Week 10

AP Biology

Homework bundle for this week

本周作业合集

exercises.lol

Contents 目录

4. Cell Communication and Cell Cycle

Starter Quiz · 课前小测

AP Biology Name: _____ Score: _____

1. Why do the cells of a body need to communicate?
   - ☐ to coordinate their actions as one organism
   - ☐ to compete and destroy each other
   - ☐ they do not communicate at all
   - ☐ only to store energy
2. **Signal transduction** is the process of…
   - ☐ converting an outside signal into an inside cellular action
   - ☐ copying DNA
   - ☐ making ATP
   - ☐ digesting food
3. A **signal transduction pathway** is…
   - ☐ a chain of molecules that each activate the next
   - ☐ a single molecule doing everything alone
   - ☐ a type of DNA
   - ☐ a kind of cell wall
4. **Homeostasis** is…
   - ☐ keeping the body's internal conditions steady
   - ☐ growing as fast as possible
   - ☐ copying DNA
   - ☐ making the body colder over time
5. The **cell cycle** is the sequence a cell follows to…
   - ☐ grow, copy its DNA, and divide into two
   - ☐ make ATP
   - ☐ send hormones
   - ☐ digest food
6. A cell that has the right receptor and can respond to a signal is called a _____ cell.

   _____

7. The three stages are reception, transduction, and _____.

   _____

8. When one signal produces a huge response through a cascade, we call it _____.

   _____

9. The target value that the body tries to hold is called the _____ point.

   _____

10. **Mitosis** produces two daughter cells that are genetically identical to the parent.
    - ☐ True ☐ False

AP Biology

1. **to coordinate their actions as one organism**

   Cells must communicate to act together — growing, defending, and responding as one coordinated body.

2. **converting an outside signal into an inside cellular action**

   Signal transduction turns a signal arriving outside the cell into a response inside it.

3. **a chain of molecules that each activate the next**

   A **pathway** is a relay: molecule A activates B, B activates C, and so on inside the cell.

4. **keeping the body's internal conditions steady**

   Homeostasis keeps internal conditions (temperature, glucose, water) steady around a set point.

5. **grow, copy its DNA, and divide into two**

   The **cell cycle** takes a cell through growth, DNA copying, and division into two new cells.

6. **target**

   Only a **target cell** with the matching receptor responds; other cells ignore the signal.

7. **response**

   The final stage is the **response** — the cell actually does something.

8. **amplification**

   Each step activates many of the next, so **amplification** turns a tiny signal into a large effect.

9. **set**

   The body compares the current value with the **set point** and corrects any difference.

10. **True**

    Mitosis splits the copied chromosomes evenly, so each daughter cell is an identical copy.

AP BIOLOGY • EXERCISE SHEET

4.1 Cell Communication

Name: _____ Class: _____ Date: _____ **Total: 11 marks**

KEY WORDS receptor 受体 • signals 信号 • hormones 激素

Objective

Build the skills to answer exam questions on **cell communication**.

You must be able to:

- describe how cells communicate over short and long distances
- name the types of signaling (direct, local, long-distance)
- explain the roles of a **signal** and a **receptor** 受体

1 Worked examples

Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

■ Signals and receptors

Cells communicate using chemical **signals** (like hormones). A target cell has a specific **receptor** protein that binds the signal — only cells with the matching receptor respond.

■ Types of signaling by distance

- **Direct contact** — cells touch and exchange signals through junctions.
- **Local signaling** — a signal diffuses to nearby cells (e.g. neurotransmitters).
- **Long-distance signaling** — hormones travel through the blood to distant target cells.

■ Specificity

Only cells with the **correct receptor** respond to a signal, which is why a hormone affects some tissues but not others.

■ A worked example

Insulin (a hormone) travels in the blood (long-distance) and binds receptors on liver and muscle cells, which respond by taking up glucose.

2 Practice

Now apply the methods above.

2.1 What binds a chemical signal on the target cell? [1]

2.2 Name the three types of signaling by distance. [3]

2.3 Why does a hormone affect only some cells? [1]

3 Exam-style questions

3.1 Only cells that respond to a particular signal have the correct [1]

- **A** enzyme
- **B** receptor
- **C** ribosome
- **D** membrane

3.2 Insulin travels in the blood to reach liver and muscle cells.

(a) Name this type of signaling. [1]

(b) Explain why insulin affects these cells but not others. [2]

3.3 Explain the difference between local and long-distance signaling. [2]

Solutions

2.1 A receptor (protein).

2.2 Direct contact, local signaling, long-distance signaling.

2.3 Only cells with the matching receptor can bind the hormone and respond.

3.1 B — receptor.

3.2 (a) Long-distance (hormonal) signaling. (b) Only liver and muscle cells have the insulin receptor, so only they can bind it and respond.

3.3 Local signaling reaches nearby cells by diffusion over short distances; long-distance signaling uses hormones carried in the blood to reach distant target cells.

2. Many insects rely on pheromones (chemical signals) that are released by the females to find mating partners. Scientists hypothesize that, in a certain type of moth, the behavior of male moths in response to pheromones is regulated by the extracellular signaling molecule 20E.

A. Many receptors are embedded in the plasma membrane. **Describe** the polarity of the portion of the receptor that is inside the membrane.

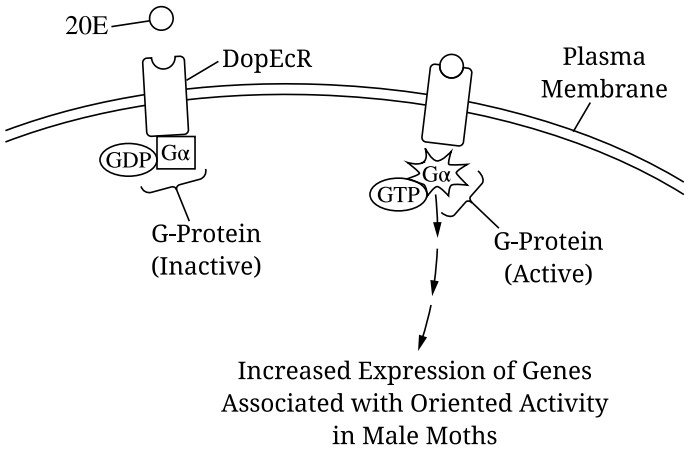
To investigate whether the binding of 20E to its receptor, DopEcR, affects behavior in moths, scientists injected male moths with saline (control solution) or with small interfering RNA molecules (siRNAs) that inhibit the expression of the gene encoding DopEcR. The scientists then exposed the moths to the pheromone and determined the percent of total time observed that the moths engaged in general activity, defined as movement in any direction. The scientists also determined the percent of the general activity time that the moths spent in oriented activity, defined as movement toward an area of high pheromone concentration (Table 1).

Table 1. Average General and Oriented Activity in Male Moths Injected With Saline or siRNA Molecules

Treatment	General Activity (percent of total time observed, average $\pm 2SE_{\bar{x}}$)	Oriented Activity (percent of general activity, average $\pm 2SE_{\bar{x}}$)
Male moths injected with saline (control solution)	95 ± 5	60 ± 4
Male moths injected with siRNAs that inhibit expression of the gene encoding DopEcR	90 ± 8	25 ± 6

DopEcR is a G protein-coupled receptor. When 20E binds to DopEcR, GTP displaces the GDP bound to the G protein, and a signaling pathway is activated. The scientists hypothesize that this leads to the transcription of genes associated with the oriented activity observed in the male moths (Figure 1).

Figure 1. A simplified model of a signaling pathway activated by the binding of 20E to its receptor, DopEcR



B.

i. Using the template in the space provided for your response, **construct** an appropriate type of graph that represents the data in Table 1. Your graph should be appropriately plotted and labeled.

ii. Based on the data in Table 1, **determine** the type of activity that was affected by inhibiting the expression of the DopEcR receptor.

C.

i. Based on Table 1, **identify** the treatment group in which the oriented activity was greater than 50% of the general activity.

ii. The scientists studied some moths with a mutation in the gene encoding the G protein. The mutation prevents GTP from displacing the GDP bound to the G protein. Based on Figure 1, **predict** the effect of this mutation on the oriented activity in male moths exposed to the pheromone.

Expression of the gene encoding DopEcR is low in the male moths during their first few days as adults, when they are sexually immature. Gene expression rapidly increases as the moths reach sexual maturity. The scientists claim that this increase in gene expression increases the likelihood of males finding females with whom to mate.

D.

i. Use evidence from the information provided to **support** the scientists' claim.

ii. Based on Figure 1, **explain** how an inhibitor of the DopEcR pathway might serve as an effective chemical to protect crops from moth damage.

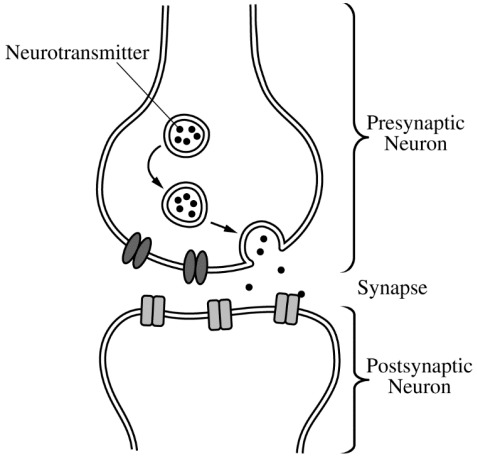


Figure 1. Release of neurotransmitters into the synapse in response to an action potential

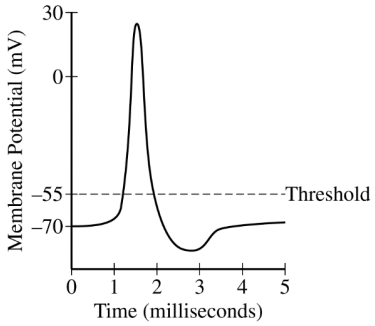


Figure 2. Model of a typical action potential in a neuron

4. Acetylcholine is a neurotransmitter that can activate an action potential in a postsynaptic neuron (Figures 1 and 2). A researcher is investigating the effect of a particular neurotoxin that causes the amount of acetylcholine released from presynaptic neurons to increase.

   (a) **Describe** the immediate effect of the neurotoxin on the number of action potentials in a postsynaptic neuron. **Predict** whether the maximum membrane potential of the postsynaptic neuron will increase, decrease, or stay the same.

   (b) The researcher proposes two models, A and B, for using acetylcholinesterase (AChE), an enzyme that degrades acetylcholine, to prevent the effect of the neurotoxin. In model A, AChE is added to the synapse. In model B, AChE is added to the cytoplasm of the postsynaptic cell. **Predict** the effectiveness of EACH proposed model. **Provide reasoning** to support your predictions.

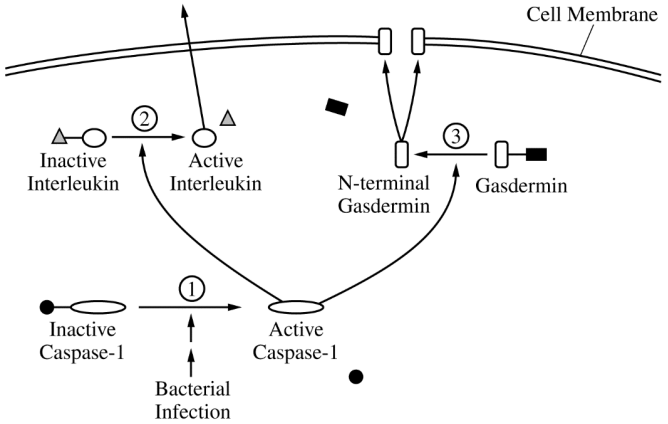


Figure 1. Cellular response to infection by pathogenic bacteria

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-κB (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-κB 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.

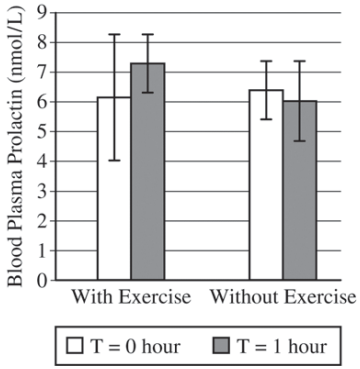


Figure 1. Effect of exercise on blood prolactin levels in adult males. The data represent the means $\pm 2SE_{\bar{x}}$.

8. Researchers conducted a study to investigate the effect of exercise on the release of prolactin into the blood. The researchers measured the concentration of prolactin in the blood of eight adult males before (T = 0 hour) and after one hour (T = 1 hour) of vigorous exercise. As a control, the researchers measured the concentration of blood prolactin in the same group of individuals at the same times of day one week later, but without having them exercise. The results are shown in Figure 1.

   (a) **Justify** the use of the without-exercise treatment as the control in the study design.

   (b) Using evidence from the specific treatments, **determine** whether prolactin release changes after exercise. **Justify** your answer.

STOP

END OF EXAM

AP BIOLOGY • EXERCISE SHEET

4.2 Introduction to Signal Transduction

Name: _____ Class: _____ Date: _____ **Total: 12 marks**

KEY WORDS signal transduction 信号转导 • receptor 受体 • ligand 配体

Objective

Build the skills to answer exam questions on **signal transduction** — reception, transduction, response.

You must be able to:

- name the three stages: **reception, transduction, response**
- explain that a signal is converted into a cellular change
- describe binding at the receptor as the first step

1 Worked examples

Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

The three stages

Signal transduction has three steps:

1. **Reception** — the signal molecule binds its receptor.
2. **Transduction** — the signal is passed and changed through a series of molecules inside the cell.
3. **Response** — the cell does something (e.g. turns a gene on, changes activity).

Reception

The signal (**ligand**) binds a specific **receptor**, often on the membrane. This binding **changes the receptor's shape**, starting the pathway.

Transduction relays the message

A chain of molecules passes the signal along, often amplifying it, converting the outside signal into an inside action.

A worked example

Adrenaline binds a receptor (reception) → activates internal messengers (transduction) → the cell breaks down glycogen for energy (response).

2 Practice

Now apply the methods above.

2.1 Name the three stages of signal transduction. [3]

2.2 What happens during reception? [1]

2.3 What is the final stage called? [1]

3 Exam-style questions

3.1 The first stage of signal transduction is [1]

- **A** response
- **B** transduction
- **C** reception
- **D** replication

3.2 Adrenaline binds a receptor and the cell breaks down glycogen.

(a) Identify the reception and response steps. [2]

(b) State what happens during transduction. [2]

3.3 Explain why binding of the signal changes the receptor, and why this matters. [2]

Solutions

2.1 Reception, transduction, response.

2.2 The signal molecule binds its receptor.

2.3 Response.

3.1 C — reception.

3.2 (a) Reception: adrenaline binds the receptor; response: glycogen is broken down. (b) The signal is relayed and amplified through a chain of internal molecules that carry the message to the response.

3.3 Binding changes the receptor's shape, which activates it to start the internal pathway; without this change the signal could not be passed on.

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.

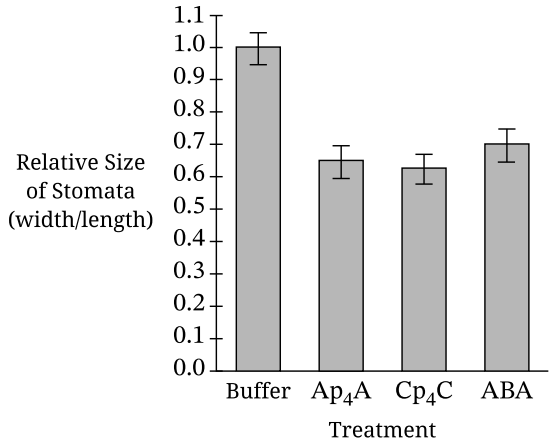
The following information applies to parts B, C, and D.

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 $\pm SE_{\bar{x}}$)



Part B

i. **Identify** the dependent variable in the scientists' first experiment.

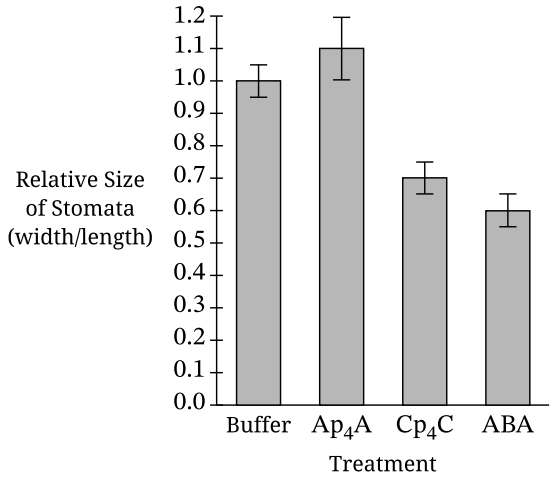
ii. Based on Figure 1, **describe** the relative size of the stomata in the Cp_4C treatment group as compared with the size of the stomata in the group treated with buffer alone.

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 $\pm SE_{\bar{x}}$)



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.

2. Many insects rely on pheromones (chemical signals) that are released by the females to find mating partners. Scientists hypothesize that, in a certain type of moth, the behavior of male moths in response to pheromones is regulated by the extracellular signaling molecule 20E.

A. Many receptors are embedded in the plasma membrane. **Describe** the polarity of the portion of the receptor that is inside the membrane.

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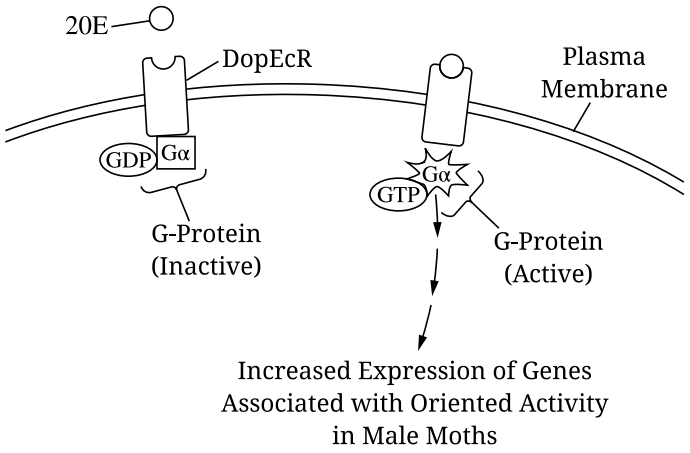

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i. Based on Table 1, **identify** the treatment group in which the oriented activity was greater than 50% of the general activity.

ii. The scientists studied some moths with a mutation in the gene encoding the G protein. The mutation prevents GTP from displacing the GDP bound to the G protein. Based on Figure 1, **predict** the effect of this mutation on the oriented activity in male moths exposed to the pheromone.

Expression of the gene encoding DopEcR is low in the male moths during their first few days as adults, when they are sexually immature. Gene expression rapidly increases as the moths reach sexual maturity. The scientists claim that this increase in gene expression increases the likelihood of males finding females with whom to mate.

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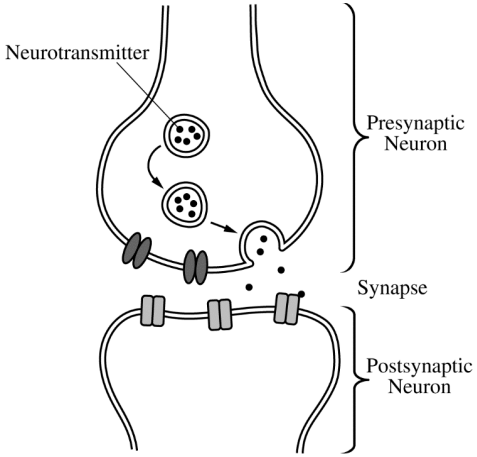


Figure 1. Release of neurotransmitters into the synapse in response to an action potential

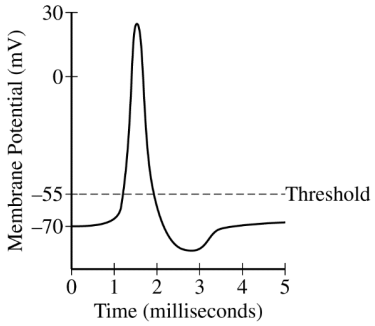


Figure 2. Model of a typical action potential in a neuron

4. Acetylcholine is a neurotransmitter that can activate an action potential in a postsynaptic neuron (Figures 1 and 2). A researcher is investigating the effect of a particular neurotoxin that causes the amount of acetylcholine released from presynaptic neurons to increase.

   (a) **Describe** the immediate effect of the neurotoxin on the number of action potentials in a postsynaptic neuron. **Predict** whether the maximum membrane potential of the postsynaptic neuron will increase, decrease, or stay the same.

   (b) The researcher proposes two models, A and B, for using acetylcholinesterase (AChE), an enzyme that degrades acetylcholine, to prevent the effect of the neurotoxin. In model A, AChE is added to the synapse. In model B, AChE is added to the cytoplasm of the postsynaptic cell. **Predict** the effectiveness of EACH proposed model. **Provide reasoning** to support your predictions.

8. Acetylcholine receptor (AChR) proteins are found at the synapse between neurons and skeletal muscle cells. Acetylcholine released from neurons binds to a specific site on the receptor proteins, which causes an ion channel in the receptors to open and allow sodium ions (Na^+) to enter muscle cells. The resulting depolarization of muscle cells initiates muscle contractions. Another molecule, nicotine, can also bind to certain types of AChR proteins and activate the receptors.

   A researcher is investigating two different types of AChR proteins: type 1 and type 2. To determine which stimuli activate the receptors, the researcher exposes muscle cells expressing the different types of receptor proteins to stimuli and observes the results indicated in Table 1.

   TABLE 1. RESPONSE OF AChR PROTEINS TO DIFFERENT STIMULI

AChR Protein Type	Acetylcholine	Nicotine
Type 1	+	+
Type 2	+	–

   + indicates activation
   – indicates no activation

   (a) **Describe** the difference in the structure AND function between AChR type 1 and AChR type 2.

   (b) Acetylcholinesterase is an enzyme that breaks down acetylcholine in the synapse. **Describe** the effect of inhibiting acetylcholinesterase on the muscle cells with AChR type 2.

STOP

END OF EXAM

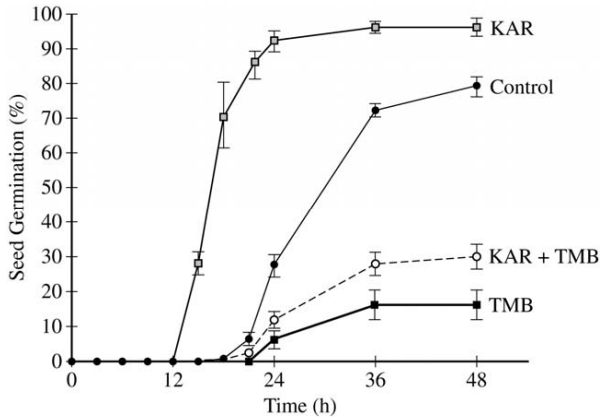


Figure 1. The effect of karrikins (KAR) and trimethylbutenolides (TMB) on seed germination in *Lactuca* plants. Error bars represent $\pm 2SE_{\bar{x}}$.

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.

8. Estrogens are small hydrophobic lipid hormones that promote cell division and the development of reproductive structures in mammals. Estrogens passively diffuse across the plasma membrane and bind to their receptor proteins in the cytoplasm of target cells.

(a) **Describe** ONE characteristic of the plasma membrane that allows estrogens to passively cross the membrane.

(b) In a laboratory experiment, a researcher generates antibodies that bind to purified estrogen receptors extracted from cells. The researcher uses the antibodies in an attempt to treat estrogen-dependent cancers but finds that the treatment is ineffective. **Explain** the ineffectiveness of the antibodies for treating estrogen-dependent cancers.

STOP

END OF EXAM

AP BIOLOGY • EXERCISE SHEET

4.3 Signal Transduction Pathways

Name: _____ Class: _____ Date: _____ **Total: 10 marks**

KEY WORDS amplification 放大 • receptor 受体 • signal transduction 信号转导

Objective

Build the skills to answer exam questions on **signal transduction pathways**.

You must be able to:

- describe a pathway as a **cascade** of activated molecules
- explain **amplification** 放大 of the signal
- explain how the same signal can give different responses in different cells

1 Worked examples

Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

A cascade

A transduction pathway is a **cascade**: molecule A activates B, which activates C, and so on, each step relaying the signal toward the response.

Amplification

At each step one active molecule can activate **many** of the next, so a **small** signal produces a **large** response — the signal is **amplified**.

Second messengers

Small molecules (like cyclic AMP or Ca^{2+}) can spread the signal quickly through the cell as **second messengers**, reaching many targets.

Different responses

The **same** signal can cause **different** responses in different cell types, because each cell has a different set of internal proteins and genes to act on.

2 Practice

Now apply the methods above.

2.1 What is a signal cascade? [1]

2.2 How does a small signal cause a large response? [1]

2.3 Give an example of a second messenger. [1]

3 Exam-style questions

3.1 Signal amplification means that one signal molecule can lead to [1]

- **A** no response
- **B** exactly one product
- **C** many activated molecules
- **D** the receptor breaking down

3.2 The same hormone triggers different responses in two cell types.

(a) Explain how this is possible. [2]

(b) State one advantage of amplifying a signal. [1]

3.3 Describe how a cascade relays and amplifies a signal from the receptor to the response. [3]

Solutions

2.1 A series of molecules that each activate the next, relaying the signal.

2.2 Each step activates many of the next molecule, amplifying the signal.

2.3 Cyclic AMP (or calcium ions).

3.1 C — many activated molecules.

3.2 (a) Each cell type has a different set of internal proteins and genes, so the same signal is acted on differently. (b) A small amount of signal can produce a large, fast response.

3.3 The receptor activates the first molecule, which activates the next, and so on (a cascade); at each step one active molecule activates many of the next, so the signal grows and reaches the response amplified.

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.

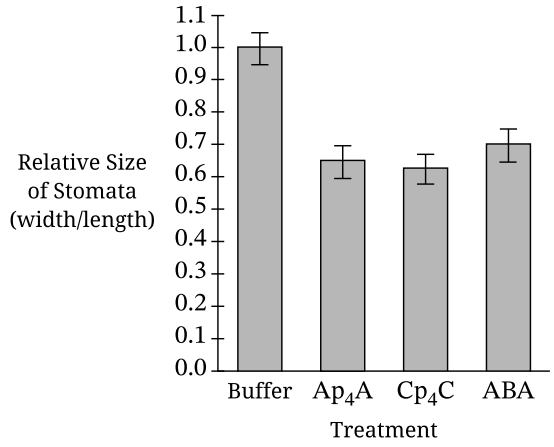
The following information applies to parts B, C, and D.

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 $\pm SE_{\bar{x}}$)



Part B

i. **Identify** the dependent variable in the scientists' first experiment.

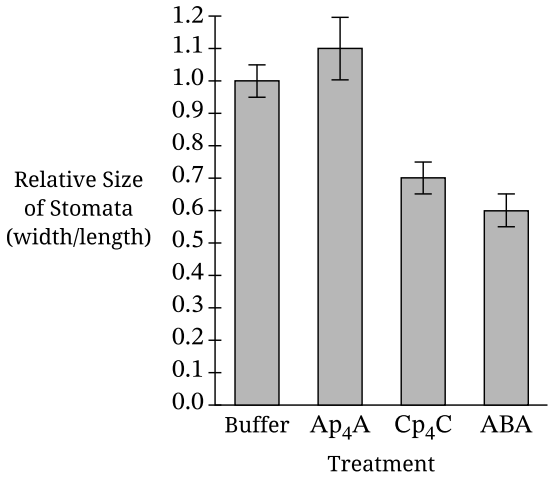
ii. Based on Figure 1, **describe** the relative size of the stomata in the Cp_4C treatment group as compared with the size of the stomata in the group treated with buffer alone.

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 $\pm SE_{\bar{x}}$)



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.

2. Many insects rely on pheromones (chemical signals) that are released by the females to find mating partners. Scientists hypothesize that, in a certain type of moth, the behavior of male moths in response to pheromones is regulated by the extracellular signaling molecule 20E.

A. Many receptors are embedded in the plasma membrane. **Describe** the polarity of the portion of the receptor that is inside the membrane.

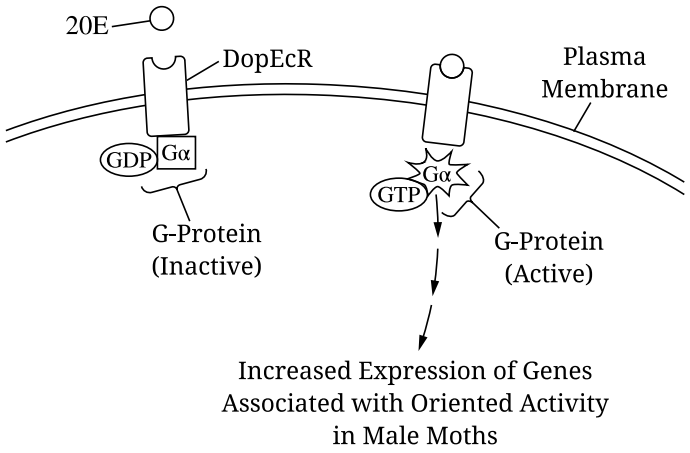
To investigate whether the binding of 20E to its receptor, DopEcR, affects behavior in moths, scientists injected male moths with saline (control solution) or with small interfering RNA molecules (siRNAs) that inhibit the expression of the gene encoding DopEcR. The scientists then exposed the moths to the pheromone and determined the percent of total time observed that the moths engaged in general activity, defined as movement in any direction. The scientists also determined the percent of the general activity time that the moths spent in oriented activity, defined as movement toward an area of high pheromone concentration (Table 1).

Table 1. Average General and Oriented Activity in Male Moths Injected With Saline or siRNA Molecules

Treatment	General Activity (percent of total time observed, average $\pm 2SE_{\bar{x}}$)	Oriented Activity (percent of general activity, average $\pm 2SE_{\bar{x}}$)
Male moths injected with saline (control solution)	95 ± 5	60 ± 4
Male moths injected with siRNAs that inhibit expression of the gene encoding DopEcR	90 ± 8	25 ± 6

DopEcR is a G protein-coupled receptor. When 20E binds to DopEcR, GTP displaces the GDP bound to the G protein, and a signaling pathway is activated. The scientists hypothesize that this leads to the transcription of genes associated with the oriented activity observed in the male moths (Figure 1).

Figure 1. A simplified model of a signaling pathway activated by the binding of 20E to its receptor, DopEcR



B.

i. Using the template in the space provided for your response, **construct** an appropriate type of graph that represents the data in Table 1. Your graph should be appropriately plotted and labeled.

ii. Based on the data in Table 1, **determine** the type of activity that was affected by inhibiting the expression of the DopEcR receptor.

C.

i. Based on Table 1, **identify** the treatment group in which the oriented activity was greater than 50% of the general activity.

ii. The scientists studied some moths with a mutation in the gene encoding the G protein. The mutation prevents GTP from displacing the GDP bound to the G protein. Based on Figure 1, **predict** the effect of this mutation on the oriented activity in male moths exposed to the pheromone.

Expression of the gene encoding DopEcR is low in the male moths during their first few days as adults, when they are sexually immature. Gene expression rapidly increases as the moths reach sexual maturity. The scientists claim that this increase in gene expression increases the likelihood of males finding females with whom to mate.

D.

i. Use evidence from the information provided to **support** the scientists' claim.

ii. Based on Figure 1, **explain** how an inhibitor of the DopEcR pathway might serve as an effective chemical to protect crops from moth damage.

1. In eukaryotic microorganisms, the PHO signaling pathway regulates the expression of certain genes. These genes, *Pho* target genes, encode proteins involved in regulating phosphate homeostasis. When the level of extracellular inorganic phosphate (Pi) is high, a transcriptional activator Pho4 is phosphorylated by a complex of two proteins, Pho80–Pho85. As a result, the *Pho* target genes are not expressed. When the level of extracellular Pi is low, the activity of the Pho80–Pho85 complex is inhibited by another protein, Pho81, enabling Pho4 to induce the expression of these target genes. A simplified model of this pathway is shown in Figure 1.

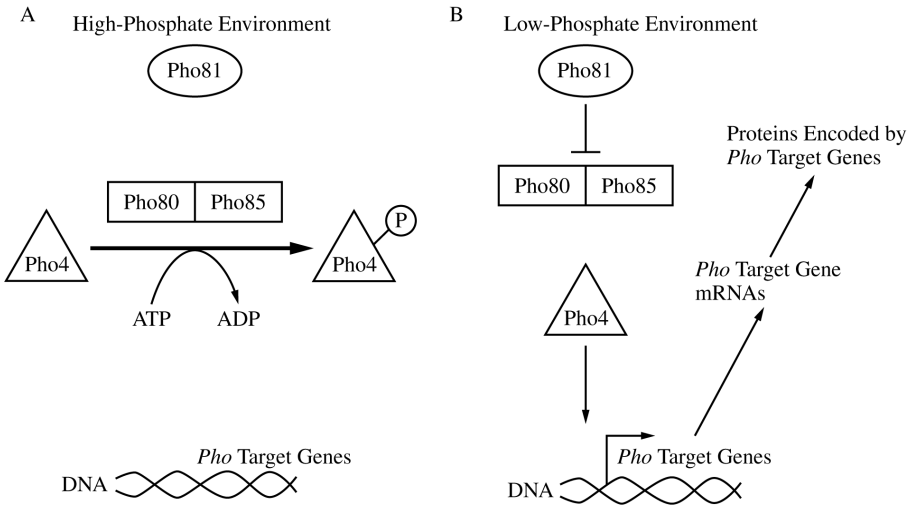


Figure 1. A simplified model of the regulation of expression of *Pho* target genes in (A) a high-phosphate (high-Pi) environment and (B) a low-phosphate (low-Pi) environment

To study the role of the different proteins in the PHO pathway, researchers used a wild-type strain of yeast to create a strain with a mutant form of Pho81 (*pho81mt*) and a strain with a mutant form of Pho4 (*pho4mt*). In each of these mutant strains, researchers measured the activity of a particular enzyme, APase, which removes phosphates from its substrates and is encoded by *PHO1*, a *Pho* target gene (Table 1). They then determined the level of *PHO1* mRNA relative to that of the wild-type yeast strain, which was set to 10.

TABLE 1. APase ACTIVITY AND RELATIVE AMOUNTS OF *PHO1* mRNA IN WILD-TYPE AND MUTANT STRAINS OF YEAST IN HIGH- AND LOW-PHOSPHATE ENVIRONMENTS

Yeast Strain	Mutation	APase Activity in High-Pi Environment (mU/mL/OD_{600}) $\pm 2SE_{\bar{x}}$	APase Activity in Low-Pi Environment (mU/mL/OD_{600}) $\pm 2SE_{\bar{x}}$	Relative Amounts of *PHO1* mRNA in High-Pi Environment $\pm 2SE_{\bar{x}}$	Relative Amounts of *PHO1* mRNA in Low-Pi Environment $\pm 2SE_{\bar{x}}$
Wild-type	None	0.5 ± 0.1	17.3 ± 0.9	0.1 ± 0.0	10 ± 2.0
pho81mt	Nonfunctional Pho81	0.4 ± 0.1	0.6 ± 0.1	0.7 ± 0.2	0.9 ± 0.8
pho4mt	Nonfunctional Pho4	0.5 ± 0.0	0.8 ± 0.2	0.6 ± 0.4	0.3 ± 0.1

(a) **Describe** the effect that the addition of a charged phosphate group can have on a protein that would cause the protein to become inactive. **Explain** how a signal can be amplified during signal transduction in a pathway such as the PHO signaling pathway.

(b) Based on Table 1, **identify** a dependent variable in the researchers' experiment. **Justify** the researchers' using the wild-type strain for the creation of the mutant strains. **Justify** the researchers' using mutant strains in which only a single component of the pathway was mutated in each strain.

(c) Based on the data in Table 1, **identify** the yeast strain and growth conditions that lead to the highest relative amount of *PHO1* mRNA. **Calculate** the percent change in APase activity in wild-type yeast cells in a high-Pi environment compared with that of wild-type cells in a low-Pi environment.

(d) In a follow-up experiment, researchers created a strain of yeast with a mutation that resulted in a nonfunctional Pho85 protein. Based on Figure 1, **predict** the effects of this mutation on *PHO1* expression in the mutant strain in a high-Pi environment. Provide reasoning to **justify** your prediction.

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

1. The binding of an extracellular ligand to a G protein-coupled receptor in the plasma membrane of a cell triggers intracellular signaling (Figure 1, A). After ligand binding, GTP replaces the GDP that is bound to Gsα, a subunit of the G protein (Figure 1, B). This causes Gsα to activate other cellular proteins, including adenylyl cyclase that converts ATP to cyclic AMP (cAMP). The cAMP activates protein kinases (Figure 1, C). In cells that line the small intestine, a cAMP-activated protein kinase causes further signaling that ultimately results in the secretion of chloride ions (Cl^-) from the cells. Under normal conditions, Gsα hydrolyzes GTP to GDP, thus inactivating adenylyl cyclase and stopping the signal (Figure 1, A).

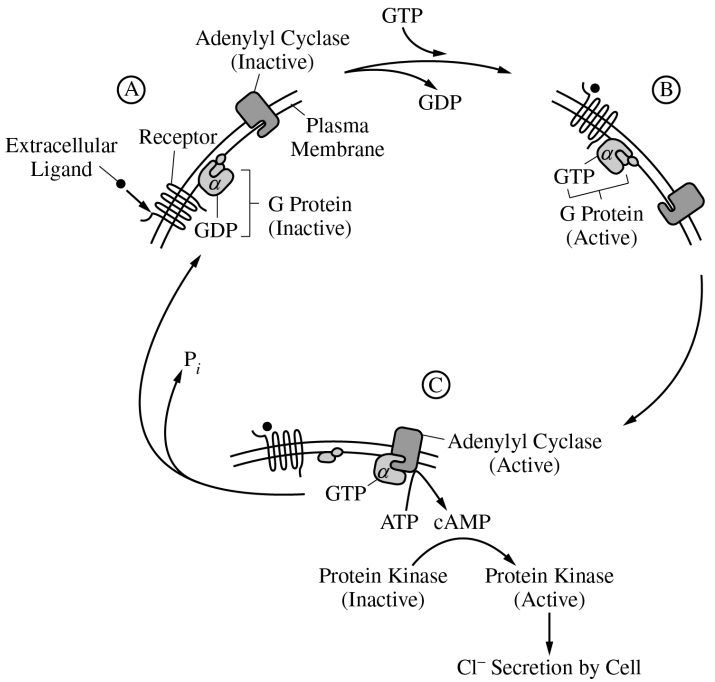


Figure 1. Under normal conditions, ligand binding to a G protein-coupled receptor results in chloride ion transport from an intestinal cell.

Individuals infected with the bacterium *Vibrio cholerae* experience severe loss of water from the body (dehydration). This is due to the effects of the bacterial cholera toxin that enters intestinal cells. Scientists studied the effects of cholera toxin on four samples of isolated intestinal cell membranes containing the G protein-related signal transduction components shown in Figure 1. GTP was added to samples II and IV only; cholera toxin was added to samples III and IV only. The scientists then measured the amount of cAMP produced by the adenylyl cyclase in each sample (Table 1).

TABLE 1. AMOUNT OF cAMP PRODUCED FROM INTESTINAL CELL MEMBRANES IN THE ABSENCE OR PRESENCE OF CHOLERA TOXIN

Sample	GTP	Cholera Toxin	Rate of cAMP Production (pmol per mg adenylyl cyclase per min)
I	−	−	0.5
II	+	−	10.0
III	−	+	0.5
IV	+	+	127.0

present, +; absent, −

(a) **Describe** one characteristic of a membrane that requires a channel be present for chloride ions to passively cross the membrane. **Explain** why the movement of chloride ions out of intestinal cells leads to water loss.

(b) **Identify** an independent variable in the experiment. **Identify** a negative control in the experiment. **Justify** why the scientists included Sample III as a control treatment in the experiment.

(c) Based on the data, **describe** the effect of cholera toxin on the synthesis of cAMP. **Calculate** the percent change in the rate of cAMP production due to the presence of cholera toxin in sample IV compared with sample II.

(d) A drug is designed to bind to cholera toxin before it crosses the intestinal cell membrane. Scientists mix the drug with cholera toxin and then add this mixture and GTP to a sample of intestinal cell membranes. **Predict** the rate of cAMP production in pmol per mg adenylyl cyclase per min if the drug binds to all of the toxin. In a separate experiment, scientists engineer a mutant adenylyl cyclase that cannot be activated by Gsα. The scientists claim that cholera toxin will not cause excessive water loss from whole intestinal cells that contain the mutant adenylyl cyclase. **Justify** this claim.

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

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.

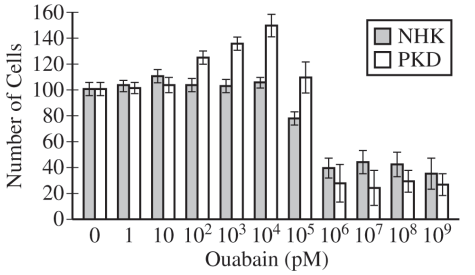


Figure 1. Cell number compared with the number of cells at 0 pM ouabain. Normal human kidney (NHK) cells and polycystic kidney disease (PKD) cells were treated with increasing concentrations of ouabain. Error bars represent $\pm 2SE_{\bar{x}}$.

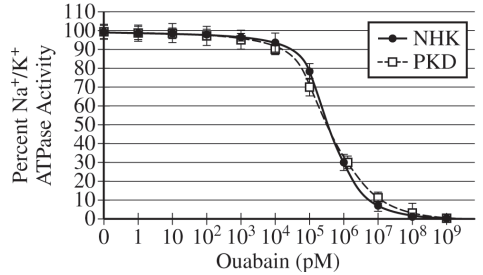


Figure 2. Percent Na^+/K^+ATPase activity of NHK and PKD cells treated with increasing concentrations of ouabain. Error bars represent $\pm 2SE_{\bar{x}}$.

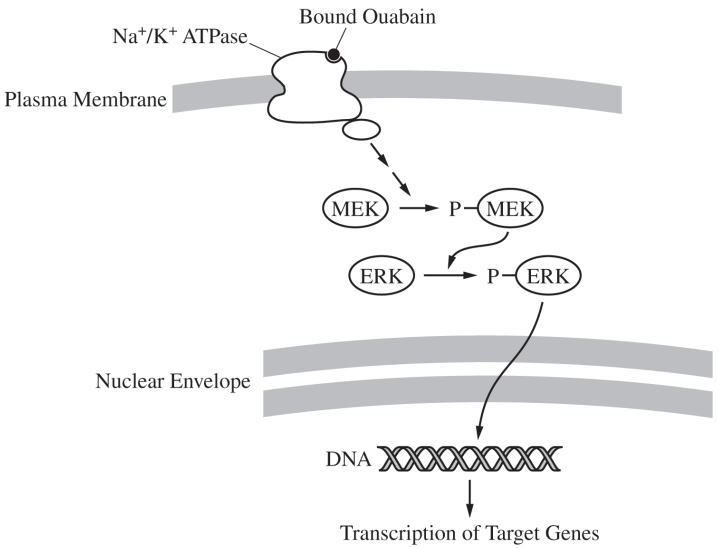


Figure 3. Signal transduction pathway hypothesized to play a role in the increased number of PKD cells

(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.

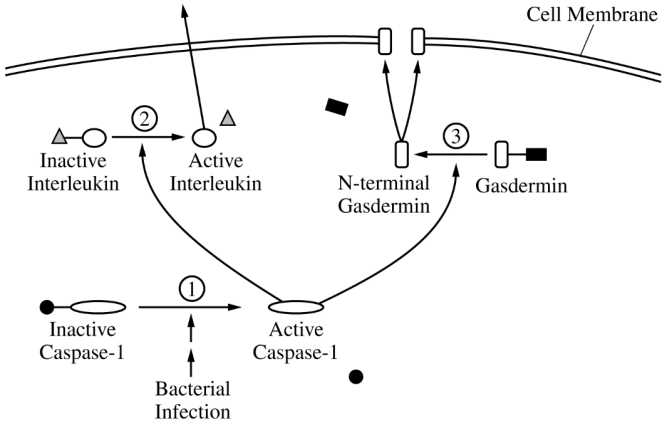


Figure 1. Cellular response to infection by pathogenic bacteria

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-κB (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-κB 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.

8. Acetylcholine receptor (AChR) proteins are found at the synapse between neurons and skeletal muscle cells. Acetylcholine released from neurons binds to a specific site on the receptor proteins, which causes an ion channel in the receptors to open and allow sodium ions (Na^+) to enter muscle cells. The resulting depolarization of muscle cells initiates muscle contractions. Another molecule, nicotine, can also bind to certain types of AChR proteins and activate the receptors.

A researcher is investigating two different types of AChR proteins: type 1 and type 2. To determine which stimuli activate the receptors, the researcher exposes muscle cells expressing the different types of receptor proteins to stimuli and observes the results indicated in Table 1.

TABLE 1. RESPONSE OF AChR PROTEINS TO DIFFERENT STIMULI

AChR Protein Type	Acetylcholine	Nicotine
Type 1	+	+
Type 2	+	–

+ indicates activation
– indicates no activation

(a) **Describe** the difference in the structure AND function between AChR type 1 and AChR type 2.

(b) Acetylcholinesterase is an enzyme that breaks down acetylcholine in the synapse. **Describe** the effect of inhibiting acetylcholinesterase on the muscle cells with AChR type 2.

STOP

END OF EXAM

AP BIOLOGY • EXERCISE SHEET

4.4 Feedback

Name: _____ Class: _____ Date: _____ **Total: 10 marks**

KEY WORDS feedback 反馈 • positive feedback 正反馈 • negative feedback 负反馈 • homeostasis 稳态

Objective

Build the skills to answer exam questions on **feedback** — negative and positive.

You must be able to:

- distinguish **negative feedback** 负反馈 from **positive feedback** 正反馈
- give a biological example of each
- explain how negative feedback maintains **homeostasis** 稳态

1 Worked examples

Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

■ Negative feedback

Negative feedback reverses a change to restore a set point — it keeps conditions stable (**homeostasis**). The response **opposes** the stimulus.

■ A worked negative example

Blood glucose rises → insulin is released → cells take up glucose → blood glucose falls back to normal. The rise triggers a response that lowers it.

■ Positive feedback

Positive feedback amplifies a change, pushing it further from the start — used for processes that must go to completion. The response **reinforces** the stimulus.

■ A worked positive example

During childbirth, stretching of the uterus releases oxytocin → stronger contractions → more stretching → more oxytocin, until birth. The change builds on itself.

2 Practice

Now apply the methods above.

2.1 Which type of feedback keeps a condition stable? [1]

2.2 Does positive feedback oppose or amplify a change? [1]

2.3 Give one example of negative feedback. [1]

3 Exam-style questions

3.1 Negative feedback maintains homeostasis by [1]

- **A** amplifying the change
- **B** reversing the change toward the set point
- **C** stopping all responses
- **D** ignoring the stimulus

3.2 Blood glucose rises after a meal.

(a) Describe the negative-feedback response that returns it to normal. [3]

(b) State whether childbirth (oxytocin) is negative or positive feedback. [1]

3.3 Explain why positive feedback is useful for a process like blood clotting or childbirth. [2]

Solutions

2.1 Negative feedback.

2.2 Amplify.

2.3 Any one: blood glucose control, body temperature regulation.

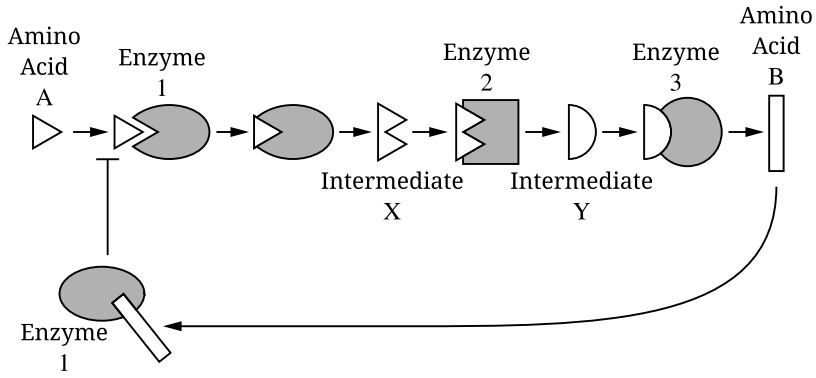
3.1 B — reversing the change toward the set point.

3.2 (a) The rise triggers insulin release; insulin makes cells take up glucose; blood glucose falls back to normal. (b) Positive feedback.

3.3 Positive feedback amplifies the change so the process quickly runs to completion (e.g. a clot forms fast, or birth finishes), which is exactly what these one-time events need.

5. Figure 1 shows the reactions of the metabolic pathway used to synthesize amino acid B from amino acid A in cells.

Figure 1. Synthesis of amino acid B from amino acid A



A. Describe a characteristic of an enzyme's active site that allows it to catalyze a specific chemical reaction.

B. Based on Figure 1, **explain** how the binding of amino acid A to enzyme 1 is regulated by amino acid B.

C. Using the information in Figure 1, **identify** the product of the reaction catalyzed by enzyme 2: intermediate X, intermediate Y, or amino acid B.

D. Based on Figure 1, **explain** how a change in pH could affect enzyme 3 in such a way that amino acid B cannot be produced.

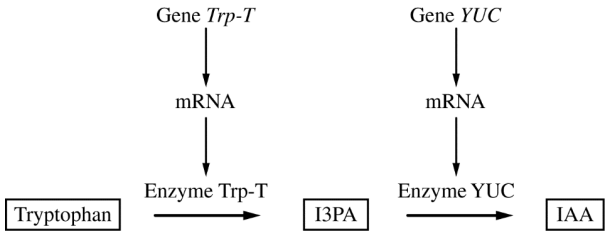


Figure 1. Model of two-step enzymatic plant pathway for synthesis of IAA from tryptophan

1. Auxins are plant hormones that coordinate several aspects of root growth and development. Indole-3-acetic acid (IAA) is an auxin that is usually synthesized from the amino acid tryptophan (Figure 1). Gene *Trp-T* encodes an enzyme that converts tryptophan to indole-3-pyruvic acid (I3PA), which is then converted to IAA by an enzyme encoded by the gene *YUC*.

   (a) **Circle** ONE arrow that represents transcription on the template pathway. **Identify** the molecule that would be absent if enzyme YUC is nonfunctional.

   (b) **Predict** how the deletion of one base pair in the fourth codon of the coding region of gene *Trp-T* would most likely affect the production of IAA. **Justify** your prediction.

   (c) **Explain** one feedback mechanism by which a cell could prevent production of too much IAA without limiting I3PA production.

   (d) Rhizobacteria are a group of bacteria that live in nodules on plant roots. Rhizobacteria can produce IAA and convert atmospheric nitrogen into forms that can be used by plants. Plants release carbon-containing molecules into the nodules. Based on this information, **identify** the most likely ecological relationship between plants and rhizobacteria. **Describe** ONE advantage to the bacteria of producing IAA.

   (e) A researcher removed a plant nodule and identified several "cheater" rhizobacteria that do not produce IAA or fix nitrogen. **Describe** the evolutionary advantage of being a bacterial cheater in a population composed predominantly of noncheater bacteria. Plants can adjust the amount of carbon-containing molecules released into nodules in response to the amount of nitrogen fixed in the nodule. **Predict** the change in the bacterial population that would cause the plant to reduce the amount of carbon-containing molecules provided to the nodule.

8. Acetylcholine receptor (AChR) proteins are found at the synapse between neurons and skeletal muscle cells. Acetylcholine released from neurons binds to a specific site on the receptor proteins, which causes an ion channel in the receptors to open and allow sodium ions (Na^+) to enter muscle cells. The resulting depolarization of muscle cells initiates muscle contractions. Another molecule, nicotine, can also bind to certain types of AChR proteins and activate the receptors.

   A researcher is investigating two different types of AChR proteins: type 1 and type 2. To determine which stimuli activate the receptors, the researcher exposes muscle cells expressing the different types of receptor proteins to stimuli and observes the results indicated in Table 1.

TABLE 1. RESPONSE OF AChR PROTEINS TO DIFFERENT STIMULI

AChR Protein Type	Acetylcholine	Nicotine
Type 1	+	+
Type 2	+	–

+ indicates activation
– indicates no activation

   (a) **Describe** the difference in the structure AND function between AChR type 1 and AChR type 2.

   (b) Acetylcholinesterase is an enzyme that breaks down acetylcholine in the synapse. **Describe** the effect of inhibiting acetylcholinesterase on the muscle cells with AChR type 2.

STOP

END OF EXAM

AP BIOLOGY • EXERCISE SHEET

4.5 Cell Cycle

Name: _____ Class: _____ Date: _____ **Total: 10 marks**

KEY WORDS mitosis 有丝分裂 • cell cycle 细胞周期 • interphase 间期

Objective

Build the skills to answer exam questions on the **cell cycle**.

You must be able to:

- name the phases (**interphase** 间期: G1, S, G2; then **mitosis** 有丝分裂 and cytokinesis)
- state what happens in each phase
- explain that DNA is copied in S phase

1 Worked examples

Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

■ The phases

The cell cycle is **interphase** followed by division:

- **G1** — the cell grows and does its normal work.
- **S** — DNA is **replicated** (copied).
- **G2** — the cell grows more and prepares to divide.
- **Mitosis (M)** — the nucleus divides; then **cytokinesis** splits the cell.

■ DNA copied in S

The genetic material is copied during **S phase**, so each new cell gets a full copy. After S, the cell has double the DNA until it divides.

■ Mitosis divides the nucleus

Mitosis separates the copied chromosomes into two identical nuclei; cytokinesis then splits the cytoplasm into two cells.

■ A worked link

A cell that has just finished S phase has twice its normal DNA; after mitosis and cytokinesis, each daughter cell has the normal amount again.

2 Practice

Now apply the methods above.

2.1 In which phase is DNA replicated? [1]

2.2 What happens during G1? [1]

2.3 What does cytokinesis do? [1]

3 Exam-style questions

3.1 DNA replication occurs during [1]

- **A** G1
- **B** S phase
- **C** G2
- **D** mitosis

3.2 A cell completes S phase.

(a) State how its amount of DNA compares to before S phase. [1]

(b) Explain what mitosis and cytokinesis then achieve. [3]

3.3 Explain why DNA must be copied before mitosis, not after. [2]

Solutions

2.1 S phase.

2.2 The cell grows and carries out its normal functions.

2.3 It divides the cytoplasm, splitting the cell into two.

3.1 B — S phase.

3.2 (a) It has doubled. (b) Mitosis separates the copied chromosomes into two identical nuclei, and cytokinesis splits the cytoplasm, producing two identical daughter cells.

3.3 Each daughter cell needs a full copy of the DNA; copying it first (in S) ensures there are two complete sets for mitosis to separate.

The following information applies to all parts.

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4. The process of meiosis enables animals that reproduce sexually to produce gametes.

Part A

Describe one characteristic of chromosome movement during Meiosis I.

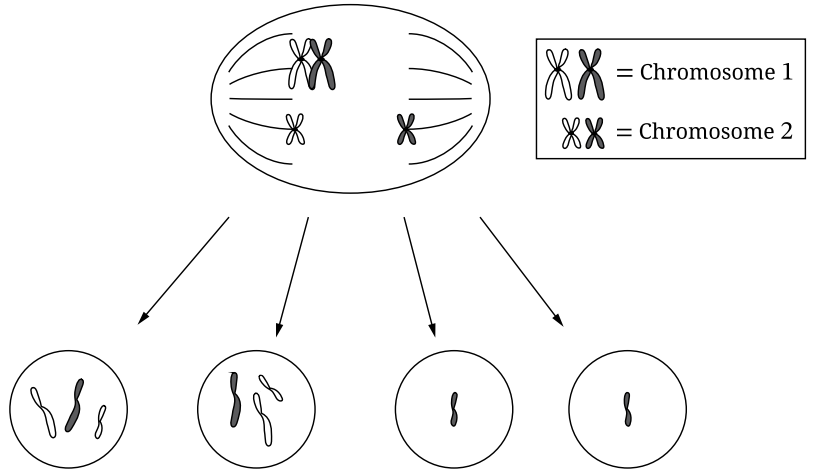
Part B

Explain why chromosomes are more visible when viewed under a microscope during mitosis or meiosis than at any other time in the cell cycle.

Part C

An animal cell with two pairs of homologous chromosomes (a diploid number of four) has undergone meiosis to produce four gametes, and an error occurred at one step, as shown in the figure. One set of chromosomes is represented in white, and the other set is represented in gray.

An Animal Cell Undergoing Meiosis



Assume that each gamete produced by the cell shown in the figure is fertilized by a gamete with a complete haploid set of chromosomes. Also assume gene regulation on Chromosome 1 is not affected by the number of copies of Chromosome 1 in the four resulting viable zygotes. **Predict** the difference in mRNA production from genes on Chromosome 1 among the four possible zygotes.

Part D

Triploidy describes a condition in which an organism has three complete sets of chromosomes in each cell. Provide reasoning to **justify** the claim that most organisms with triploidy cannot produce gametes with the chromosome number typical of the species.

1. Crossing over in meiosis I is required for homologous chromosomes to properly align during metaphase and segregate during the first cell division.

(a)

(i) **Describe** the function of S phase of interphase.

Some regions of a chromosome called hotspots display a higher frequency of crossing over than other regions do. Crossing over is suppressed in chromosomal regions near the centromeres. The centromere region of a duplicated chromosome includes a collection of proteins that form a structure called the kinetochore. Scientists hypothesized that one or more of these kinetochore proteins are responsible for suppressing crossing over around the centromere.

To investigate their hypothesis, scientists modified chromosome 8 in yeast such that, in each cell, one chromosome from the pair of homologous chromosome 8s contained the gene encoding red fluorescent protein (RFP), while the other chromosome from the pair contained the gene encoding green fluorescent protein (GFP). Cells expressing RFP emit (give off) red light, and cells expressing GFP emit green light. Models of the modified chromosome 8 both before and after crossing over are shown in Figure 1.

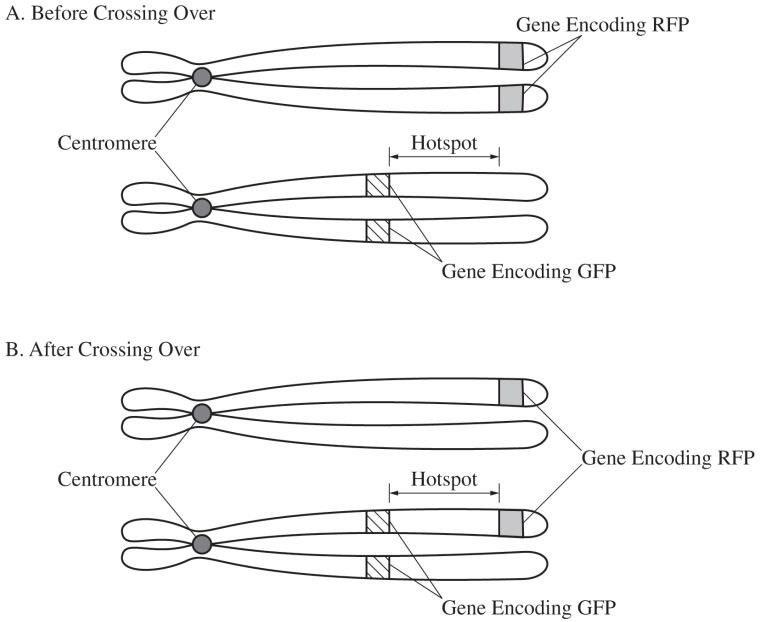


Figure 1. Models of modified chromosome 8 used in the experiment (A) before and (B) after crossing over occurs at the hotspot

(ii) **Explain** why some haploid cells formed after meiosis in this experiment will have only one fluorescent marker.

The scientists then investigated whether attaching individual kinetochore proteins to a specific DNA sequence present in a known crossing-over hotspot on chromosome 8 affected the frequency of crossing over at this location. In their first experiment, they examined three groups of yeast cells containing the modified chromosome 8. Group 1 contained no kinetochore proteins attached to the hotspot, group 2 contained the kinetochore protein CTF attached to the hotspot, and group 3 contained the kinetochore protein IML attached to the hotspot. For each group, the scientists determined the frequency of crossing over between the RFP and GFP genes. To determine the frequency, the scientists added the number of cells emitting both red and green light to the number of cells that emitted no light and divided by the total number of cells (Figure 2).

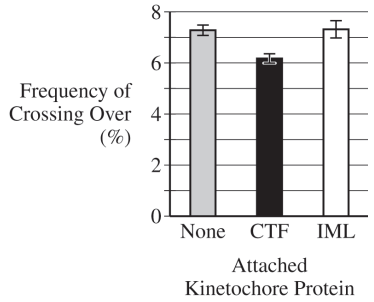


Figure 2. The frequency of crossing over in a hotspot on yeast chromosome 8 for cell groups treated with different kinetochore proteins. Error bars represent $\pm 2SE_{\bar{x}}$.

(b)

(i) **Identify** the control group for the scientists' first experiment, shown in Figure 2.

(ii) In a follow-up experiment, the scientists created a modified version of CTF in which the DNA-binding portion had been removed. They compared the frequency of crossing over in yeast cells in the presence and absence of unmodified CTF with that in yeast cells in the presence and absence of the modified CTF protein (data not shown). In the follow-up experiment, **justify** why the scientists used a modified CTF protein that is unable to bind to DNA as a control.

(iii) **Identify** the independent variable in the follow-up experiment.

(c) Based on Figure 2, **describe** the effect on the frequency of crossing over when CTF is attached to the chromosome 8 hotspot compared with the effect when IML is attached to the hotspot.

(d)

(i) **Predict** the effect on the number of copies of chromosome 8 likely to be present in the resulting daughter cells when CTF is attached to the hotspot.

(ii) Provide reasoning to **justify** your prediction.

(iii) **Explain** how the presence of hotspots (Figure 1) could increase the likelihood that a population will survive in the presence of selective pressures.

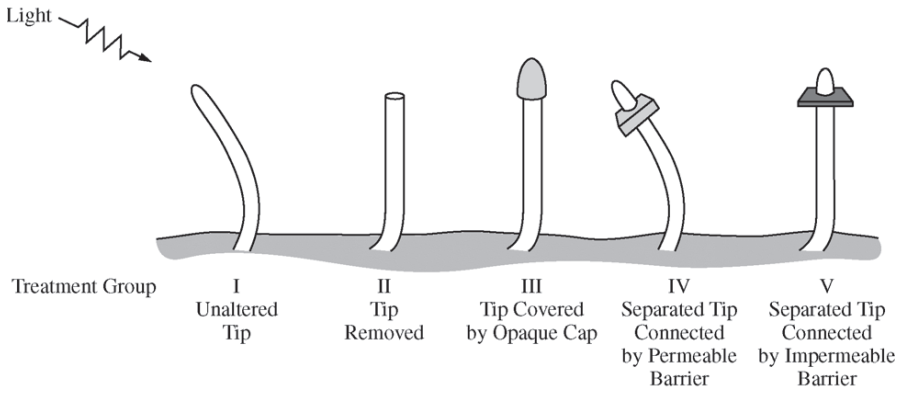
Write your responses to this question only on the designated pages in the separate Free Response booklet.

If there are multiple parts to this question. write the part letter with your response.

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.



AP BIOLOGY • EXERCISE SHEET

4.6 Regulation of Cell Cycle

Name: _____ Class: _____ Date: _____ **Total: 9 marks**

KEY WORDS checkpoints 检查点 • cancer 癌症 • cell cycle 细胞周期 • homeostasis 稳态 • signals 信号

Objective

Build the skills to answer exam questions on the **regulation of the cell cycle**.

You must be able to:

- describe **checkpoints** 检查点 that control the cycle
- explain the role of regulatory proteins
- link loss of control to **cancer** 癌症

1 Worked examples

Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

■ Checkpoints

The cell cycle has **checkpoints** (mainly G1, G2, and M) where the cell verifies conditions are right — enough resources, DNA copied correctly, chromosomes attached — before proceeding.

■ Regulatory proteins

Proteins (like cyclins and their kinases) control passage through checkpoints. They act as the "go/stop" signals for division.

■ The G1 checkpoint

At the **G1 checkpoint** the cell decides whether to divide. If conditions are poor or DNA is damaged, it pauses or exits the cycle to repair or wait.

■ Loss of control → cancer

If checkpoints fail (e.g. mutated regulatory genes), cells may divide uncontrollably, forming a tumor — the basis of **cancer**.

2 Practice

Now apply the methods above.

2.1 What do cell-cycle checkpoints do? [1]

2.2 At which checkpoint does the cell decide whether to divide? [1]

2.3 What can result from a loss of cell-cycle control? [1]

3 Exam-style questions

3.1 Uncontrolled cell division caused by failed checkpoints can lead to [1]

- **A** apoptosis
- **B** cancer
- **C** homeostasis
- **D** meiosis

3.2 A cell has DNA damage at the G2 checkpoint.

(a) State what a healthy checkpoint should do. [1]

(b) Explain what could happen if the checkpoint fails. [2]

3.3 Explain why checkpoints are important for producing healthy daughter cells. [2]

Solutions

2.1 They check that conditions are correct before the cell proceeds to the next phase.

2.2 The G1 checkpoint.

2.3 Cancer (uncontrolled cell division).

3.1 **B** — cancer.

3.2 (a) It should pause the cycle to repair the DNA (or prevent division). (b) If it fails, the cell divides with damaged DNA, passing the errors on and possibly leading to uncontrolled division (cancer).

3.3 Checkpoints ensure the DNA is copied correctly and conditions are right before division, so each daughter cell receives a complete, accurate set of chromosomes.

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.

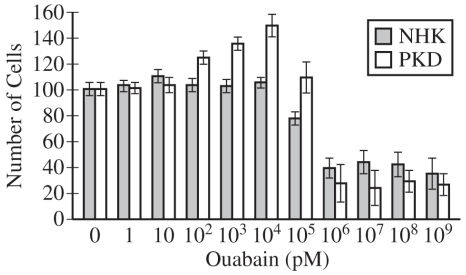


Figure 1. Cell number compared with the number of cells at 0 pM ouabain. Normal human kidney (NHK) cells and polycystic kidney disease (PKD) cells were treated with increasing concentrations of ouabain. Error bars represent $\pm 2SE_{\bar{x}}$.

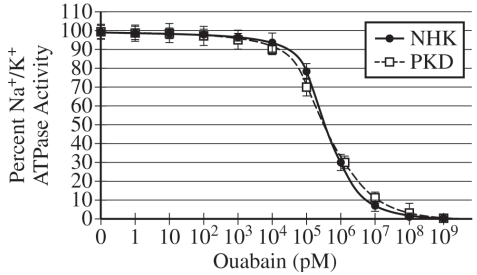


Figure 2. Percent Na^+/K^+ATPase activity of NHK and PKD cells treated with increasing concentrations of ouabain. Error bars represent $\pm 2SE_{\bar{x}}$.

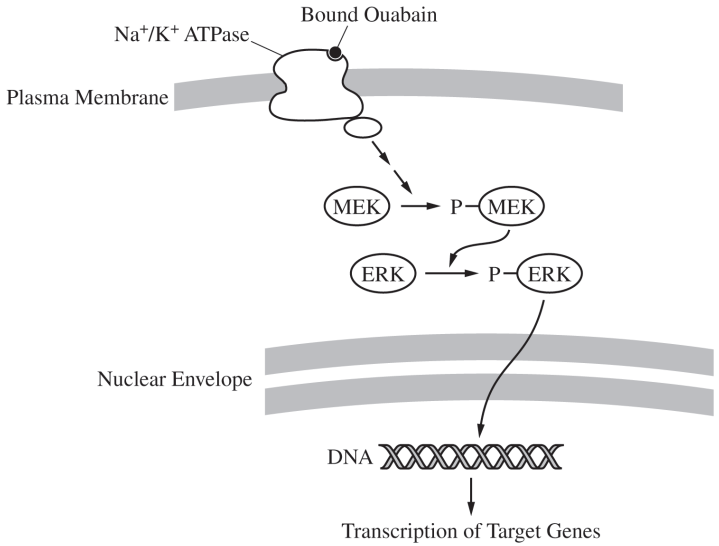


Figure 3. Signal transduction pathway hypothesized to play a role in the increased number of PKD cells

(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.