is located in the cytoplasm until the protein is needed for transcription. **Justify** the student's claim with evidence. **Identify TWO** fractions where N-terminal gasdermin would be found in cells infected with pathogenic bacteria.
- (d) **Describe** the most likely effect of gasdermin pore formation on water balance in the cell in a hypotonic environment.
- (e) **Explain** how gasdermin pore formation AND interleukin release contribute to an organism's defense against a bacterial pathogen.

BIOLOGY**Section II****8 Questions****Total Time—90 minutes****Reading Period—10 minutes****Writing Period—80 minutes**

Directions: Questions 1 and 2 are long free-response questions that require about 22 minutes each to answer and are worth 10 points each. Questions 3–8 are short free-response questions that require about 6 minutes each to answer. Questions 3–5 are worth 4 points each and questions 6–8 are worth 3 points each.

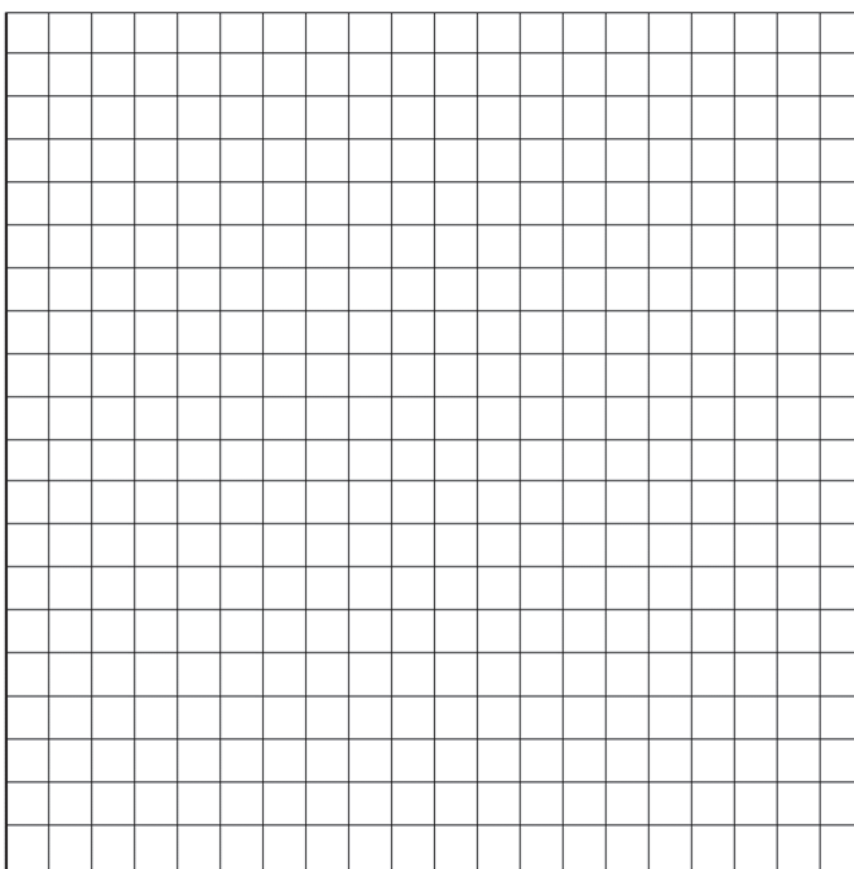
Read each question carefully and completely. You are advised to spend the 10-minute reading period planning your answers. You may begin writing your responses before the reading period is over. Write your response in the space provided for each question. Only material written in the space provided will be scored. Answers must be written out in paragraph form. Outlines, bulleted lists, or diagrams alone are not acceptable.

TABLE 1. EFFECT OF 0.1 mM CAFFEINE ON MEMORY IN BEES

Treatment	Memory (average probability of revisiting a nectar source $\pm 2SE_{\bar{X}}$)	
	10 Minutes	24 Hours
Control	0.72 $\pm$ 0.09	0.41 $\pm$ 0.07
Caffeine	0.83 $\pm$ 0.07	0.78 $\pm$ 0.08

1. In flowering plants, pollination is a process that leads to the fertilization of an egg and the production of seeds. Some flowers attract pollinators, such as bees, using visual and chemical cues. When a bee visits a flower, in addition to transferring pollen, the bee can take nectar from the flower and use it to make honey for the colony. Nectar contains sugar, but certain plants also produce caffeine in the nectar. Caffeine is a bitter-tasting compound that can be toxic to insects at high concentrations. To investigate the role of caffeine in nectar, a group of researchers studied the effect of 0.1 mM caffeine on bee behavior. The results of an experiment to test the effect of caffeine on bees' memory of a nectar source are shown in Table 1.

- (a) On the axes provided, **construct** an appropriately labeled graph to illustrate the effect of caffeine on the probability of bees revisiting a nectar source (memory).
- (b) Based on the results, **describe** the effect of caffeine on each of the following:
- Short-term (10 minute) memory of a nectar source
 - Long-term (24 hour) memory of a nectar source
- (c) **Design an experiment** using artificial flowers to investigate potential negative effects of increasing caffeine concentrations in nectar on the number of floral visits by bees. **Identify** the null hypothesis, an appropriate control treatment, and the predicted results that could be used to reject the null hypothesis.
- (d) Researchers found that nectar with caffeine tends to have a lower sugar content than nectar without caffeine. Plants use less energy to produce the caffeine in nectar than they do to produce the sugar in nectar. **Propose ONE benefit** to plants that produce nectar with caffeine and a lower sugar content. **Propose ONE cost** to bees that visit the flowers of plants that produce nectar with caffeine and a lower sugar content.



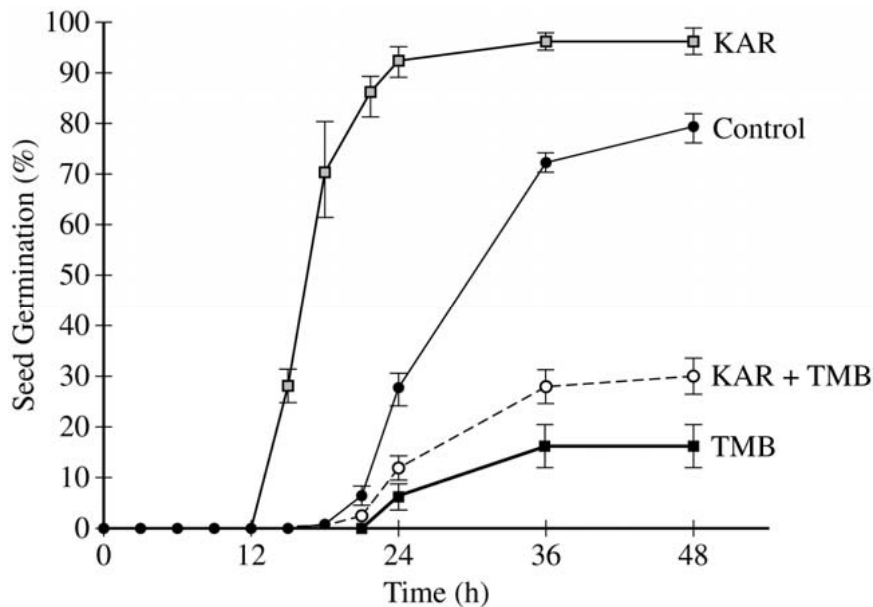


Figure 1. The effect of karrikins (KAR) and trimethylbutenolides (TMB) on seed germination in *Lactuca* plants. Error bars represent $\pm 2SE_{\bar{x}}$.

2. Fires frequently occur in some ecosystems and can destroy all above-ground vegetation. Many species of plants in these ecosystems respond to compounds in smoke that regulate seed germination after a major fire. Karrikins (KAR) and trimethylbutenolides (TMB) are water-soluble compounds found in smoke that are deposited in the soil as a result of a fire. KAR and TMB bind to receptor proteins in a seed. In a study on the effects of smoke on seeds, researchers recorded the timing and percent of seed germination in the presence of various combinations of KAR and TMB. The results are shown in Figure 1.

In a second investigation into the effect of available water on seed germination after a fire, researchers treated seeds with KAR or TMB. The treated seeds were then divided into two treatment groups. One group received a water rinse and the other group received no water rinse. The seeds were then incubated along with a group of control seeds that were not treated. The results are shown in the table.

EFFECT OF CHEMICAL TREATMENT AND WATER RINSE ON GERMINATION

Treatment Group	Chemical Treatment		Water	Germination Result
	KAR	TMB		
1 (control)	–	–	–	Control result
2	+	–	–	Different from control
3	–	+	–	Different from control
4 (control)	–	–	+	Control result
5	+	–	+	Different from control
6	–	+	+	Same as control

(a) The researchers made the following claims about the effect of KAR and the effect of TMB on seed germination relative to the control treatment.

- KAR alone affects the timing of seed germination.
- KAR alone affects the percentage of seeds that germinate.
- TMB alone affects the timing of seed germination.
- TMB alone affects the percentage of seeds that germinate.

Provide support using data from Figure 1 for each of the researchers' claims.

- (b) **Make a claim** about the effect of rinsing on the binding of KAR to the receptor in the seed and about the effect of rinsing on the binding of TMB to the receptor in the seed. Identify the appropriate treatment groups and results from the table that, when compared with the controls, **provide support** for each claim.
- (c) There is intense competition by plants to successfully colonize areas that have been recently cleared by a fire. **Describe** ONE advantage of KAR regulation and ONE advantage of TMB regulation to plants that live in an ecosystem with regular fires.

BIOLOGY**Section II****8 Questions****Planning Time—10 minutes****Writing Time—80 minutes**

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Read each question carefully and completely. Write your response in the space provided for each question. Only material written in the space provided will be scored. Answers must be written out in paragraph form. Outlines, bulleted lists, or diagrams alone are not acceptable.

1. Many species have circadian rhythms that exhibit an approximately 24-hour cycle. Circadian rhythms are controlled by both genetics and environmental conditions, including light.

Researchers investigated the effect of light on mouse behavior by using a running wheel with a motion sensor to record activity on actograms, as shown in Figure 1.

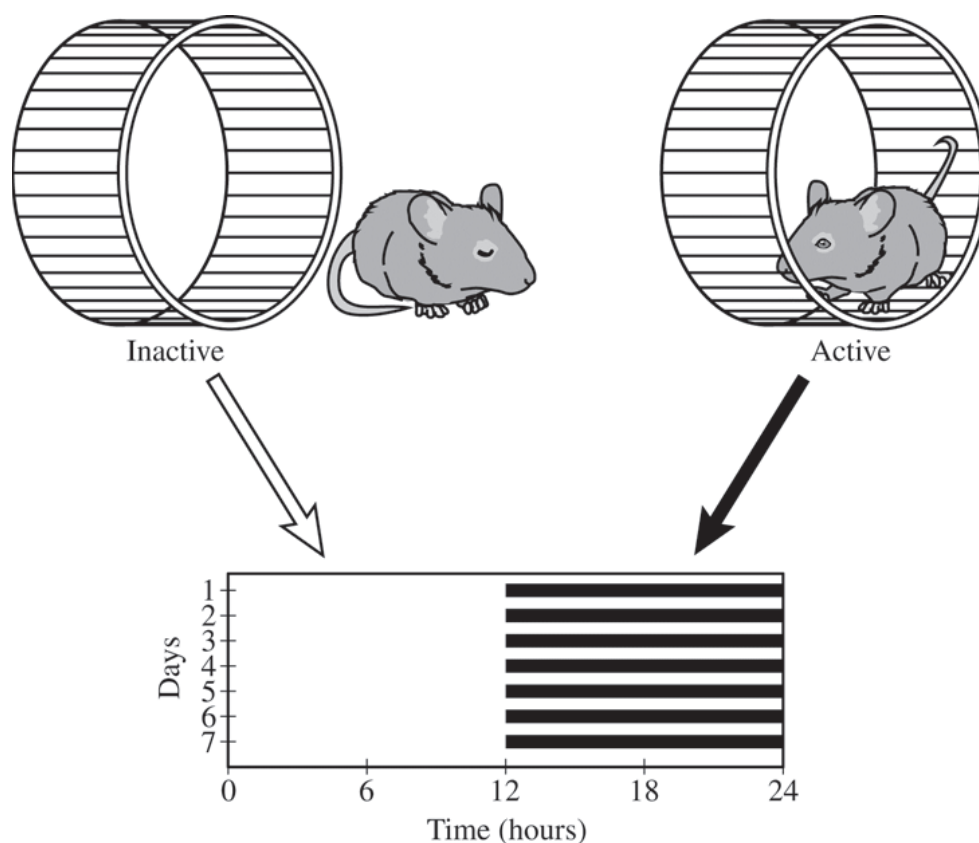


Figure 1. Strategy for recording mouse activity data. When a mouse is active on the running wheel, the activity is recorded as a dark horizontal line on an actogram. When the mouse is inactive, no dark line is recorded.

For the investigation, adult male mice were individually housed in cages in a soundproof room at 25°C. Each mouse was provided with adequate food, water, bedding material, and a running wheel. The mice were exposed to daily periods of 12 hours of light (L) and 12 hours of dark (D) (L12:D12) for 14 days, and their activity was continuously monitored. The activity data are shown in Figure 2.

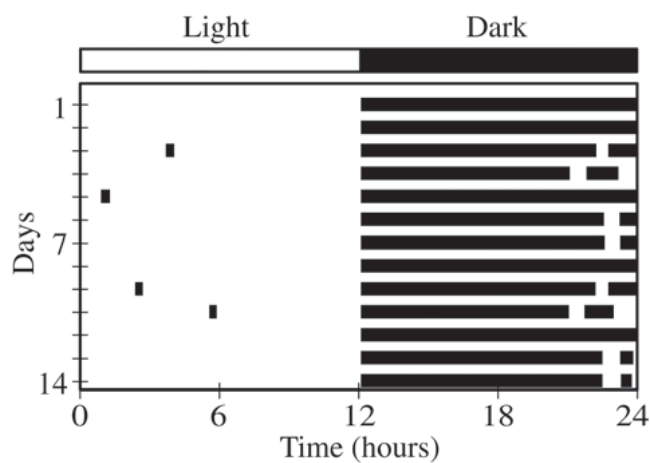


Figure 2. Actogram of mouse activity under L12:D12 conditions. Each row represents a 24-hour period, and the dark horizontal lines represent activity on the running wheel.

After 14 days in L12:D12, the mice were placed in continuous darkness (DD), and their activity on the running wheel was recorded as before. The activity data under DD conditions are shown in Figure 3.

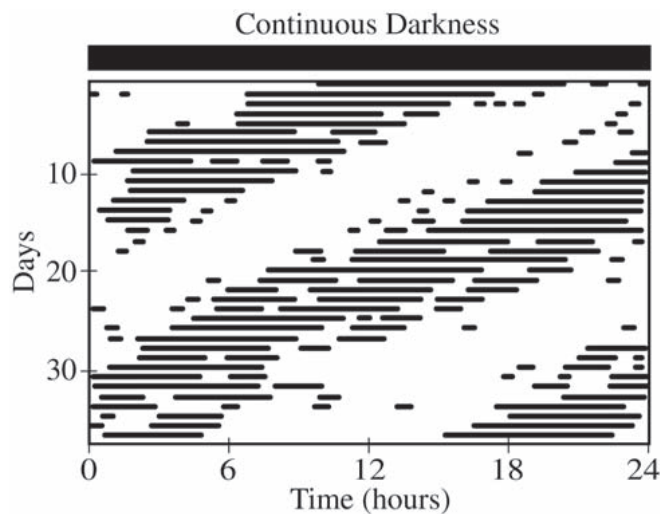
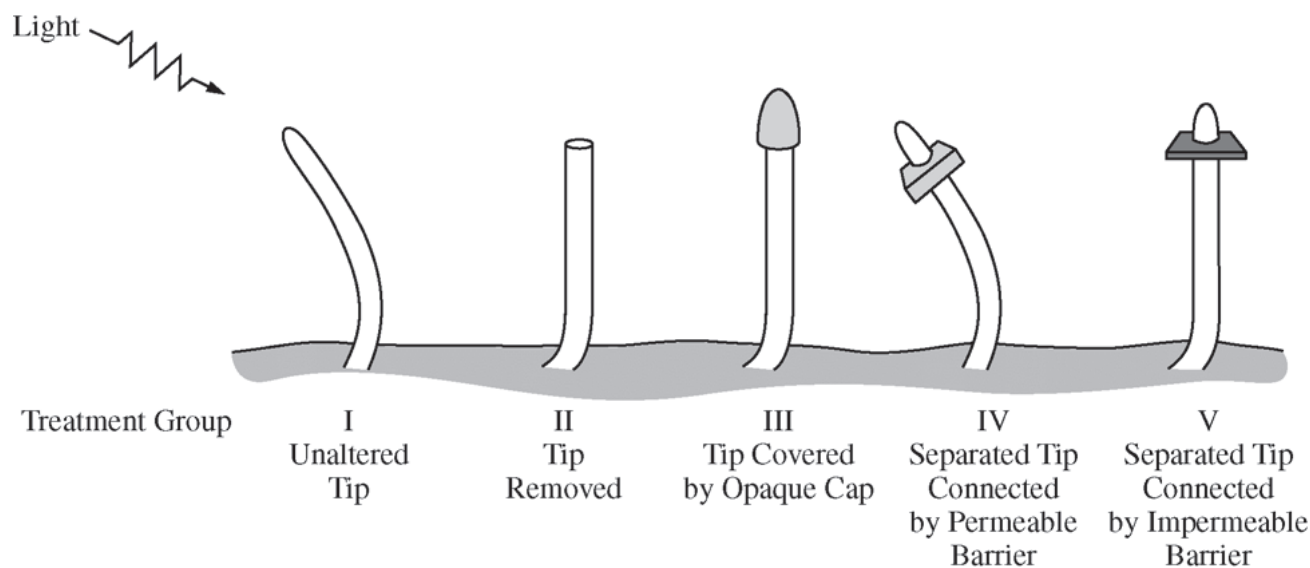


Figure 3. Actogram of mouse activity under DD conditions. Each row represents a 24-hour period, and the dark horizontal lines represent activity on the running wheel.

- (a) The nervous system plays a role in coordinating the observed activity pattern of the mice in response to light-dark stimuli. **Describe** ONE role of each of the following anatomical structures in responding to light-dark stimuli.
- A photoreceptor in the retina of the eye
 - The brain
 - A motor neuron
- (b) Based on an analysis of the data in Figure 2, **describe** the activity pattern of the mice during the light and dark periods of the L12:D12 cycle.
- (c) The researchers claim that the genetically controlled circadian rhythm in the mice does not follow a 24-hour cycle. **Describe** ONE difference between the daily pattern of activity under L12:D12 conditions (Figure 2) and under DD conditions (Figure 3), and use the data to **support** the researchers' claim.
- (d) To investigate the claim that exposure to light overrides the genetically controlled circadian rhythm, the researchers plan to repeat the experiment with mutant mice lacking a gene that controls the circadian rhythm. **Predict** the observed activity pattern of the mutant mice under L12:D12 conditions and under DD conditions that would support the claim that light overrides the genetically controlled circadian rhythm.
- (e) In nature, mice are potential prey for some predatory birds that hunt during the day. **Describe** TWO features of a model that represents how the predator-prey relationship between the birds and the mice may have resulted in the evolution of the observed activity pattern of the mice.

4. Both mitosis and meiosis are forms of cell division that produce daughter cells containing genetic information from the parent cell.
- (a) **Describe** TWO events that are common to both mitosis and meiosis that ensure the resulting daughter cells inherit the appropriate number of chromosomes.
- (b) The genetic composition of daughter cells produced by mitosis differs from that of the daughter cells produced by meiosis. **Describe** TWO features of the cell division processes that lead to these differences.
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5. Phototropism in plants is a response in which a plant shoot grows toward a light source. The results of five different experimental treatments from classic investigations of phototropism are shown above.
- (a) **Give support** for the claim that the cells located in the tip of the plant shoot detect the light by comparing the results from treatment group I with the results from treatment group II and treatment group III.
- (b) In treatment groups IV and V, the tips of the plants are removed and placed back onto the shoot on either a permeable or impermeable barrier. Using the results from treatment groups IV and V, **describe** TWO additional characteristics of the phototropism response.
7. Smell perception in mammals involves the interactions of airborne odorant molecules from the environment with receptor proteins on the olfactory neurons in the nasal cavity. The binding of odorant molecules to the receptor proteins triggers action potentials in the olfactory neurons and results in transmission of information to the brain. Mammalian genomes typically have approximately 1,000 functional odorant-receptor genes, each encoding a unique odorant receptor.
- (a) **Describe** how the signal is transmitted across the synapse from an activated olfactory sensory neuron to the interneuron that transmits the information to the brain.
- (b) **Explain** how the expression of a limited number of odorant receptor genes can lead to the perception of thousands of odors. Use the evidence about the number of odorant receptor genes to **support** your answer.
-

8. An individual has lost the ability to activate B cells and mount a humoral immune response.
- (a) **Propose** ONE direct consequence of the loss of B-cell activity on the individual's humoral immune response to the initial exposure to a bacterial pathogen.
 - (b) **Propose** ONE direct consequence of the loss of B-cell activity on the speed of the individual's humoral immune response to a second exposure to the bacterial pathogen.
 - (c) **Describe** ONE characteristic of the individual's immune response to the bacterial pathogen that is not affected by the loss of B cells.

STOP

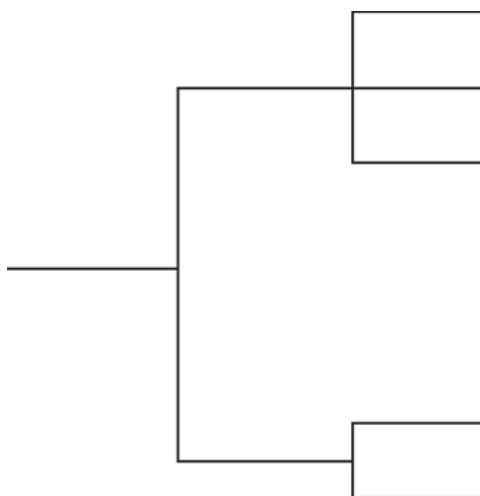
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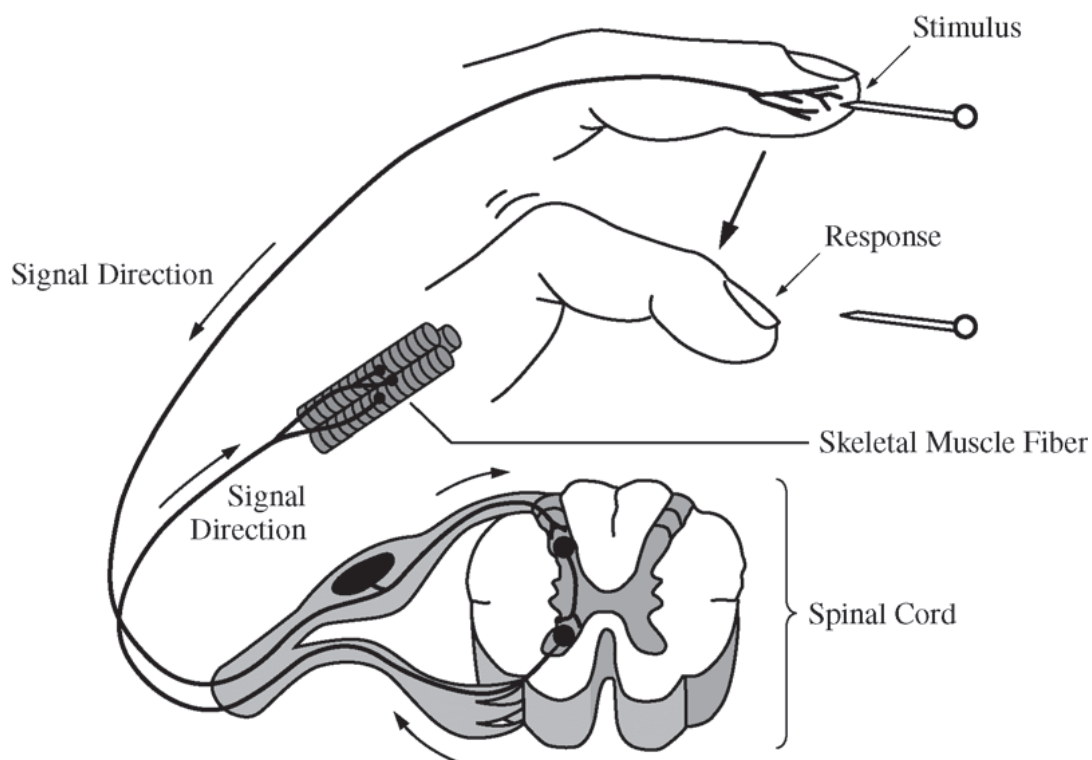
2. Mammalian milk contains antibodies that are produced by the mother's immune system and passed to offspring during feeding. Mammalian milk also contains a sugar (lactose) and may contain proteins (protein A, protein B, and casein), as indicated in the table.

MILK COMPONENTS IN DIFFERENT MAMMALS

Character	Cat	Cow	Horse	Human	Pig
Lactose	+	+	+	+	+
Protein A	+	+	+	+	+
Protein B	–	+	+	–	+
Casein	–	+	+	–	+
+ indicates the presence of the character, and – indicates the absence of the character					

- (a) Using the data in the table, **construct** a cladogram on the template provided to indicate the most likely evolutionary relationships among the different mammals. **Indicate** on the cladogram where each of the characters most likely arose in the evolutionary process, and **justify** the placement of the characters on the cladogram.
- (b) **Describe** FOUR steps in the activation of the mother's specific immune response following exposure to a bacterial pathogen. **Predict** how the mother's immune response would differ upon a second exposure to the same bacterial pathogen a year later.
- (c) **Predict** the most likely consequence for a nursing infant who is exposed to an intestinal bacterial pathogen (e.g., *Salmonella*) to which the mother was exposed three months earlier. **Justify** your prediction.

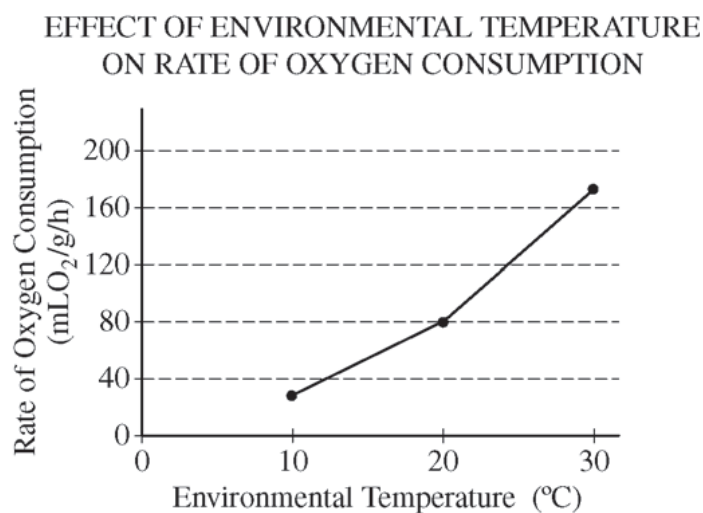




Cross Section of Spinal Cord and Skeletal Muscle Fiber

6. Information processing involves complex neural pathways that require a certain amount of time between recognition of a stimulus and the resulting response. For some types of stimuli, a reflex arc replaces the typical stimulus-response pathway. A representation of a reflex arc is shown in the figure above.

Based on the figure, **describe** TWO ways that the reflex arc differs from typical stimulus-response transmission pathways. **Provide** reasoning to support the claim that reflex arcs help organisms avoid serious injury.



7. (a) Based on the graph, **describe** a specific method of thermoregulation used by the species of animal. **Provide** support for your answer using the data.
- (b) On the labeled axis provided below, **draw** a line to indicate the most likely relationship between body temperature and environmental temperature in the species.

