

2021

AP[®]

CollegeBoard

AP[®] Biology

Scoring Guidelines

© 2021 College Board. College Board, Advanced Placement, AP, AP Central, and the acorn logo are registered trademarks of College Board. Visit College Board on the web: collegeboard.org.

AP Central is the official online home for the AP Program: apcentral.collegeboard.org.

Question 1: Interpreting and Evaluating Experimental Results

10 points

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.

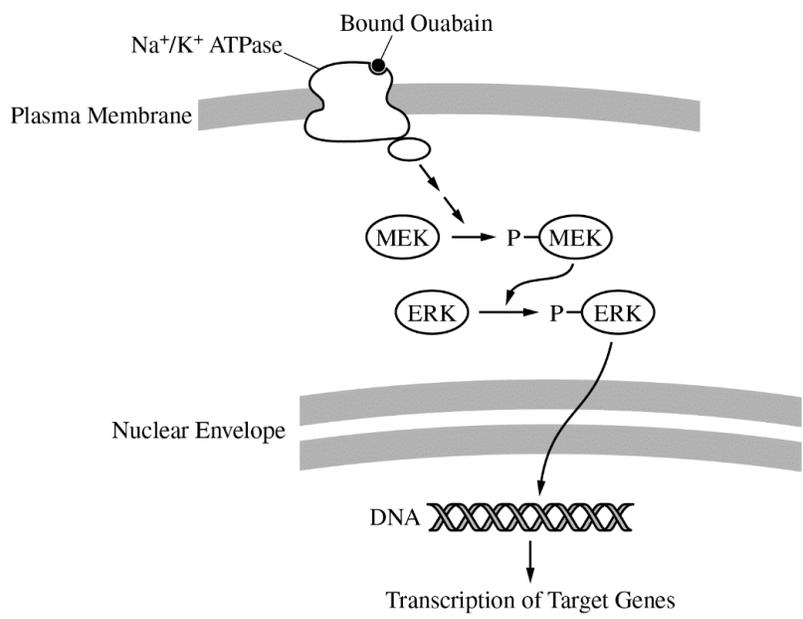
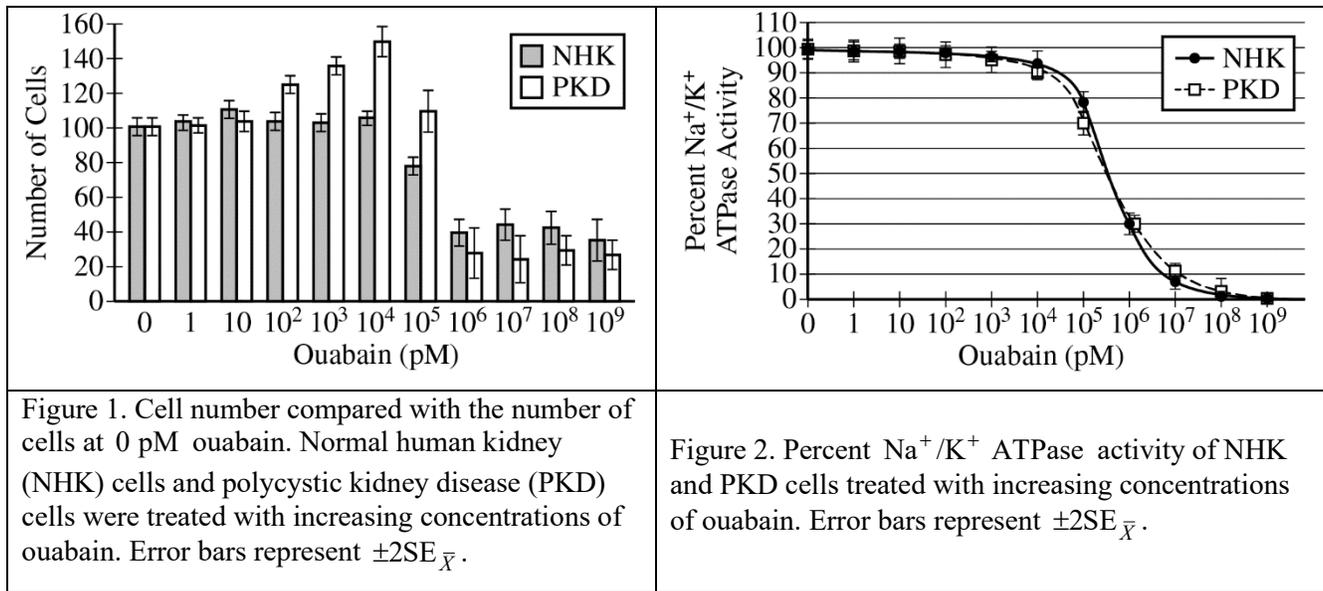


Figure 3. Signal transduction pathway hypothesized to play a role in the increased number of PKD cells

(a)	Describe the characteristics of the plasma membrane that prevent simple diffusion of Na^+ and K^+ across the membrane. Accept one of the following: <ul style="list-style-type: none">• The interior of the plasma membrane is hydrophobic/nonpolar.• The phospholipid tails are hydrophobic/nonpolar.• The exterior of the plasma membrane is hydrophilic/polar.• The phospholipid heads are hydrophilic/polar.	1 point
	Explain why ATP is required for the activity of the Na^+/K^+ ATPase . <ul style="list-style-type: none">• The Na^+/K^+ ATPase pumps ions against their concentration gradients. This requires an input of (metabolic) energy.	1 point
Total for part (a)		2 points
(b)	Identify a dependent variable in the experiment represented in Figure 1. <ul style="list-style-type: none">• The number of cells Justify the use of normal human kidney NHK cells as a control in the experiments. Accept one of the following: <ul style="list-style-type: none">• It allows the scientists to determine the effect of PKD on the cells' responses to (various concentrations of) ouabain.• It allows the scientists to compare the responses of PKD cells and normal cells (to ouabain). Justify the use of a range of ouabain concentrations in the experiment represented in Figure 1. Accept one of the following: <ul style="list-style-type: none">• The scientists need to determine whether different concentrations have different effects on the cell numbers.• The scientists did not know at which concentration of ouabain there would be an effect.	1 point
Total for part (b)		3 points
(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. Accept one of the following: <ul style="list-style-type: none">• Increasing concentrations of ouabain result in decreasing ATPase activity (in both types of cells).• There is an inverse relationship/negative correlation between the concentration of ouabain and the ATPase activity (in both types of 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. <ul style="list-style-type: none">• 45 (Accept between 40 and 50)	1 point
Total for part (c)		2 points

-
- (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. **1 point**

Accept one of the following:

- Option 1: The ratio of ERK to pERK will increase in the cells with the inhibitor.
- Option 2: The ratio of ERK to pERK will stay the same in the cells with the inhibitor.

Provide reasoning to **justify** your prediction. **1 point**

- The justification must indicate that the pMEK inhibitor blocks further phosphorylation of ERK AND one of the following:

Option 1:

- The amount of pERK will not increase as it does in cells without the inhibitor.
- The amount of ERK will not decrease as it does in cells without the inhibitor.
- The cell continues to synthesize ERK.
- Phosphorylated ERK is being dephosphorylated to ERK.

Option 2:

- No additional ERK is synthesized/pERK is not being dephosphorylated.

-
- Using the data in Figure 1 AND the signal transduction pathway represented in Figure 3, **explain** why the concentration of cyclin proteins may increase in PKD cells treated with 10^4 pM ouabain. **1 point**

- The cell number increases to a maximum at 10^4 pM ouabain. The signaling pathway stimulates transcription of genes involved in cell division. The target genes likely include those for cyclins because cyclins regulate the cell cycle.

Total for part (d) 3 points

Total for question 1 10 points

Question 2: Interpreting and Evaluating Experimental Results with Graphing**8 points**

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.

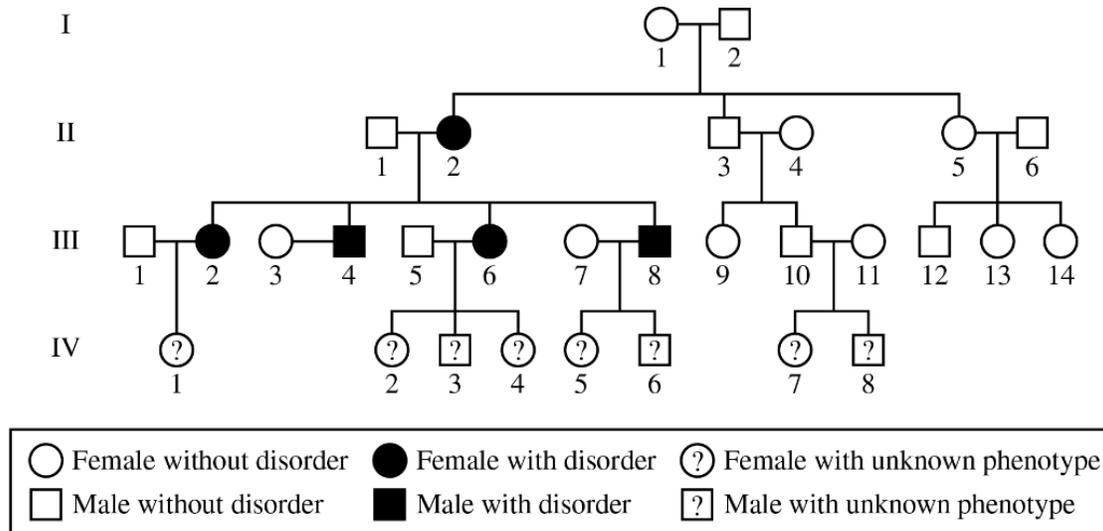


Figure 1. Pedigree of a family showing individuals with the glucose metabolism disorder. A question mark indicates that the phenotype is unknown.

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

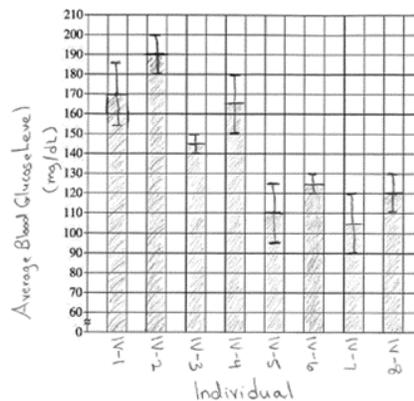
Individual	Average Blood Glucose Level (mg/dL \pm 2SE \bar{x})
IV – 1	170 \pm 15
IV – 2	190 \pm 10
IV – 3	145 \pm 5
IV – 4	165 \pm 15
IV – 5	110 \pm 15
IV – 6	125 \pm 5
IV – 7	105 \pm 15
IV – 8	120 \pm 10

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	\geq 200 mg/dL

- (a) The disorder alters glucose metabolism. **Describe** the atoms AND types of bonds in a glucose molecule. **1 point**
- The atoms are carbon, hydrogen, and oxygen (C, H, and O) and are held together by covalent bonds.

- (b) Use the template provided to **construct** an appropriately labeled graph based on the data in Table 1. **3 points**



- Point distribution: Axis labels; plotting in a bar graph or modified bar graph; error bars

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. **1 point**

- IV-3

Total for part (b) 4 points

- (c) Based on the pedigree, **identify** all individuals in generation IV who can pass on the mutation to their children. **1 point**

- IV-1, IV-2, IV-4

- (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. **1 point**

- III-4 and III-8

Based on the pedigree, **justify** why the data do NOT support the student's claim. **1 point**

Accept one of the following:

- The data do not support the claim because females III-2 and III-6 have the disorder and, if inheritance is X-linked recessive, they could only do so if their father II-1 had the disorder, which he does not.
- The data instead support mitochondrial inheritance, because all of the offspring of individual II-2, not only the sons, have the disorder.

Total for part (d) 2 points

Total for question 2 8 points

Question 3: Scientific Investigation**4 points**

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. **1 point**
- More ATP (per glucose molecule) is produced by aerobic respiration.
-
- (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. **1 point**
- Accept one of the following:
- The researchers must run the experiment without adding resveratrol.
 - The researchers must treat the cells with DMSO alone.
-
- (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. **1 point**
- Accept one of the following:
- No ATP production
 - Reduced ATP production
-
- (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. **1 point**
- More electrons can be transferred so that more oxygen is required as the final electron acceptor.
-

Total for question 3 4 points

Question 4: Conceptual Analysis**4 points**

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 F₁ 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.

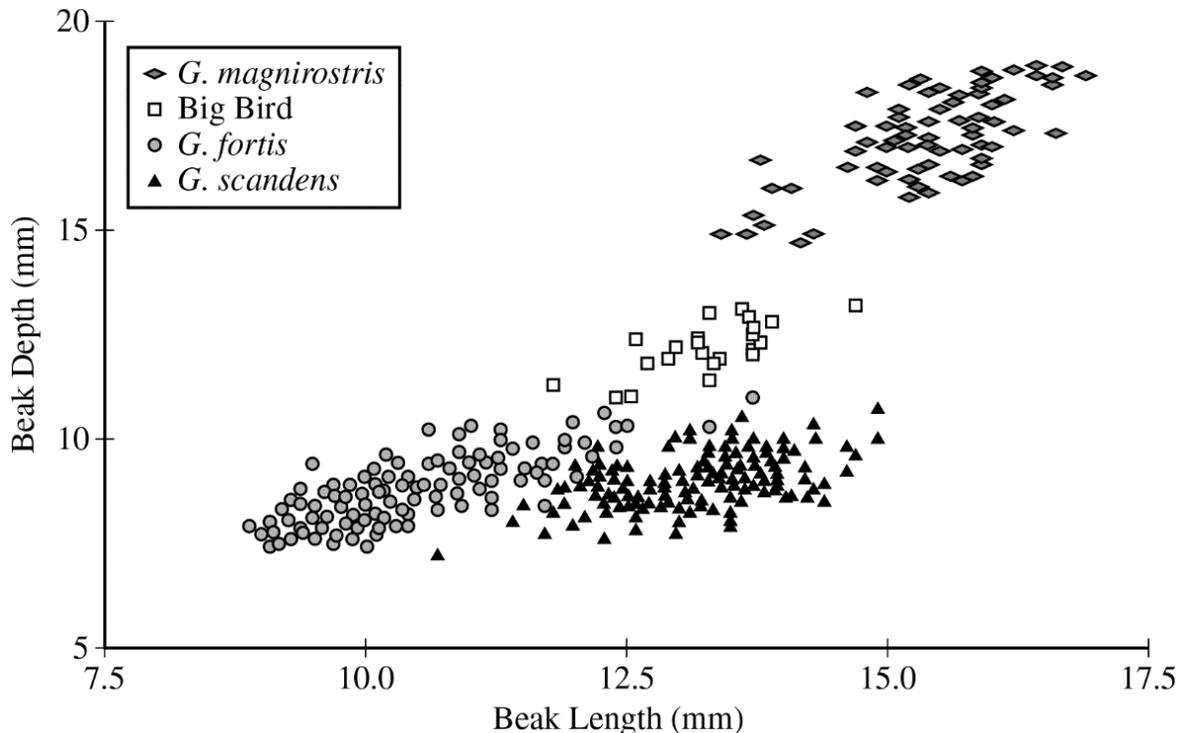


Figure 1. The dimensions of the beaks of the Big Bird lineage and of its major competitor species in 2012 on Daphne Major. Each symbol represents the beak dimensions of a single bird.

- (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*. **1 point**
- Accept one of the following:
- Beak shape/size or song or behavior or mechanical/chemical differences or time of mating or location on the island or primary food source differs between the Big Bird lineage and *G. fortis*.
 - Description of another mechanism that prevents males and females from different populations from encountering each other/recognizing each other as potential mates.
-
- (b) Based on the data in Figure 1, **explain** why the Big Bird population has been able to survive and reproduce on Daphne Major. **1 point**
- The birds have a beak size/shape that differs from the beaks of the competitor finches on the island. Thus, they probably do not compete with the other finch species for food but instead, eat food that the other finches do not consume.

-
- (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. **1 point**

Accept one of the following predictions:

- Option 1: The (mean) beak size will increase (in the population).
- Option 2: The (average) beak (in the population) will be longer and deeper.
- Option 3: The frequency of large beaks will increase (in the population).
- Option 4: The (mean) beak size will stay the same (in the population).

-
- (d) Provide reasoning to **justify** your prediction in part (c). **1 point**

Accept one of the following:

- Justification for options 1, 2, and 3: There will be directional selection for larger beaks because larger seeds are more accessible.
- Justification for option 4: There is little genetic diversity because all birds are descended from a single pair, and the birds are only six generations from the founder.

Total for question 4 4 points

Question 5: Analyze a Model or Visual Representation**4 points**

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.

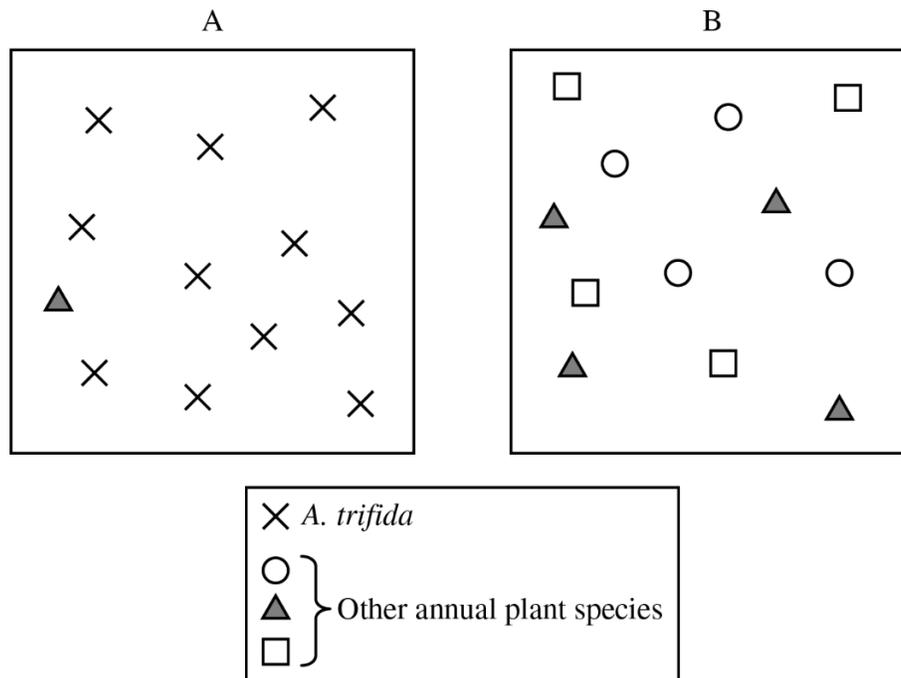
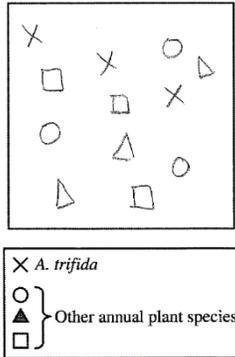


Figure 1. Representations of plant identity and distribution in experimental plots in late summer. Each box represents one typical experimental plot, and each symbol represents 10 individual plants.

- (a) **Describe** a cause of logistic growth of the ragweed population. **1 point**
- Accept one of the following:
- A factor that becomes limiting would cause the population size to stabilize.
 - Space/sunlight/herbivory/phosphorus/nitrogen/other density-dependent factor becomes limiting, and the population stabilizes.
-
- (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. **1 point**
- (Plot B is more resilient) because it has much greater (species) diversity than plot A does.

- (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. **1 point**



- All four species, including *A. trifida*, must be added to the template.

- (d) **Explain** how an invasive species such as ragweed affects ecosystem biodiversity, as illustrated in Figure 1. **1 point**
- The explanation requires a process or relationship - and must state that biodiversity decreases.
 - Examples of appropriate responses include:
 - There are no predators of the invasive species, so its population grows faster and reduces biodiversity.
 - The invasive species germinates earlier, uses up resources, and reduces biodiversity.
 - The invasive species outcompetes other species and reduces biodiversity.

Total for question 5 4 points

Question 6: Analyze Data**4 points**

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).

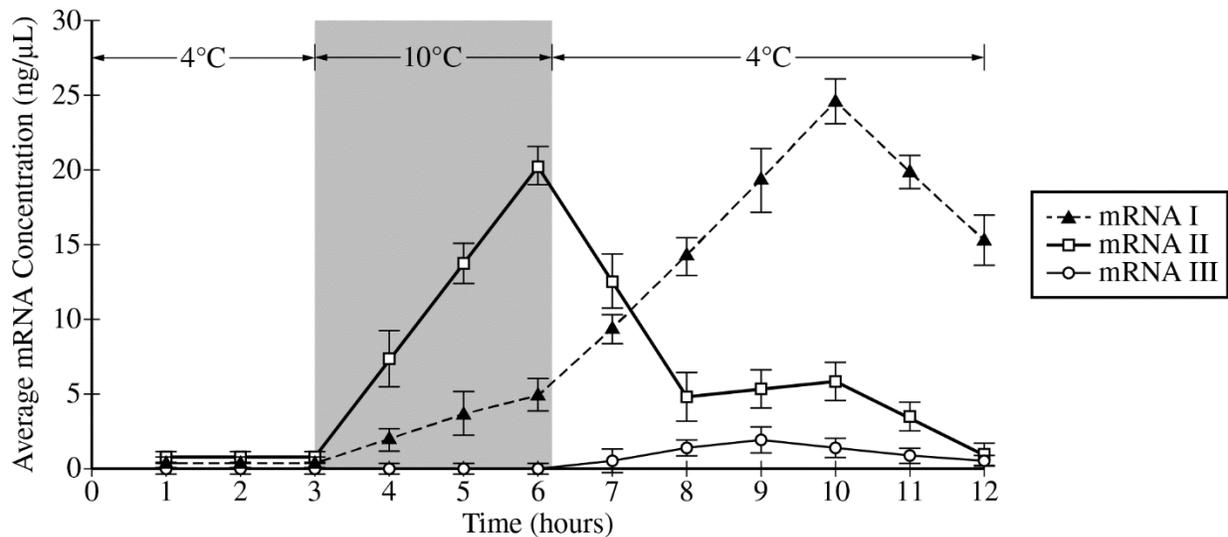


Figure 1. Average concentration of three mRNAs (I, II, III) transcribed from *hsp* genes in krill heat shocked at 10°C. Error bars represent $\pm 2SE_{\bar{x}}$.

-
- (a) **Identify** the *hsp* mRNA that has the slowest rate of concentration increase in response to heat-shock treatment. **1 point**
- (mRNA) III
-
- (b) **Describe** the trend in the average concentration of mRNA I throughout the experiment. **1 point**
- (No change in concentration from 1 to 3 hours) increased concentration (slightly) between 3 and 6 hours/during the heat shock, increased concentration at a greater rate from 6 to 10 hours/for 4 hours after the heat shock, and then decreased concentration after hour 10.
-

(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. **1 point**

- mRNA I is still expressed at a high level after the heat-shock period, while mRNA II levels decrease after the heat shock, when proteins would need to be refolded.

(d) mRNAs I and II are transcribed from the same gene. **Explain** how a cell can produce two different mRNAs from the same gene. **1 point**

Accept one of the following:

- The cell expresses different exons/performs alternative splicing.
- The cell uses different transcription termination sites (poly(A) sites).
- The cell uses different promoters.

Total for question 6 4 points