2021

AP CollegeBoard

AP® Biology

Free-Response Questions

AP® BIOLOGY EQUATIONS AND FORMULAS

Statistical Analysis and Probability

Mean

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

Standard Deviation

$$s = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}}$$

Standard Error of the Mean

$$SE_{\bar{x}} = \frac{s}{\sqrt{n}}$$

Chi-Square

$$\chi^2 = \sum \frac{(o-e)^2}{e}$$

Chi-Square Table

p value	Degrees of Freedom							
	1	2	3	4	5	6	7	8
0.05	3.84	5.99	7.81	9.49	11.07	12.59	14.07	15.51
0.01	6.63	9.21	11.34	13.28	15.09	16.81	18.48	20.09

Laws of Probability

If A and B are mutually exclusive, then:

$$P(\text{A or B}) = P(\text{A}) + P(\text{B})$$

If A and B are independent, then:

$$P(\text{A and B}) = P(\text{A}) \times P(\text{B})$$

Hardy-Weinberg Equations

$p^2 + 2pq + q^2 = 1$

$p + q = 1$

p = frequency of allele 1 in a population

q = frequency of allele 2 in a population

$\bar{x}$ = sample mean

n = sample size

s = sample standard deviation (i.e., the sample-based estimate of the standard deviation of the population)

o = observed results

e = expected results

Σ = sum of all

Degrees of freedom are equal to the number of distinct possible outcomes minus one.

Metric Prefixes

Factor	Prefix	Symbol
10^9	giga	G
10^6	mega	M
10^3	kilo	k
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

Mode = value that occurs most frequently in a data set

Median = middle value that separates the greater and lesser halves of a data set

Mean = sum of all data points divided by number of data points

Range = value obtained by subtracting the smallest observation (sample minimum) from the greatest (sample maximum)

Rate and Growth

Rate

$$\frac{dY}{dt}$$

dY = amount of change

dt = change in time

Population Growth

$$\frac{dN}{dt} = B - D$$

B = birth rate

D = death rate

Exponential Growth

$$\frac{dN}{dt} = r_{\max} N$$

N = population size

K = carrying capacity

$r_{\max}$ = maximum per capita growth rate of population

Logistic Growth

$$\frac{dN}{dt} = r_{\max} N \left(\frac{K - N}{K} \right)$$

Simpson's Diversity Index

$$\text{Diversity Index} = 1 - \sum \left(\frac{n}{N} \right)^2$$

n = total number of organisms of a particular species

N = total number of organisms of all species

Water Potential (Ψ)

$$\Psi = \Psi_P + \Psi_S$$

Ψ_P = pressure potential

Ψ_S = solute potential

The water potential will be equal to the solute potential of a solution in an open container because the pressure potential of the solution in an open container is zero.

The Solute Potential of a Solution

$$\Psi_S = -iCRT$$

i = ionization constant (1.0 for sucrose because sucrose does not ionize in water)

C = molar concentration

R = pressure constant (R = 0.0831 liter bars/mole K)

T = temperature in Kelvin (ºC + 273)

pH = $-\log[H^+]$

Surface Area and Volume

Surface Area of a Sphere

$$SA = 4\pi r^2$$

Surface Area of a Rectangular Solid

$$SA = 2lh + 2lw + 2wh$$

Surface Area of a Cylinder

$$SA = 2\pi rh + 2\pi r^2$$

Surface Area of a Cube

$$SA = 6s^2$$

Volume of a Sphere

$$V = \frac{4}{3}\pi r^3$$

Volume of a Rectangular Solid

$$V = lwh$$

Volume of a Cylinder

$$V = \pi r^2 h$$

Volume of a Cube

$$V = s^3$$

r = radius

l = length

h = height

w = width

s = length of one side of a cube

SA = surface area

V = volume

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.**

Question 1 is on the following page.

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1. Polycystic kidney disease (PKD) is an inherited disease that causes water loss from the body and affects cell division in the kidneys. Because water movement across cell membranes is related to ion movement, scientists investigated the role of the Na^+/K^+ATPase (also known as the sodium/potassium pump) in this disease. Ouabain, a steroid hormone, binds to the Na^+/K^+ATPase in plasma membranes. Individuals with PKD have a genetic mutation that results in an increased binding of ouabain to the Na^+/K^+ATPase. The scientists treated normal human kidney (NHK) cells and PKD cells with increasing concentrations of ouabain and measured the number of cells (Figure 1) and the activity of the Na^+ / K^+ATPase (Figure 2) after a period of time. The scientists hypothesized that a signal transduction pathway that includes the protein kinases MEK and ERK (Figure 3) may play a role in PKD symptoms.

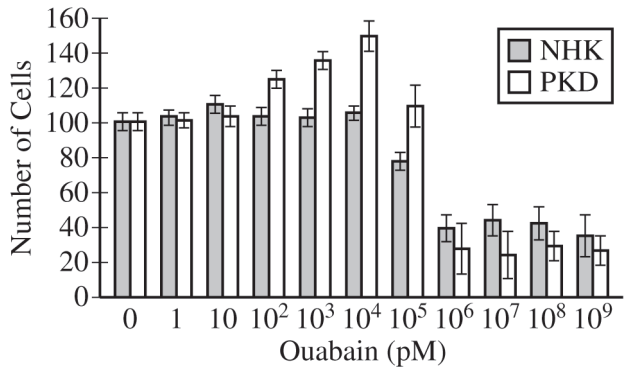

Figure 1. Cell number compared with the number of cells at 0 pM ouabain. Normal human kidney (NHK) cells and polycystic kidney disease (PKD) cells were treated with increasing concentrations of ouabain. Error bars represent $\pm 2SE_{\bar{x}}$.

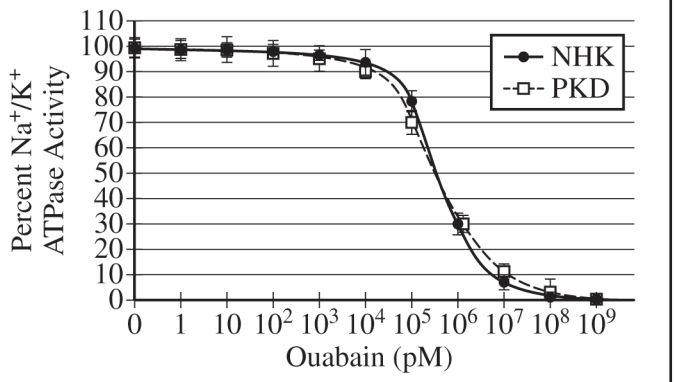

Figure 2. Percent Na^+/K^+ATPase activity of NHK and PKD cells treated with increasing concentrations of ouabain. Error bars represent $\pm 2SE_{\bar{x}}$.

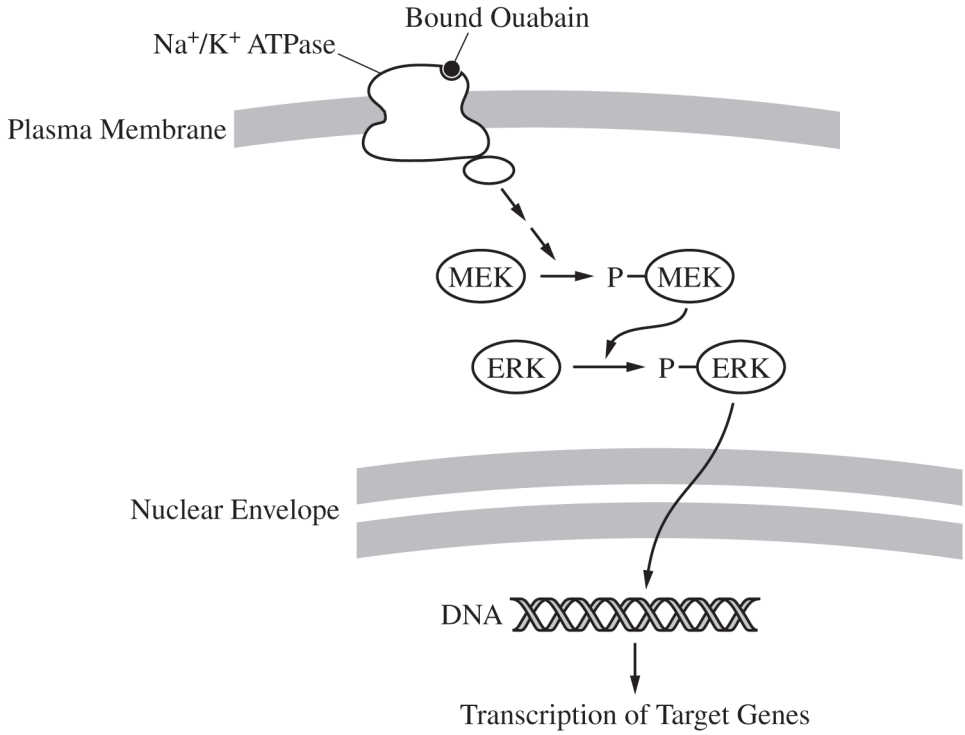

Figure 3. Signal transduction pathway hypothesized to play a role in the increased number of PKD cells

(a) **Describe** the characteristics of the plasma membrane that prevent simple diffusion of Na^+ and K^+ across the membrane. **Explain** why ATP is required for the activity of the Na^+ / K^+ATPase.

(b) **Identify** a dependent variable in the experiment represented in Figure 1. **Justify** the use of normal human kidney (NHK) cells as a control in the experiments. **Justify** the use of a range of ouabain concentrations in the experiment represented in Figure 1.

(c) Based on the data shown in Figure 2, **describe** the relationship between the concentration of ouabain and the Na^+ / K^+ ATPase activity both in normal human kidney (NHK) cells AND in PKD cells. The scientists determined that Na^+ / K^+ATPase activity in PKD cells treated with 1 pM ouabain is 150 units of ATP hydrolyzed/sec. **Calculate** the expected Na^+ / K^+ATPase activity (units/sec) in PKD cells treated with 10^6 pM ouabain.

(d) In a third experiment, the scientists added an inhibitor of phosphorylated MEK (pMEK) to the PKD cells exposed to 10^4 pM ouabain. Based on Figure 3, **predict** the change in the relative ratio of ERK to pERK in ouabain-treated PKD cells with the inhibitor compared with ouabain-treated PKD cells without the inhibitor. Provide reasoning to **justify** your prediction. Using the data in Figure 1 AND the signal transduction pathway represented in Figure 3, **explain** how the concentration of cyclin proteins may increase in PKD cells treated with 10^4 pM ouabain.

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

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2. Geneticists investigated the mode of inheritance of a rare disorder that alters glucose metabolism and first shows symptoms in adulthood. The geneticists studied a family in which some individuals of generations II and III are known to have the disorder. Based on the pedigree (Figure 1), the geneticists concluded that the disorder arose in individual II−2 and was caused by a mutation in mitochondrial DNA.

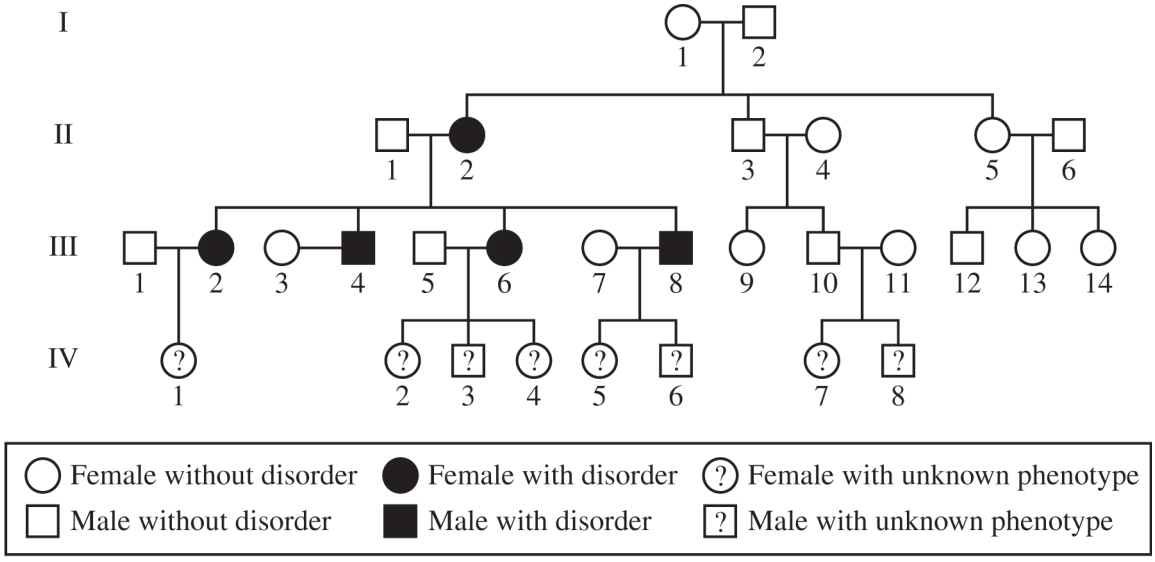

Figure 1. Pedigree of a family showing individuals with the glucose metabolism disorder. A question mark indicates that the phenotype is unknown.

TABLE 1. AVERAGE BLOOD GLUCOSE LEVELS OF INDIVIDUALS IN GENERATION IV

Individual	Average Blood Glucose Level (mg/dL ± $2SE_{\bar{x}}$)
IV−1	170 ± 15
IV−2	190 ± 10
IV−3	145 ± 5
IV−4	165 ± 15
IV−5	110 ± 15
IV−6	125 ± 5
IV−7	105 ± 15
IV−8	120 ± 10

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TABLE 2. PHENOTYPIC CLASSIFICATIONS BASED ON BLOOD GLUCOSE LEVELS

Phenotype	Blood Glucose Level (mg/dL)
Normal	< 140 mg/dL
At risk	140 – 199 mg/dL
Affected	≥ 200 mg/dL

(a) The disorder alters glucose metabolism. **Describe** the atoms AND types of bonds in a glucose molecule.

(b) Using the template in the space provided for your response, **construct** an appropriately labeled graph based on the data in Table 1. **Determine** one individual who is both at risk of developing the disorder and has a significantly different blood glucose level from that of individual IV–1.

(c) Based on the pedigree, **identify** all individuals in generation IV who can pass on the mutation to their children.

(d) Based on the fact that individual II–2 is affected, a student claims that the disorder is inherited in an X-linked recessive pattern. Based on the student's claim, **predict** which individuals of generation III will be affected by the disorder. Based on the pedigree, **justify** why the data do NOT support the student's claim.

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

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3. Researchers hypothesize that the plant compound resveratrol improves mitochondrial function. To test this hypothesis, researchers dissolve resveratrol in dimethyl sulfoxide (DMSO). The solution readily passes through cell membranes. They add the resveratrol solution to mammalian muscle cells growing in a nutrient-rich solution (culture medium) that contains glucose. They measure ATP production at several time points after the addition of the resveratrol solution and find an increase in ATP production by the muscle cells.

   (a) **Describe** the primary advantage for a mammalian muscle cell in using aerobic respiration over fermentation.

   (b) **Identify** an appropriate negative control for this experiment that would allow the researchers to conclude that ATP is produced in response to the resveratrol treatment.

   (c) **Predict** the effect on short-term ATP production when resveratrol-treated mammalian muscle cells are grown in a culture medium that lacks glucose or other sugars.

   (d) The researchers find that resveratrol stimulates the production of components of the electron transport chain. The researchers claim that treatment with resveratrol will also increase oxygen consumption by the cells if glucose is not limiting. **Justify** the claim.

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

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4. In 1981 a single immature male *Geospiza conirostris* finch flew more than 100 kilometers from the Galápagos island of Española to the Galápagos island of Daphne Major, where no *G. conirostris* finches were living. The immigrant finch bred with a female *G. fortis*, a species of finch common on Daphne Major. The F_1 finches and later generations interbred only within their lineage. By 2012 scientists counted 23 individuals, including eight breeding pairs, within this hybrid lineage on Daphne Major. The hybrid lineage became known as Big Bird.

   Birds with different beak shapes and sizes eat different types of food. The dimensions of the Big Bird beaks relative to the beaks of the major competitor finch species on Daphne Major are shown in Figure 1.

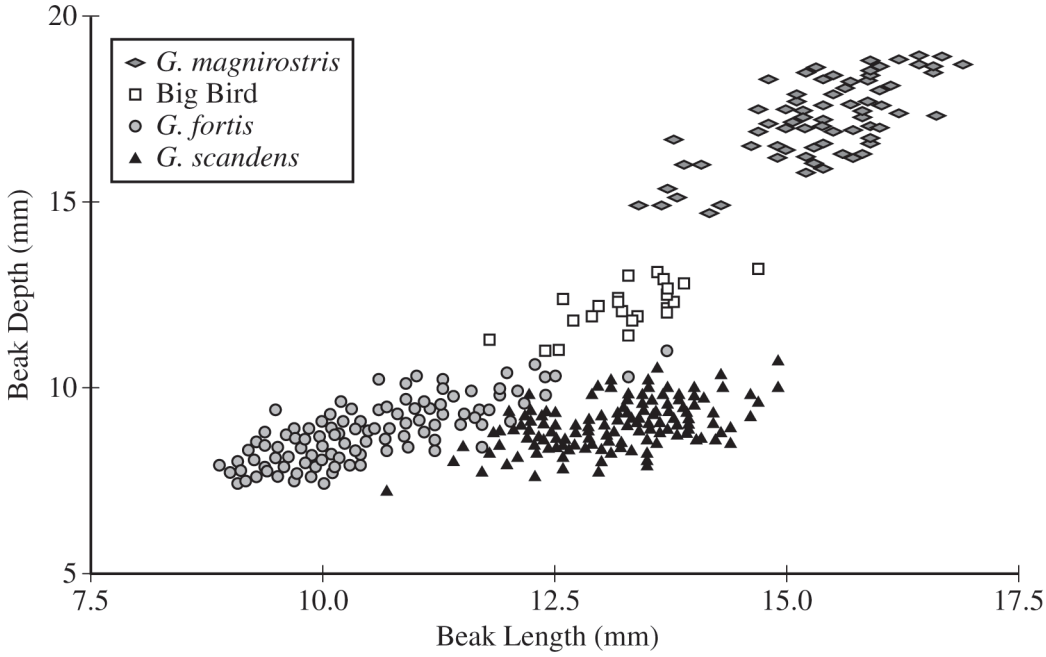

Figure 1. The dimensions of the beaks of the Big Bird lineage and of its major competitor species in 2012 on Daphne Major. Each symbol represents the beak dimensions of a single bird.

(a) The Big Bird lineage became reproductively isolated from *G. fortis*. **Describe** one prezygotic mechanism that likely contributed to the reproductive isolation of the Big Bird lineage from *G. fortis*.

(b) Based on the data in Figure 1, **explain** why the Big Bird population has been able to survive and reproduce on Daphne Major.

(c) A virus infects and kills all *G. magnirostris* on Daphne Major but does not affect the other finch species. Assuming food type and availability stay the same, **predict** the most likely change in the beak phenotype of the Big Bird population after six more generations.

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

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

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5. Annual plants complete their life cycle, including germination, seed production, and death, within one year. *Ambrosia trifida* (giant ragweed) is an annual plant that readily colonizes any land that has had a disturbance such as plowing. The plant is considered an invasive species in regions outside of its native range. In a particular region, the seeds of *A. trifida* germinate from early March through the end of the summer, while the seeds of other annual plants require warmer soil temperatures and thus germinate from late April through the end of the summer.

   Researchers studied the influence of *A. trifida* on the biodiversity of other annual plant species that grow in the same field. In early spring, the researchers marked off identical plots of land in a field that had been plowed the previous fall and not replanted with new crops. All plants that grew on one half of the plots were left untouched (Figure 1A), while all germinating *A. trifida* seedlings were removed from the other half of the plots throughout the spring and summer (Figure 1B). In late summer, the researchers counted and identified all plants that grew in the plots. The distribution of plants is represented by the symbols in Figures 1A and 1B.

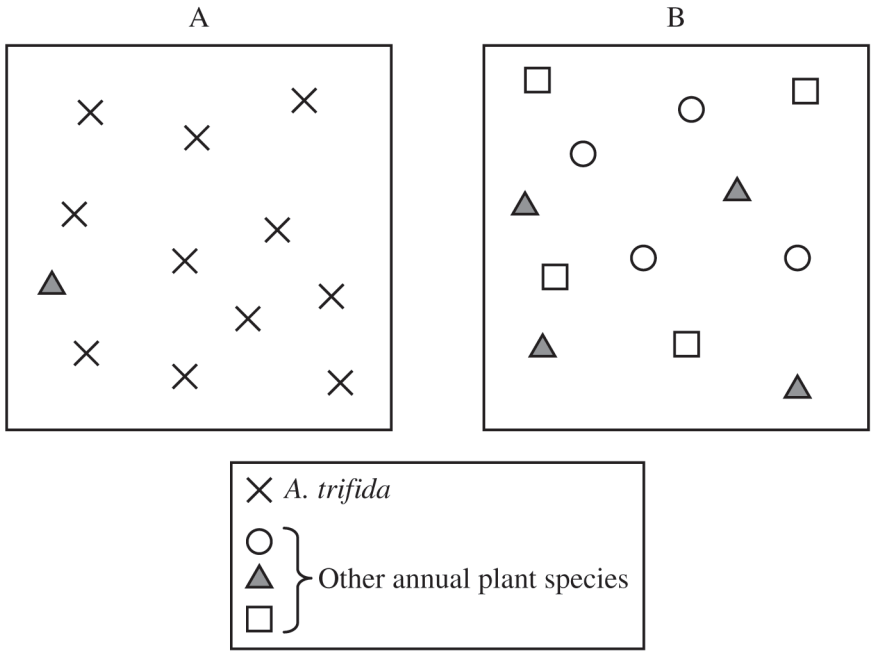

Figure 1. Representations of plant identity and distribution in experimental plots in late summer. Each box represents one typical experimental plot, and each symbol represents 10 individual plants.

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(a) **Describe** a cause of logistic growth of the ragweed population.

(b) Based on the representation in Figure 1, **explain** why the scientists claim that plot B would be more resilient than plot A in response to a sudden environmental change.

(c) In a third group of plots, the researchers removed all seedlings of all plants that germinated before June 1. All plants that germinated after June 1 were left untouched. Using the template in the space provided for your response and the symbols shown in Figure 1, **represent** the expected plant species that would be found in this third group of plots three months later. Draw no more than 12 symbols. Assume all other environmental conditions are the same as for the initial study described.

(d) **Explain** how an invasive species such as ragweed affects ecosystem biodiversity, as illustrated in Figure 1.

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

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6. The small invertebrate krill species *Thysanoessa inermis* is adapted to cold (4°C) seawater. Over the past ten years, there has been a gradual increase in the water temperature of the krill's habitat. A sustained increase in water temperature may ultimately affect the ability of the krill to survive.

   One effect of higher temperatures is protein misfolding within cells. Krill have several *hsp* genes that code for heat-shock proteins (HSPs). These proteins help prevent protein misfolding or help to refold proteins to their normal shapes.

   Scientists conducted experiments on *T. inermis* to detect changes in the expression of *hsp* genes when the krill were exposed to temperatures above 4°C. An experimental group of krill was maintained in tanks with 4°C seawater and then placed into tanks with 10°C seawater for approximately three hours. The krill were then given a six-hour recovery period in the 4°C seawater tanks. A control group of krill was moved from a tank of 4°C seawater to another tank of 4°C seawater for approximately three hours and then returned to the original tank. The scientists analyzed *hsp* gene expression by measuring the concentrations of three mRNAs (I, II, III) transcribed from certain *hsp* genes in both the heat-shocked krill (Figure 1) and the control krill. For the control krill, no transcription of the *hsp* genes was detected throughout the test period (data not shown).

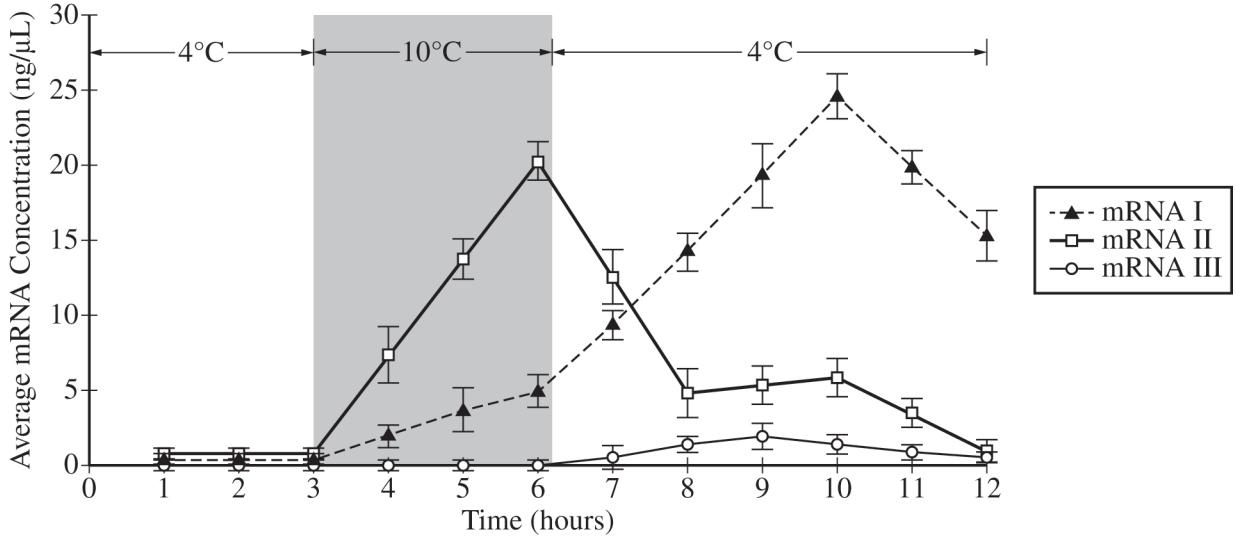

Figure 1. Average concentration of three mRNAs (I, II, III) transcribed from *hsp* genes in krill heat shocked at 10°C. Error bars represent $\pm 2SE_{\bar{x}}$.

(a) **Identify** the *hsp* mRNA that has the slowest rate of concentration increase in response to heat-shock treatment.

(b) **Describe** the trend in the average concentration of mRNA I throughout the experiment.

(c) The scientists hypothesized that the heat-shock protein (HSP) translated from mRNA I plays a greater role in refolding proteins than does the HSP translated from mRNA II. Use the data to **support** the hypothesis.

(d) mRNAs I and II are transcribed from the same gene. **Explain** how a cell can produce two different mRNAs from the same gene.

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

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END OF EXAM