**Week 5**

# AP Biology

Homework bundle for this week

本周作业合集

exercises.lol

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# 2. Cell Structure and Function

**Starter Quiz · 课前小测**

AP Biology Name: _____ Score: _____

1. An **organelle** is…
   - ☐ a small structure inside a cell with a specific job
   - ☐ a whole organ, like the heart
   - ☐ a type of cell
   - ☐ a molecule of DNA
2. Why must most cells stay very small?
   - ☐ A small cell has a high surface-area-to-volume ratio for fast exchange
   - ☐ Small cells weigh less
   - ☐ Small cells have more DNA
   - ☐ Big cells cannot hold water
3. The plasma membrane is built mainly from a…
   - ☐ phospholipid bilayer
   - ☐ single layer of protein
   - ☐ sheet of DNA
   - ☐ solid wall of cellulose
4. In **diffusion**, particles move…
   - ☐ from high concentration to low concentration
   - ☐ from low concentration to high concentration
   - ☐ only upward
   - ☐ only if pushed by a pump
5. **Passive transport** moves substances…
   - ☐ down the gradient, using no energy
   - ☐ up the gradient, using ATP
   - ☐ only into the cell
   - ☐ only when the cell is dead
6. As a cell gets bigger, its surface-area-to-volume ratio falls.

   ☐ True ☐ False

7. The model of the membrane, with proteins floating in a moving lipid sheet, is the _____ mosaic model.

   _____

8. Diffusion is **passive** — it needs no energy from the cell.

   ☐ True ☐ False

9. The organelle that stores DNA and controls the cell is the _____.

   _____

10. A cube of side 2 has surface area 24 and volume 8. What is its SA:V ratio (surface ÷ volume)?

    _____

# 2. Cell Structure and Function

**Answers · 答案**

AP Biology

1. **a small structure inside a cell with a specific job**

   An **organelle** is a specialised structure inside a cell — like the nucleus or a mitochondrion — each doing a specific job.

2. **A small cell has a high surface-area-to-volume ratio for fast exchange**

   A small cell has a large **surface area** relative to its **volume**, so materials diffuse in and out fast enough.

3. **phospholipid bilayer**

   The membrane is a **phospholipid bilayer** — two layers of phospholipids with proteins embedded in them.

4. **from high concentration to low concentration**

   **Diffusion** is the net movement of particles down their **concentration gradient** — high to low.

5. **down the gradient, using no energy**

   **Passive transport** goes down the concentration gradient and costs the cell no energy.

6. **True**

   Volume grows faster than surface area, so the **SA:V ratio** falls as size increases.

7. **fluid**

   In the **fluid mosaic** model the lipids move like a fluid, and proteins are scattered through them like a mosaic.

8. **True**

   Diffusion is **passive**: particles move on their own random motion, so the cell spends no ATP.

9. **nucleus**

   The **nucleus** holds the DNA and directs everything the cell does.

10. **3**

    $24 \div 8 = 3$. A smaller cube (side 1) would give $6 \div 1 = 6$ — a higher ratio.

AP BIOLOGY • EXERCISE SHEET

# 2.1 Organelles and the Endomembrane System

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

**KEY WORDS** golgi 高尔基体 • mitochondria 线粒体 • endomembrane system 内膜系统 • organelles 细胞器 • nucleus 细胞核

## Objective

Build the skills to answer exam questions on **organelles and the endomembrane system**.

**You must be able to:**

- state the functions of key **organelles** 细胞器 (nucleus, mitochondria, ribosomes, ER, Golgi)
- describe the **endomembrane system** 内膜系统 pathway
- link each organelle's structure to its role

## 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.

### ■ Key organelles

- **Nucleus** — holds DNA, controls the cell.
- **Ribosomes** — build proteins.
- **Mitochondria** — carry out cellular respiration (make ATP).
- **Rough ER** — has ribosomes; makes and folds proteins.
- **Smooth ER** — makes lipids.
- **Golgi apparatus** — modifies, sorts, and ships proteins.

### ■ The endomembrane system

The **endomembrane system** is a set of connected membranes that make, process, and transport proteins and lipids: nuclear envelope → ER → Golgi → vesicles → membrane/secretion.

■ **A worked pathway**

A protein for export is made on the **rough ER**, sent in a **vesicle** to the **Golgi** for modification, then packaged and released at the cell membrane.

■ **Structure fits function**

More mitochondria appear in cells needing lots of energy (e.g. muscle); many ribosomes appear in cells making lots of protein.

## 2 Practice

Now apply the methods above.

**2.1** Which organelle makes ATP by respiration? [1]

**2.2** State the function of the Golgi apparatus. [1]

**2.3** Which organelle builds proteins? [1]

## 3 Exam-style questions

**3.1** Proteins destined for export are first made on the [1]

- **A** smooth ER
- **B** rough ER
- **C** Golgi
- **D** nucleus

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**3.2** A protein is secreted from a cell.

(a) List, in order, the organelles it passes through from synthesis to export. [3]

(b) State the role of the Golgi in this pathway. [1]

**3.3** Explain why a muscle cell contains many mitochondria. [2]

## Solutions

**2.1** Mitochondria.

**2.2** It modifies, sorts, and ships proteins.

**2.3** Ribosomes.

**3.1 B** — the rough ER.

**3.2** (a) Ribosome/rough ER → vesicle → Golgi → vesicle → cell membrane. (b) It modifies, sorts, and packages the protein for export.

**3.3** Muscle cells need a lot of ATP for contraction, and mitochondria carry out respiration to make ATP, so many are present.

AP BIOLOGY • EXERCISE SHEET

# 2.2 Why Cells Stay Small

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

**KEY WORDS** surface-area-to-volume ratio 表面积体积比

## Objective

Build the skills to answer exam questions on **why cells stay small** — the surface-area-to-volume ratio.

**You must be able to:**

- calculate a **surface-area-to-volume ratio** 表面积体积比
- explain why a high ratio helps exchange
- link small size (or folded shapes) to efficient transport

## 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.

### Surface area vs volume

As a cell grows, its **volume** (needs) grows faster than its **surface area** (exchange). So a large cell cannot exchange materials fast enough across its membrane.

### The ratio

A **high surface-area-to-volume ratio** means lots of membrane per unit of contents — good for fast exchange of nutrients, gases, and waste. Small cells have high ratios.

### A worked ratio

A cube of side 2: surface area $= 6(2^2) = 24$; volume $= 2^3 = 8$; ratio $= 24/8 = 3$. A cube of side 4: SA $= 96$, V $= 64$, ratio $= 1.5$ — lower. Bigger = lower ratio.

### Solutions to size limits

Cells stay **small**, or increase surface area by **folding** the membrane (like microvilli), to keep exchange efficient.

## 2 Practice

Now apply the methods above.

**2.1** As a cell gets bigger, which grows faster: surface area or volume? [1]

**2.2** For a cube of side 3, find the surface-area-to-volume ratio. [3]

**2.3** Why is a high surface-area-to-volume ratio helpful? [1]

## 3 Exam-style questions

**3.1** A small cell exchanges materials more efficiently because it has a [1]

- **A** lower surface-area-to-volume ratio
- **B** higher surface-area-to-volume ratio
- **C** larger volume
- **D** thicker membrane

**3.2** Two cube-shaped cells have sides 2 and 5.

(a) Find the surface-area-to-volume ratio of each. [3]

(b) State which exchanges materials more efficiently. [1]

**3.3** Explain how microvilli (tiny membrane folds) help a cell overcome the size limit on

exchange. [2]

## Solutions

**2.1** Volume.

**2.2** SA $= 6(3^2) = 54$; V $= 3^3 = 27$; ratio $= 54/27 = 2$.

**2.3** It provides more membrane per unit volume for faster exchange of materials.

**3.1 B** — a higher surface-area-to-volume ratio.

**3.2** (a) Side 2: SA $= 24$, V $= 8$, ratio $= 3$; side 5: SA $= 150$, V $= 125$, ratio $= 1.2$. (b) The smaller cell (side 2), with the higher ratio.

**3.3** Folds greatly increase the membrane surface area without adding much volume, raising the surface-area-to-volume ratio and speeding exchange.

AP BIOLOGY • EXERCISE SHEET

# 2.3 The Fluid Mosaic Model of the Membrane

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

**KEY WORDS** fluid mosaic model 流动镶嵌模型 • phospholipid bilayer 磷脂双层 • carrier 载体 • selectively permeab

## Objective

Build the skills to answer exam questions on the **fluid mosaic model** of the membrane.

**You must be able to:**

- describe the **phospholipid bilayer** 磷脂双层 with embedded proteins
- explain why it is "fluid" and a "mosaic"
- state the roles of membrane proteins and cholesterol

## 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 fluid mosaic model

The membrane is a **phospholipid bilayer** with **proteins** embedded in and on it. It is:

- **fluid** — phospholipids and proteins drift sideways;
- a **mosaic** — many different molecules dotted throughout.

### ■ Membrane proteins

Proteins act as **channels/transporters** (move substances), **receptors** (receive signals), and markers (cell recognition). They give the membrane most of its specific functions.

### ■ Cholesterol

**Cholesterol** sits among the phospholipids and stabilizes fluidity — keeping the membrane from becoming too fluid when warm or too stiff when cold.

### ■ Selective permeability

The hydrophobic core lets small nonpolar molecules pass but blocks most ions and large polar molecules, which need proteins — making the membrane **selectively permeable**.

## 2 Practice

Now apply the methods above.

**2.1** What are the two main components of the membrane? [2]

**2.2** Why is the model called “fluid”? [1]

**2.3** State one function of membrane proteins. [1]

## 3 Exam-style questions

**3.1** In the fluid mosaic model, the membrane is described as a mosaic because it [1]

- **A** is completely rigid
- **B** contains many different molecules scattered throughout
- **C** has only phospholipids
- **D** never moves

**3.2** A membrane must transport glucose into a cell.

(a) Explain why glucose cannot cross the bilayer directly. [1]

(b) State what allows glucose to cross. [2]

**3.3** Explain the role of cholesterol in maintaining membrane fluidity across temperatures. [2]

## Solutions

**2.1** A phospholipid bilayer and embedded proteins.

**2.2** The phospholipids and proteins can move sideways within the layer.

**2.3** Any one: transport (channel/carrier), receptor for signals, cell recognition.

**3.1 B** — many different molecules scattered throughout.

**3.2** (a) Glucose is large and polar, so it cannot pass through the hydrophobic core. (b) A transport (carrier/channel) protein allows glucose across.

**3.3** Cholesterol keeps the membrane from becoming too fluid at high temperatures and too rigid at low temperatures, stabilizing fluidity.

**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.

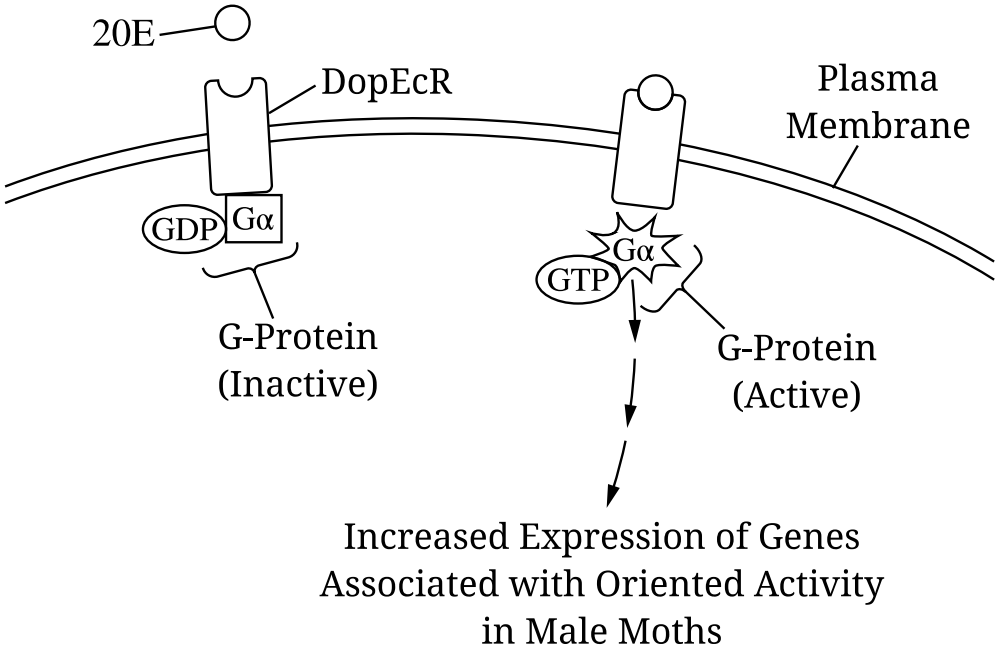
To investigate whether the binding of 20E to its receptor, DopEcR, affects behavior in moths, scientists injected male moths with saline (control solution) or with small interfering RNA molecules (siRNAs) that inhibit the expression of the gene encoding DopEcR. The scientists then exposed the moths to 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) | $95 \pm 5$ | $60 \pm 4$ |
| Male moths injected with siRNAs that inhibit expression of the gene encoding DopEcR | $90 \pm 8$ | $25 \pm 6$ |

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. 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.

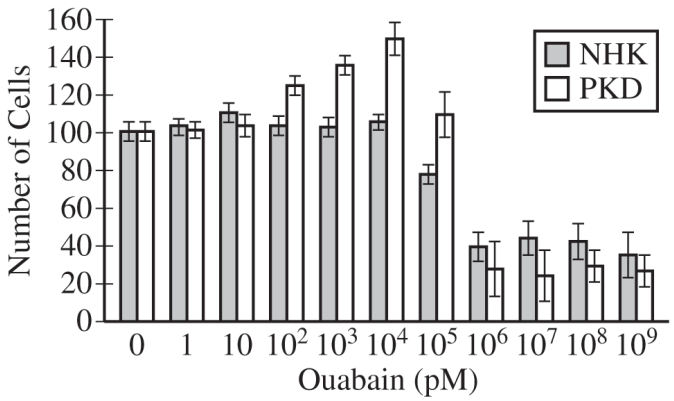



Figure 1. Cell number compared with the number of cells at 0 pM ouabain. Normal human kidney (NHK) cells and polycystic kidney disease (PKD) cells were treated with increasing concentrations of ouabain. Error bars represent $\pm 2SE_{\bar{x}}$.

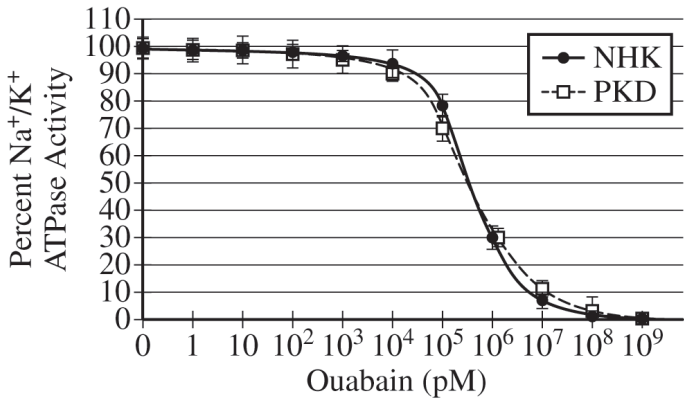



Figure 2. Percent $Na^+/K^+$ATPase activity of NHK and PKD cells treated with increasing concentrations of ouabain. Error bars represent $\pm 2SE_{\bar{x}}$.

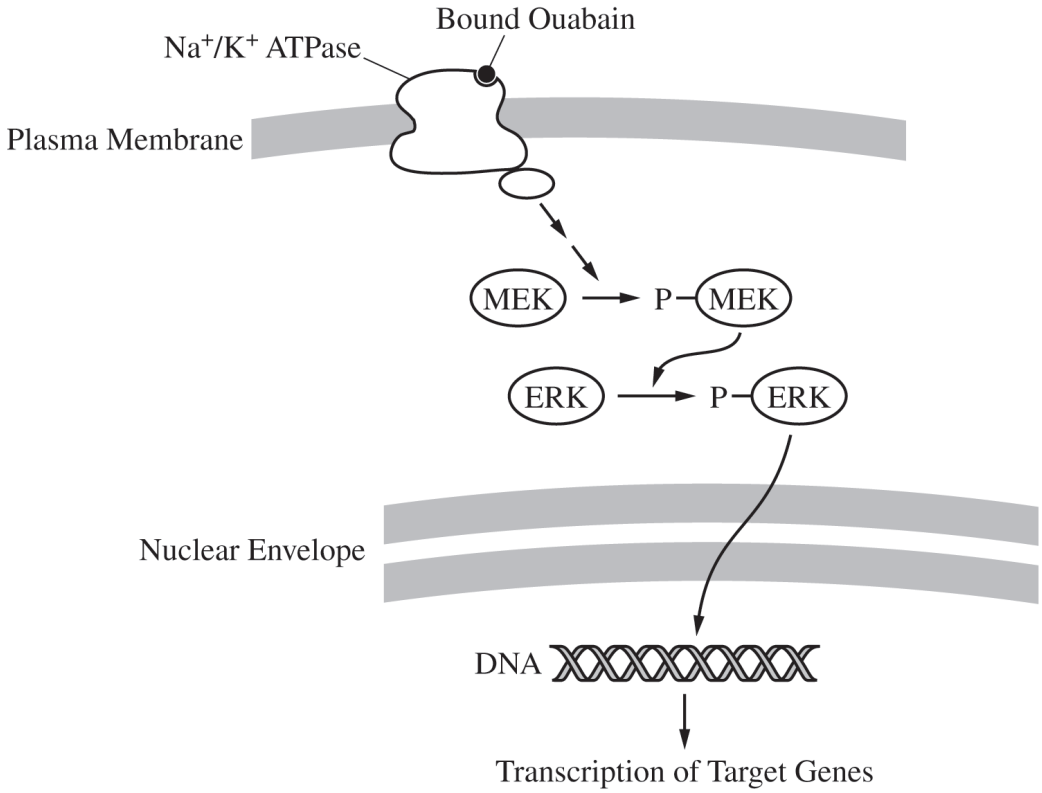



Figure 3. Signal transduction pathway hypothesized to play a role in the increased number of PKD cells

(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.

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

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**

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

# 2.4 What Can Cross the Membrane

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

**KEY WORDS** phospholipid bilayer 磷脂双分子层

## Objective

Build the skills to answer exam questions on **what can cross the membrane** — selective permeability.

**You must be able to:**

- predict which molecules cross the bilayer easily
- explain why size and polarity matter
- link the hydrophobic core to selective permeability

## 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 hydrophobic barrier

The membrane's inner core is **hydrophobic** (the nonpolar tails). Molecules that are **small and nonpolar** slip through easily; large or charged molecules do not.

### Easy crossers

- **Small nonpolar** ($O_2$, $CO_2$) — cross freely.
- **Small polar** (water, in small amounts) — cross slowly.

### Blocked without help

- **Large polar** (glucose) and **ions** ($Na^+$, $Cl^-$) — cannot cross the core; they need **transport proteins**.

### A worked prediction

Oxygen (small, nonpolar) diffuses straight through; a sodium ion (charged) is blocked and must use a channel or pump.

## 2 Practice

Now apply the methods above.

**2.1** What kind of molecule crosses the bilayer most easily? [1]

**2.2** Why can't ions cross the bilayer directly? [1]

**2.3** State one gas that diffuses freely across the membrane. [1]

## 3 Exam-style questions

**3.1** Which molecule crosses the phospholipid bilayer most easily? [1]

- **A** a sodium ion
- **B** glucose
- **C** oxygen gas
- **D** a protein

**3.2** A cell must take in oxygen and glucose.

(a) State which can cross the bilayer directly, and why. [2]

(b) State what the other needs to cross. [1]

**3.3** Explain why the membrane is described as **selectively** permeable. [2]

## Solutions

**2.1** A small, nonpolar molecule.

**2.2** They are charged, so they cannot pass through the hydrophobic core.

**2.3** Oxygen (or carbon dioxide).

**3.1 C** — oxygen gas (small and nonpolar).

**3.2** (a) Oxygen — it is small and nonpolar, so it crosses the hydrophobic core directly. (b) Glucose needs a transport protein.

**3.3** The membrane lets some molecules (small, nonpolar) cross freely but controls or blocks others (large, polar, charged), so it selects what enters and leaves.

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

# 2.5 Passive and Active Transport

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

**KEY WORDS** active 主动运输 • passive 被动运输 • diffusion 扩散 • facilitated diffusion 易化扩散 • osmosis 渗透

## Objective

Build the skills to answer exam questions on **passive and active transport**.

**You must be able to:**

- distinguish **passive** 被动运输 (no ATP, down the gradient) from **active** 主动运输 (uses ATP, against the gradient)
- give examples of each
- explain the role of the concentration gradient

## 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.

### Passive transport

**Passive transport** moves substances **down** their concentration gradient (high → low) with **no energy** needed. Examples: diffusion, osmosis, facilitated diffusion.

### Active transport

**Active transport** moves substances **against** the gradient (low → high) and **requires ATP**. A pump protein uses energy to push the substance the "wrong" way.

### A worked example

The **sodium-potassium pump** uses ATP to push $Na^+$ out and $K^+$ in, both against their gradients — active transport.

### Deciding which

Ask: is it moving **down** the gradient (passive, free) or **up** the gradient (active, needs ATP)? That tells you which type it is.

## 2 Practice

Now apply the methods above.

**2.1** Does passive transport require ATP? [1]

**2.2** In which direction (relative to the gradient) does active transport move a substance? [1]

**2.3** Give one example of active transport. [1]

## 3 Exam-style questions

**3.1** Active transport differs from passive transport because it [1]

- **A** moves substances down the gradient
- **B** requires ATP and moves against the gradient
- **C** never uses proteins
- **D** only moves gases

**3.2** A cell pumps calcium ions out against their concentration gradient.

(a) State whether this is active or passive transport. [1]

(b) Explain why ATP is needed. [2]

**3.3** Diffusion of oxygen into a cell needs no energy, but importing glucose against its gradient does. Explain the difference. [2]

## Solutions

**2.1** No.

**2.2** Against the gradient (low → high).

**2.3** The sodium-potassium pump (or any pump moving ions against the gradient).

**3.1 B** — requires ATP and moves against the gradient.

**3.2** (a) Active transport. (b) Moving ions against their gradient does not happen spontaneously, so energy from ATP is needed to power the pump.

**3.3** Oxygen moves **down** its gradient (passive, spontaneous, no energy); glucose is moved **against** its gradient, which is not spontaneous and requires ATP (active transport).

AP BIOLOGY • EXERCISE SHEET

# 2.6 Facilitated Diffusion

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

**KEY WORDS** facilitated diffusion 易化扩散 • channel 通道 • carrier 载体 • diffusion 扩散

## Objective

Build the skills to answer exam questions on **facilitated diffusion**.

**You must be able to:**

- describe **facilitated diffusion** 易化扩散 (passive, protein-assisted)
- distinguish **channel** 通道 and **carrier** 载体 proteins
- explain why it is still passive

## 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.

### Facilitated diffusion

**Facilitated diffusion** moves molecules **down** their concentration gradient **through a protein**. It is **passive** — no ATP — but needs a protein because the molecule cannot cross the bilayer alone.

### Channel vs carrier

- **Channel proteins** form a pore that lets specific ions or water pass.
- **Carrier proteins** bind the molecule and change shape to move it across.

### Still passive

Even though a protein is used, no energy is spent because the substance moves **down** its gradient — the protein just provides a route.

### A worked example

Glucose enters a cell through a **carrier protein** (facilitated diffusion) when glucose is more concentrated outside — down the gradient, no ATP.

## 2 Practice

Now apply the methods above.

**2.1** Is facilitated diffusion active or passive? [1]

**2.2** Name the two types of transport protein used. [2]

**2.3** Why does glucose need a protein to enter by facilitated diffusion? [1]

## 3 Exam-style questions

**3.1** Facilitated diffusion requires [1]

- **A** ATP and a protein
- **B** a protein but no ATP
- **C** neither a protein nor ATP
- **D** ATP but no protein

**3.2** A carrier protein moves glucose into a cell where glucose is less concentrated.

(a) State whether ATP is used, with a reason. [2]

(b) Explain how a carrier protein differs from a channel protein. [2]

**3.3** Explain why facilitated diffusion is passive even though it uses a protein. [2]

## Solutions

**2.1** Passive.

**2.2** Channel proteins and carrier proteins.

**2.3** Glucose is large and polar, so it cannot cross the hydrophobic bilayer without a protein.

**3.1 B** — a protein but no ATP.

**3.2** (a) No ATP — glucose moves down its gradient, which is spontaneous. (b) A channel forms a pore for the molecule to pass through; a carrier binds the molecule and changes shape to move it.

**3.3** The molecule still moves **down** its concentration gradient, so no energy is spent; the protein only provides a passageway across the membrane.

3. To investigate whether red blood cells of animals lose the ability to take in glucose from their environment as they age, scientists collected red blood cells from guinea pigs that ranged in age from one day old to seven months old. Scientists incubated an equal number of red blood cells in separate culture dishes that contained a 300 nM solution of radioactively labeled glucose. The amount of radioactively labeled glucose present inside the red blood cells of each group was measured over time.

   (a) **Describe** a difference between passive transport and active transport.

   (b) **Justify** why the scientists used an equal number of red blood cells in each culture dish as a control.

   (c) Glucose transporters are required for the facilitated diffusion of glucose into red blood cells. The scientists claim that the expression of the gene encoding these transporters decreases as guinea pigs age. If the scientists' claim is supported by experimental data, **predict** the effect of increased age on the amount of radioactively labeled glucose present inside the cells of each group.

   (d) **Justify** your prediction in part (c).

---

**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.**

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 Gs$\alpha$, a subunit of the G protein (Figure 1, B). This causes Gs$\alpha$ 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, Gs$\alpha$ hydrolyzes GTP to GDP, thus inactivating adenylyl cyclase and stopping the signal (Figure 1, A).

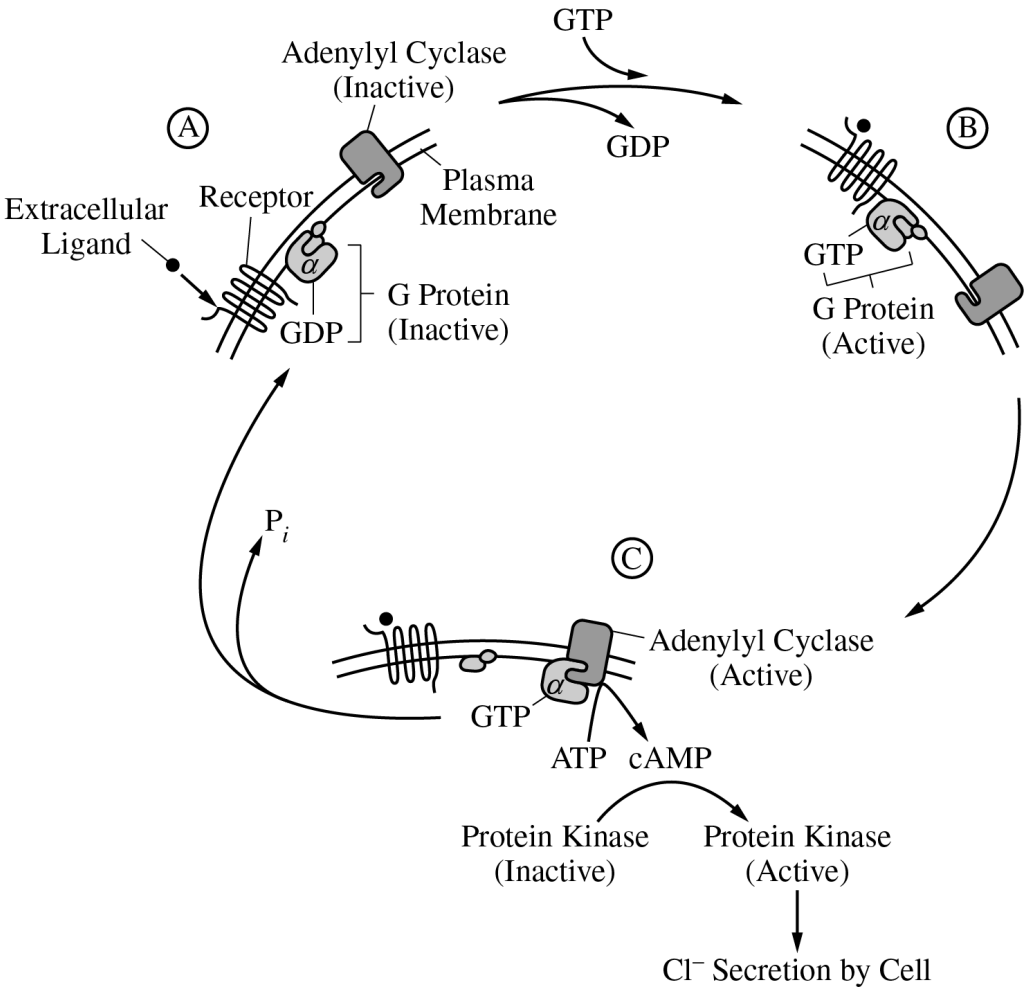


Figure 1. Under normal conditions, ligand binding to a G protein-coupled receptor results in chloride ion transport from an intestinal cell.

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 Gs$\alpha$. 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.

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

AP BIOLOGY • EXERCISE SHEET

# 2.7 Tonicity, Water Potential, and Osmoregulation

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

**KEY WORDS** hypotonic 低渗 • water potential 水势 • osmosis 渗透 • hypertonic 高渗 • isotonic 等渗

## Objective

Build the skills to answer exam questions on **tonicity, water potential, and osmoregulation**.

**You must be able to:**

- classify a solution as **hypertonic** 高渗, **hypotonic** 低渗, or **isotonic** 等渗
- predict the direction of **osmosis** 渗透 and the effect on a cell
- use the idea of **water potential** 水势

## 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.

### ■ Tonicity

Compared with the cell:

- **Hypertonic** solution — more solute outside → water **leaves** the cell (shrinks).
- **Hypotonic** solution — less solute outside → water **enters** the cell (swells, may burst).
- **Isotonic** — equal solute → no net movement.

### ■ Osmosis direction

Water moves by **osmosis** from **high water potential** (dilute) to **low water potential** (concentrated) — toward the side with more solute.

### ■ Water potential

**Water potential** measures the tendency of water to move. Adding solute **lowers** water potential; water moves from higher to lower water potential.

**■ A worked prediction**

A red blood cell in a hypotonic solution: water enters (the outside has higher water potential), so the cell swells and may lyse (burst).

## 2 Practice

Now apply the methods above.

**2.1** In a hypertonic solution, which way does water move relative to the cell? [1]

**2.2** Does adding solute raise or lower water potential? [1]

**2.3** What happens to an animal cell in a hypotonic solution? [1]

## 3 Exam-style questions

**3.1** Water moves by osmosis from a region of [1]

- **A** low to high water potential
- **B** high to low water potential
- **C** high to high water potential
- **D** it does not move

**3.2** A plant cell is placed in a very concentrated salt solution.

(a) State whether the solution is hypertonic or hypotonic. [1]

(b) Predict the direction of water movement and the effect on the cell. [3]

**3.3** Explain why a freshwater organism must actively remove excess water (osmoregula-

tion). [2]

## Solutions

**2.1** Water leaves the cell.

**2.2** Lower.

**2.3** It swells and may burst (lyse).

**3.1 B** — high to low water potential.

**3.2** (a) Hypertonic. (b) Water leaves the cell by osmosis (toward the lower water potential outside), so the cell loses water and the membrane pulls away from the wall (plasmolysis).

**3.3** Its surroundings are hypotonic (higher water potential), so water constantly enters by osmosis; it must actively remove the excess to avoid swelling and bursting.

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 Gs$\alpha$, a subunit of the G protein (Figure 1, B). This causes Gs$\alpha$ 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, Gs$\alpha$ hydrolyzes GTP to GDP, thus inactivating adenylyl cyclase and stopping the signal (Figure 1, A).

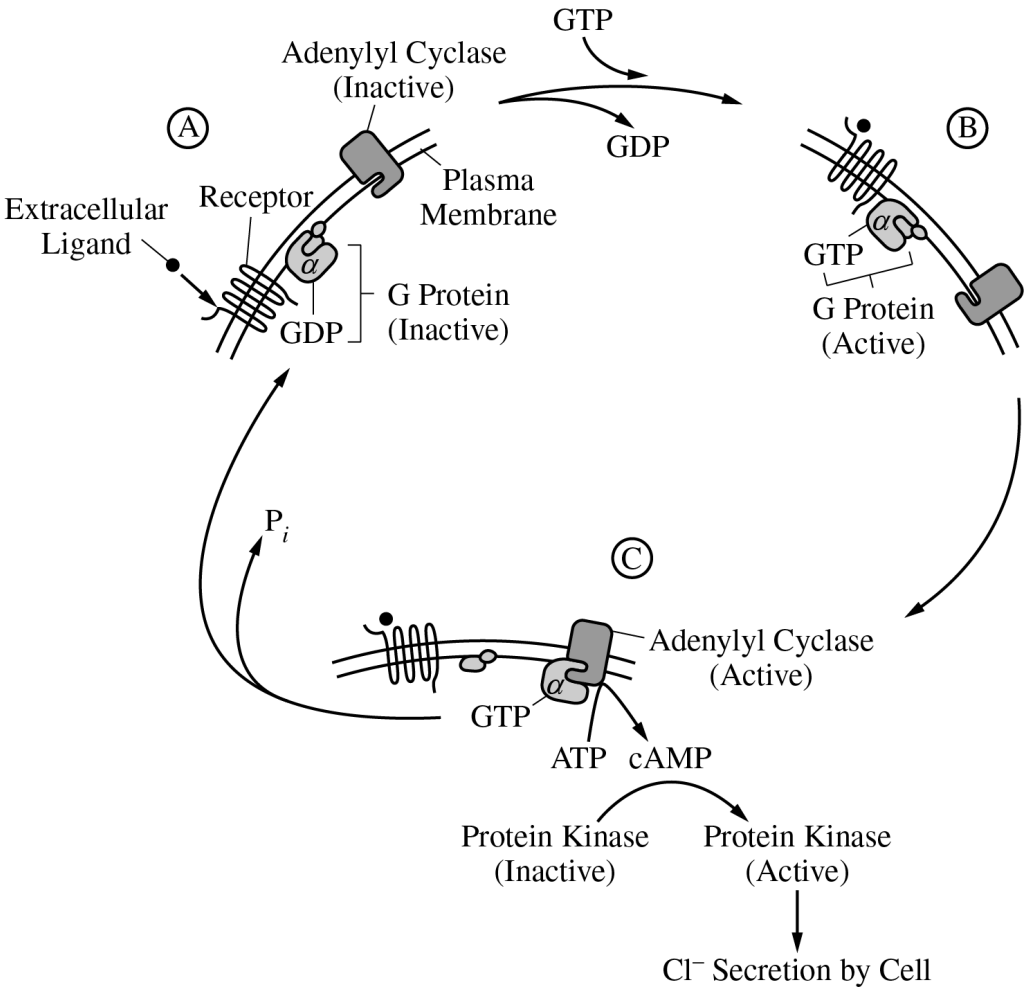


Figure 1. Under normal conditions, ligand binding to a G protein-coupled receptor results in chloride ion transport from an intestinal cell.

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).

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|---|---|---|---|
| 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 Gs$\alpha$. 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.

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

2. A student studying two different aquatic, plant-eating, unicellular protist species (species A and B) designed an experiment to investigate the ecological relationship between the two species (Table 1).

TABLE 1. EXPERIMENTAL TREATMENT GROUPS

| | |
|---|---|
| Group I. | Species A and B are each grown in separate containers. |
| Group II. | Species A and B are grown together in the same container. |

In treatment group I, the student placed 10 individuals of species A into a container with liquid growth medium and 10 individuals of species B into a separate container with an equal amount of the same liquid growth medium. In treatment group II, the student placed 5 individuals of each species into a single container with the liquid growth medium. The student then maintained the containers under the same environmental conditions and recorded the number of individuals in each population at various time points. The results are shown in Table 2.

TABLE 2. NUMBER OF INDIVIDUALS IN EACH PROTIST POPULATION IN BOTH TREATMENT GROUPS

| | Group I. Grown Separately | | Group II. Grown Together | |
|---|---|---|---|---|
| Time (h) | Species A | Species B | Species A | Species B |
| 0 | 10 | 10 | 5 | 5 |
| 10 | 100 | 50 | 45 | 20 |
| 20 | 400 | 200 | 100 | 50 |
| 30 | 1100 | 500 | 250 | 25 |
| 40 | 1400 | 650 | 525 | 20 |
| 50 | 1500 | 700 | 900 | 10 |
| 60 | 1500 | 700 | 1250 | 0 |
| 70 | 1500 | 700 | 1400 | 0 |

(a) The growth curves for species B in group I and for species A in group II (shaded columns) have been plotted on the template. Use the template to **complete** an appropriately labeled line graph to illustrate the growth of species A in treatment group I and species B in treatment group II (unshaded columns).

(b) As shown in the table, the student established treatment group II with 5 individuals of each species. **Provide reasoning** for the reduced initial population sizes.

(c) The student claims that species A and B compete for the same food source. **Provide TWO pieces of evidence** from the data that support the student's claim.

(d) **Predict** TWO factors that will most likely limit the population growth of species A in treatment group I.

(e) Many protists contain an organelle called a contractile vacuole that pumps water out of the cell. The student repeated the experiment using a growth medium with a lower solute concentration. **Predict** how the activity of the contractile vacuole will change under the new experimental conditions. **Justify** your prediction.

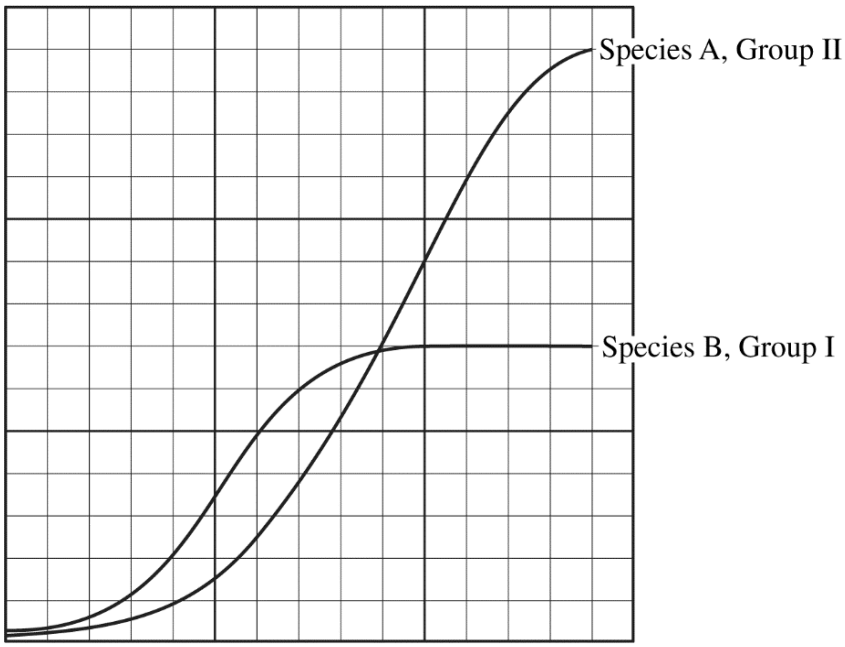
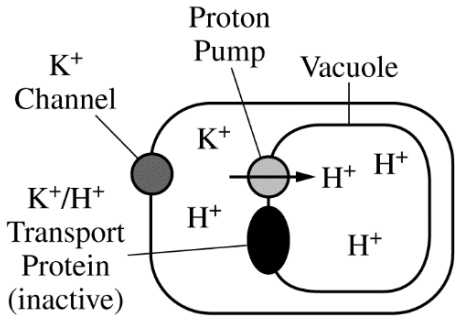
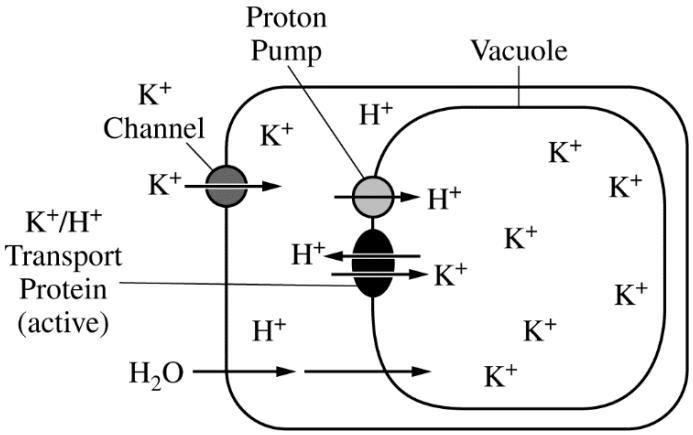

Species A, Group II
Species B, Group I

TABLE 1. CHANGES IN MORNING GLORY PETAL CELLS DURING FLOWER OPENING

| | **BUD** | **OPEN FLOWER** |
|---|---|---|
| |  |  |
| Vacuole pH | 6.6 | 7.7 |
| Flower Color | Red | Blue |
| Cell Volume | Small | Large |

8. The petal color of the Mexican morning glory (*Ipomoea tricolor*) changes from red to blue, and the petal cells swell during flower opening. The pigment heavenly blue anthocyanin is found in the vacuole of petal cells. Petal color is determined by the pH of the vacuole. A model of a morning glory petal cell before and after flower opening is shown in Table 1.

   (a) **Identify** the cellular component in the model that is responsible for the increase in the pH of the vacuole during flower opening AND **describe** the component's role in changing the pH of the vacuole.

   (b) A researcher claims that the activation of the $K^+/H^+$ transport protein causes the vacuole to swell with water. **Provide reasoning** to support the researcher's claim.

**STOP**

**END OF EXAM**

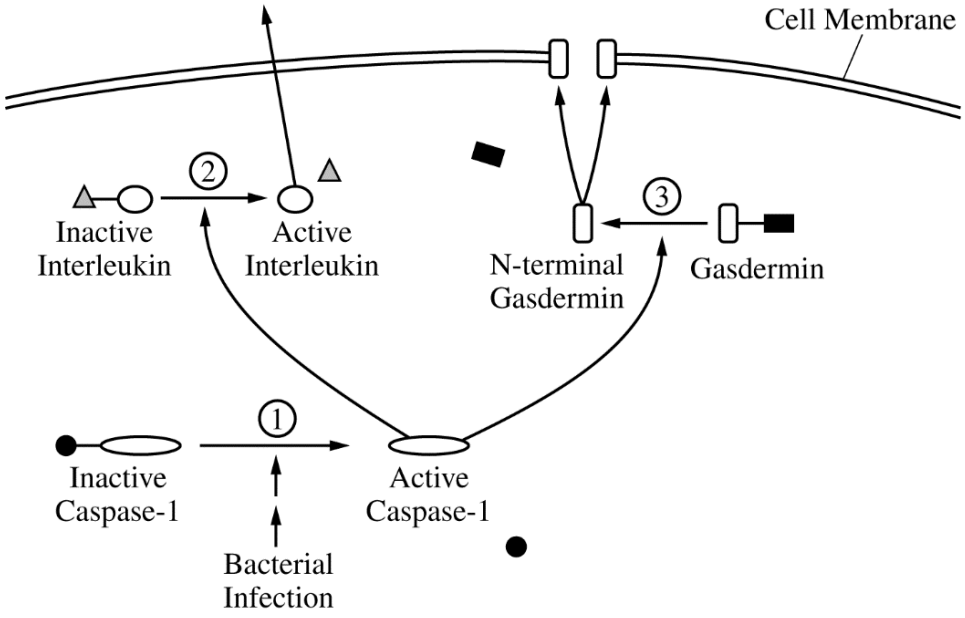



Figure 1. Cellular response to infection by pathogenic bacteria

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-$\kappa$B (Immune response protein) |
|---|---|---|---|---|---|
| Whole cell sample | + | + | + | + | + |
| Fraction 1 | + | | | | |
| Fraction 2 | | + | | | + |
| Fraction 3 | | | + | | + |
| Fraction 4 | | | | + | |
| + = presence of protein | | | | | |

(a) **Describe** the effect of inhibiting step 3 on the formation of pores AND on the release of interleukin from the cell.

(b) **Make a claim** about how cleaving inactive caspase-1 results in activation of caspase-1. A student claims that preinfection production of inactive precursors shortens the response time of a cell to a bacterial infection. **Provide ONE reason** to support the student's claim.

(c) A student claims that the NF-$\kappa$B protein is located in the cytoplasm until the protein is needed for transcription. **Justify** the student's claim with evidence. **Identify TWO** fractions where N-terminal gasdermin would be found in cells infected with pathogenic bacteria.

(d) **Describe** the most likely effect of gasdermin pore formation on water balance in the cell in a hypotonic environment.

(e) **Explain** how gasdermin pore formation AND interleukin release contribute to an organism's defense against a bacterial pathogen.

# BIOLOGY

**Section II**

**8 Questions**

**Total Time—90 minutes**

**Reading Period—10 minutes**

**Writing Period—80 minutes**

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

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

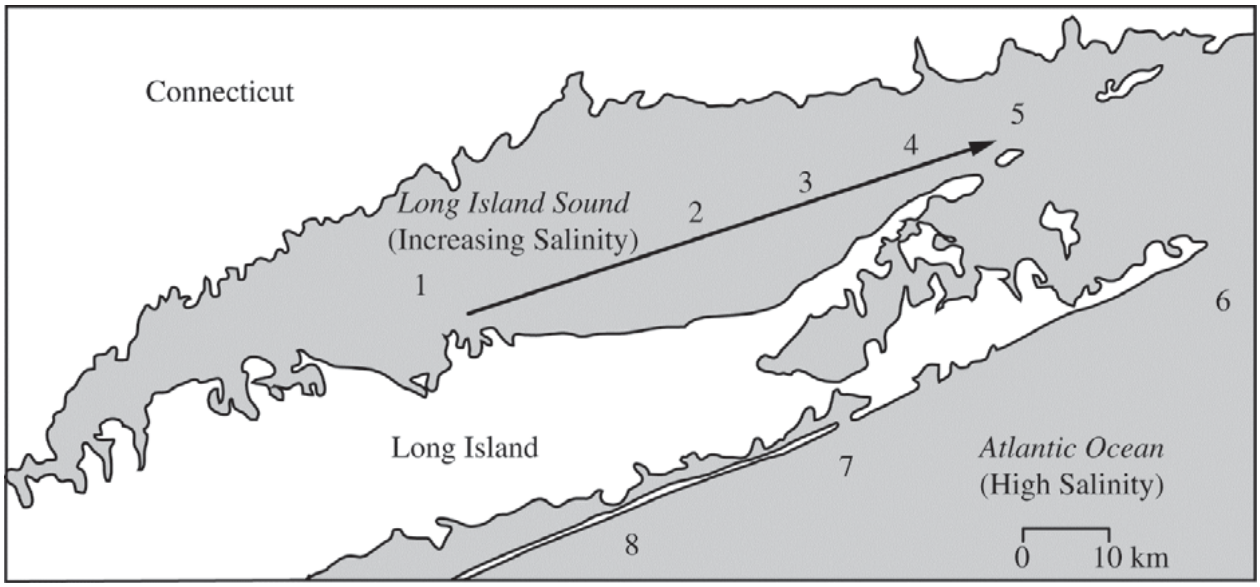



Figure 1. Sampling sites of marine mussels at various locations (1–8) in Long Island Sound and the Atlantic Ocean

TABLE 1. PERCENT OF INDIVIDUALS POSSESSING *lap*$^{94}$ ALLELE

| | Long Island Sound | | | | | Atlantic Ocean | | |
|---|---|---|---|---|---|---|---|---|
| Site | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| *lap*$^{94}$ frequency (%) | 13 | 16 | 25 | 37 | 55 | 59 | 59 | 59 |
| Salinity | Low → | | | | High | High | | |

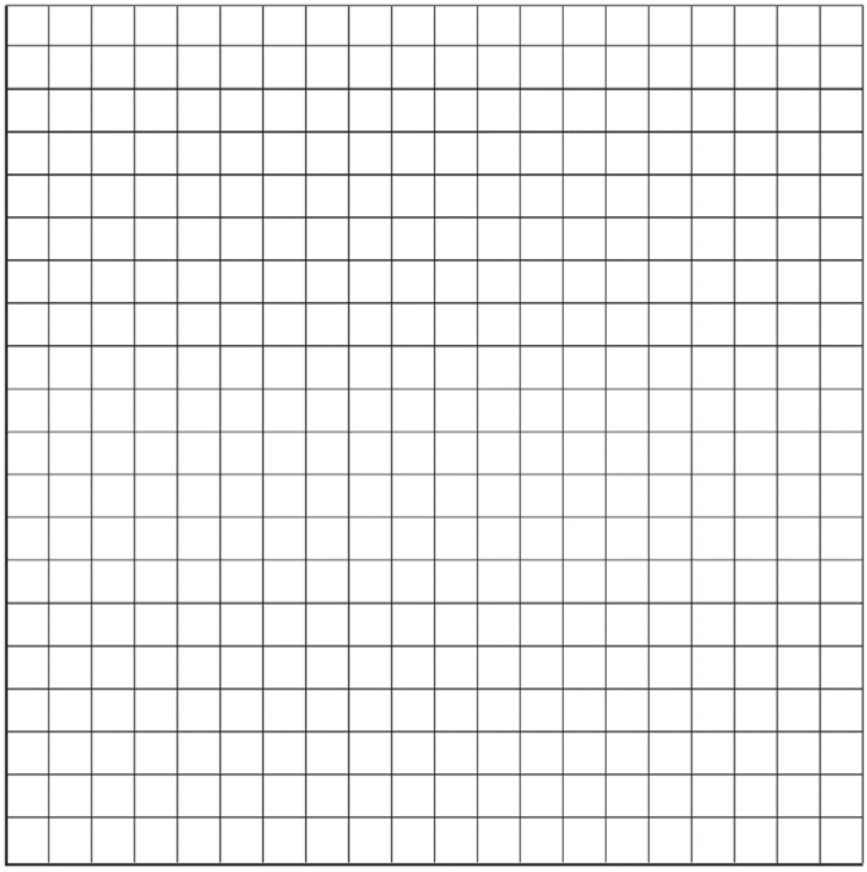
1. Leucine aminopeptidases (LAPs) are found in all living organisms and have been associated with the response of the marine mussel, *Mytilus edulis*, to changes in salinity. LAPs are enzymes that remove N-terminal amino acids from proteins and release the free amino acids into the cytosol. To investigate the evolution of LAPs in wild populations of *M. edulis*, researchers sampled adult mussels from several different locations along a part of the northeast coast of the United States, as shown in Figure 1. The researchers then determined the percent of individuals possessing a particular *lap* allele, $lap^{94}$, in mussels from each sample site (table 1).

   (a) On the axes provided, **construct** an appropriately labeled bar graph to illustrate the observed frequencies of the $lap^{94}$ allele in the study populations.

   (b) Based on the data, **describe** the most likely effect of salinity on the frequency of the $lap^{94}$ allele in the marine mussel populations in Long Island Sound. **Predict** the likely $lap^{94}$ allele frequency at a sampling site between site 1 and site 2 in Long Island Sound.

   (c) **Describe** the most likely effect of $LAP^{94}$ activity on the osmolarity of the cytosol. **Describe** the function of $LAP^{94}$ in maintaining water balance in the mussels living in the Atlantic Ocean.

   (d) Marine mussel larvae are evenly dispersed throughout the study area by water movement. As larvae mature, they attach to the rocks in the water. **Explain** the differences in $lap^{94}$ allele frequency among adult mussel populations at the sample sites despite the dispersal of larvae throughout the entire study area. **Predict** the likely effect on distribution of mussels in Long Island Sound if the $lap^{94}$ allele was found in all of the mussels in the population. **Justify** your prediction.



AP BIOLOGY • EXERCISE SHEET

# 2.8 Mechanisms of Membrane Transport

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

**KEY WORDS** endocytosis 内吞 • exocytosis 外排 • diffusion 扩散 • osmosis 渗透

## Objective

Build the skills to answer exam questions on **mechanisms of bulk membrane transport**.

**You must be able to:**

- describe **endocytosis** 内吞 and **exocytosis** 外排
- distinguish phagocytosis from pinocytosis
- explain that bulk transport uses vesicles and ATP

## 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.

### ■ Bulk transport with vesicles

Large materials cross the membrane in **vesicles**, using energy (**ATP**):

- **Endocytosis** — the membrane folds inward to bring material **in**.
- **Exocytosis** — a vesicle fuses with the membrane to release material **out**.

### ■ Types of endocytosis

- **Phagocytosis** ("cell eating") — engulfing large particles or cells.
- **Pinocytosis** ("cell drinking") — taking in droplets of fluid.

### ■ A worked example

A white blood cell **phagocytoses** (engulfs) a bacterium into a vesicle to destroy it — endocytosis. A gland cell releases hormones by **exocytosis**.

### ■ Why it needs energy

Reshaping the membrane and moving vesicles requires **ATP**, so bulk transport is an active process.

## 2 Practice

Now apply the methods above.

**2.1** Which process brings material into the cell in a vesicle? [1]

**2.2** Distinguish phagocytosis from pinocytosis. [2]

**2.3** Does bulk transport require ATP? [1]

## 3 Exam-style questions

**3.1** A vesicle fusing with the membrane to release its contents is [1]

- **A** endocytosis
- **B** exocytosis
- **C** diffusion
- **D** osmosis

**3.2** A white blood cell engulfs a bacterium.

(a) Name the process. [1]

(b) Explain why this requires energy. [2]

**3.3** A gland cell releases insulin made inside it. Describe how the insulin leaves the cell. [2]

## Solutions

**2.1** Endocytosis.

**2.2** Phagocytosis engulfs large solid particles/cells; pinocytosis takes in fluid droplets.

**2.3** Yes.

**3.1 B** — exocytosis.

**3.2** (a) Phagocytosis (endocytosis). (b) The membrane must reshape and form a vesicle to engulf the bacterium, which requires ATP.

**3.3** The insulin is packaged in a vesicle that moves to and fuses with the cell membrane, releasing the insulin outside by exocytosis.

3. To investigate whether red blood cells of animals lose the ability to take in glucose from their environment as they age, scientists collected red blood cells from guinea pigs that ranged in age from one day old to seven months old. Scientists incubated an equal number of red blood cells in separate culture dishes that contained a 300 nM solution of radioactively labeled glucose. The amount of radioactively labeled glucose present inside the red blood cells of each group was measured over time.

   (a) **Describe** a difference between passive transport and active transport.

   (b) **Justify** why the scientists used an equal number of red blood cells in each culture dish as a control.

   (c) Glucose transporters are required for the facilitated diffusion of glucose into red blood cells. The scientists claim that the expression of the gene encoding these transporters decreases as guinea pigs age. If the scientists' claim is supported by experimental data, **predict** the effect of increased age on the amount of radioactively labeled glucose present inside the cells of each group.

   (d) **Justify** your prediction in part (c).

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**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.**

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.

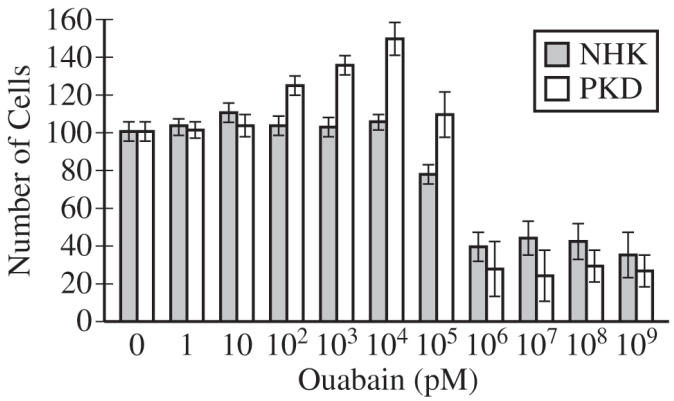


Figure 1. Cell number compared with the number of cells at 0 pM ouabain. Normal human kidney (NHK) cells and polycystic kidney disease (PKD) cells were treated with increasing concentrations of ouabain. Error bars represent $\pm 2SE_{\bar{x}}$.

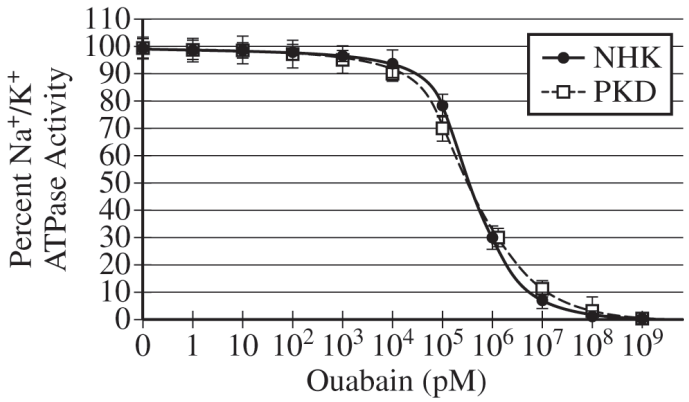


Figure 2. Percent $Na^+/K^+$ATPase activity of NHK and PKD cells treated with increasing concentrations of ouabain. Error bars represent $\pm 2SE_{\bar{x}}$.

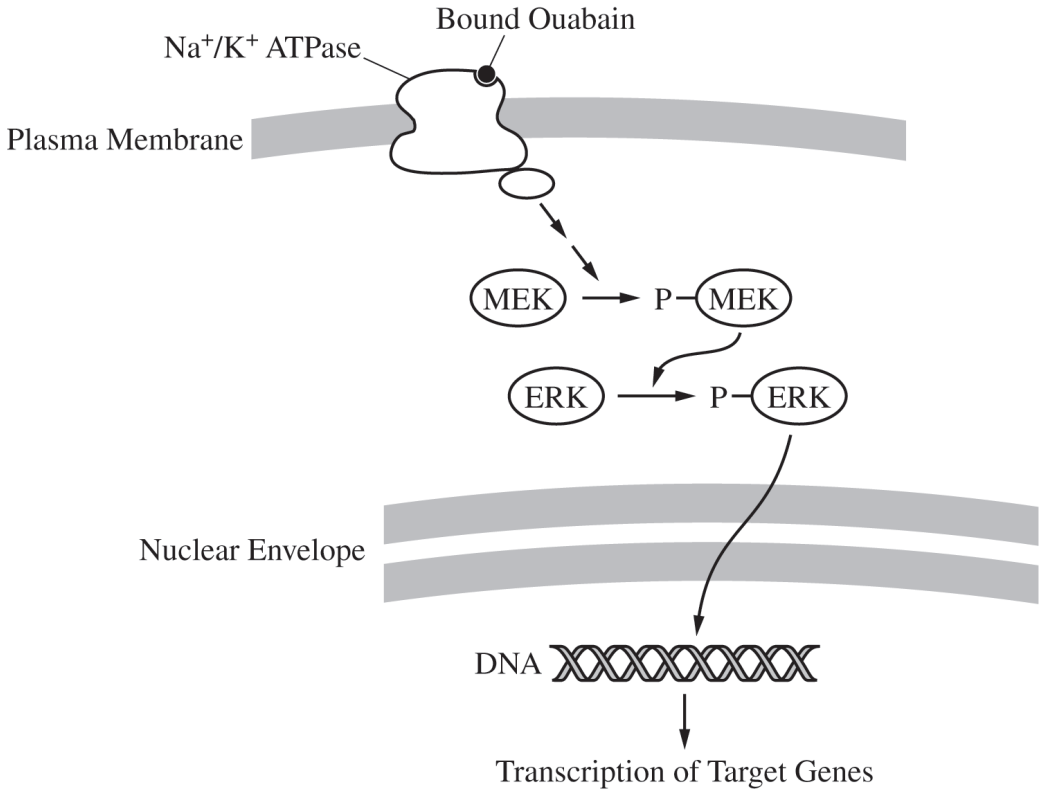


Figure 3. Signal transduction pathway hypothesized to play a role in the increased number of PKD cells

(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.

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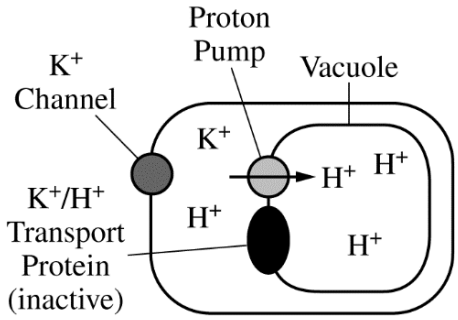
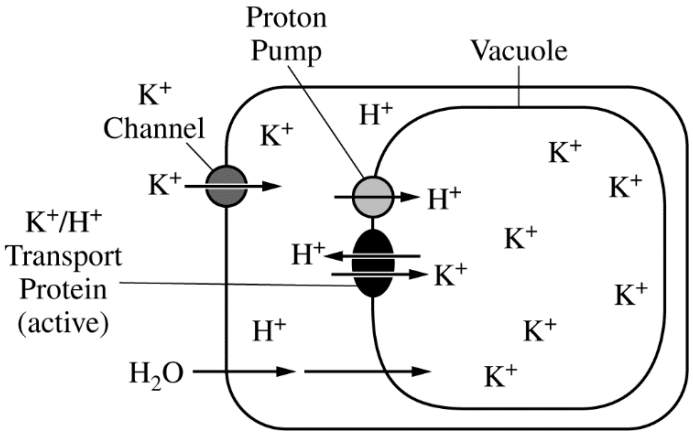
**Write your responses to this question only on the designated pages in the separate Free Response booklet.**

TABLE 1. CHANGES IN MORNING GLORY PETAL CELLS DURING FLOWER OPENING

| | **BUD** | **OPEN FLOWER** |
|---|---|---|
| |  |  |
| Vacuole pH | 6.6 | 7.7 |
| Flower Color | Red | Blue |
| Cell Volume | Small | Large |

8. The petal color of the Mexican morning glory (*Ipomoea tricolor*) changes from red to blue, and the petal cells swell during flower opening. The pigment heavenly blue anthocyanin is found in the vacuole of petal cells. Petal color is determined by the pH of the vacuole. A model of a morning glory petal cell before and after flower opening is shown in Table 1.

   (a) **Identify** the cellular component in the model that is responsible for the increase in the pH of the vacuole during flower opening AND **describe** the component's role in changing the pH of the vacuole.

   (b) A researcher claims that the activation of the $K^+/H^+$ transport protein causes the vacuole to swell with water. **Provide reasoning** to support the researcher's claim.

**STOP**

**END OF EXAM**

AP BIOLOGY • EXERCISE SHEET

# 2.9 Compartmentalization Inside the Cell

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

**KEY WORDS** compartments 区室 • membrane-bound organelles 膜结合细胞器 • organelles 细胞器 • mitochondria 线粒体

## Objective

Build the skills to answer exam questions on **compartmentalization** inside the cell.

**You must be able to:**

- explain how **membrane-bound organelles** 膜结合细胞器 create separate compartments
- state the advantages of compartmentalization
- give examples (lysosome, mitochondrion) of specialized environments

## 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.

### ■ Compartments inside the cell

Membrane-bound organelles divide the eukaryotic cell into **compartments**, each with its own conditions. This lets different, even incompatible, reactions happen at once.

### ■ Advantages

- **Separate conditions** — e.g. a lysosome can be acidic inside without harming the rest of the cell.
- **Higher efficiency** — reactants and enzymes are concentrated together.
- **Protection** — dangerous reactions (digestion) are kept contained.

### ■ A worked example

The **lysosome** keeps its digestive enzymes and low pH inside its membrane, so they break down waste without damaging the cytoplasm.

■ **Mitochondria**

The **mitochondrion's** inner membrane holds a proton gradient used to make ATP — only possible because the membrane separates two regions.

## 2 Practice

Now apply the methods above.

**2.1** What creates separate compartments in a eukaryotic cell? [1]

**2.2** State one advantage of compartmentalization. [1]

**2.3** Why is it useful for a lysosome to be enclosed by a membrane? [1]

## 3 Exam-style questions

**3.1** Compartmentalization allows a cell to [1]

- **A** carry out only one reaction at a time
- **B** maintain different conditions in different regions
- **C** avoid using membranes
- **D** remove its DNA

**3.2** A lysosome contains digestive enzymes and has an acidic interior.

(a) Explain why enclosing these in a membrane is important. [2]

(b) State one other advantage of keeping reactions in a compartment. [1]

**3.3** Explain how compartmentalization increases the efficiency of a metabolic reaction.[2]

## Solutions

**2.1** Membrane-bound organelles.

**2.2** Any one: separate conditions, greater efficiency, protection/containment of harmful reactions.

**2.3** So its digestive enzymes and acid are contained and do not damage the rest of the cell.

**3.1 B** — maintain different conditions in different regions.

**3.2** (a) The membrane keeps the enzymes and acid contained, protecting the cytoplasm from being digested. (b) Reactants and enzymes are concentrated together, raising efficiency (or: different reactions can occur at once).

**3.3** Concentrating the enzymes and substrates in one small compartment increases the chance they meet and react, speeding the reaction.

**The following information applies to all parts.**

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**2.** Eukaryotic cells use small interfering RNA (siRNA) molecules that regulate the expression of certain genes by binding to complementary sequences in target mRNAs. This binding causes the protein AGO2 to cleave the target mRNAs. As a result of the cleavage, the mRNAs are not translated.

**Part A**

**Describe** one location where ribosomes are found in eukaryotic cells.

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

To investigate the role of AGO2 in the cleavage of mRNA transcribed from two genes, Gene *G* and Gene *H*, scientists determined the amount of Gene *G* and Gene *H* mRNA produced in cells with three different *AGO2* genotypes:

- Homozygous for the wild-type AGO2 protein ($AGO2^{+/+}$)
- Heterozygous for the allele encoding a nonfunctional AGO2 protein ($AGO2^{+/-}$)
- Homozygous for the allele encoding a nonfunctional AGO2 protein ($AGO2^{-/-}$)

The scientists then calculated the amount of Gene *G* and Gene *H* mRNA produced from cells of each genotype relative to that in $AGO2^{+/+}$ cells. These results are shown in the table.

**Relative Average Amounts of Gene *G* and Gene *H* mRNA in Cells with Different *AGO2* Genotypes**

| | mRNA in $AGO2^{+/+}$ Cells $\pm$ $SE_{\bar{x}}$ | mRNA in $AGO2^{+/-}$ Cells $\pm$ $SE_{\bar{x}}$ | mRNA in $AGO2^{-/-}$ Cells $\pm$ $SE_{\bar{x}}$ |
|---|---|---|---|
| Gene *G* | 1.0 $\pm$ 0.1 | 0.9 $\pm$ 0.4 | 1.5 $\pm$ 0.5 |
| Gene *H* | 1.0 $\pm$ 0.1 | 2.0 $\pm$ 0.1 | 3.0 $\pm$ 0.4 |

**Part B**

i. Using the template in the space provided for your response, **construct** a bar graph that represents the data in the table. Your graph should be appropriately plotted and labeled.

ii. Based on the table, **determine** all the cells in which the amount of Gene *G* mRNA produced is statistically the same as the amount in the cells with the $AGO2^{+/+}$ genotype.

**Part C**

i. Based on the table, **describe** the relationship between the number of wild-type copies of the *AGO2* gene and the amount of Gene *H* mRNA in the cells.

ii. Based on the data in the table for Gene *H*, **calculate** the percent by which the average amount of mRNA in $AGO2^{-/-}$ cells increases compared with that in $AGO2^{+/-}$ cells.

**Part D**

i. The scientists claim that siRNA binding and AGO2 cleavage of mRNAs play a greater role in the regulation of Gene *H* expression than in the regulation of Gene *G* expression. Based on the table, **support** the scientists' claim.

ii. Anaphase I of meiosis is blocked in mice with the $AGO2^{-/-}$ genotype. Scientists hypothesize that the block in meiosis occurs because the continued presence of a spindle-fiber stabilizing protein prevents the chromosomes from separating. Based on the table, **explain** how the $AGO2^{-/-}$ genotype could cause this effect on the dividing cells.

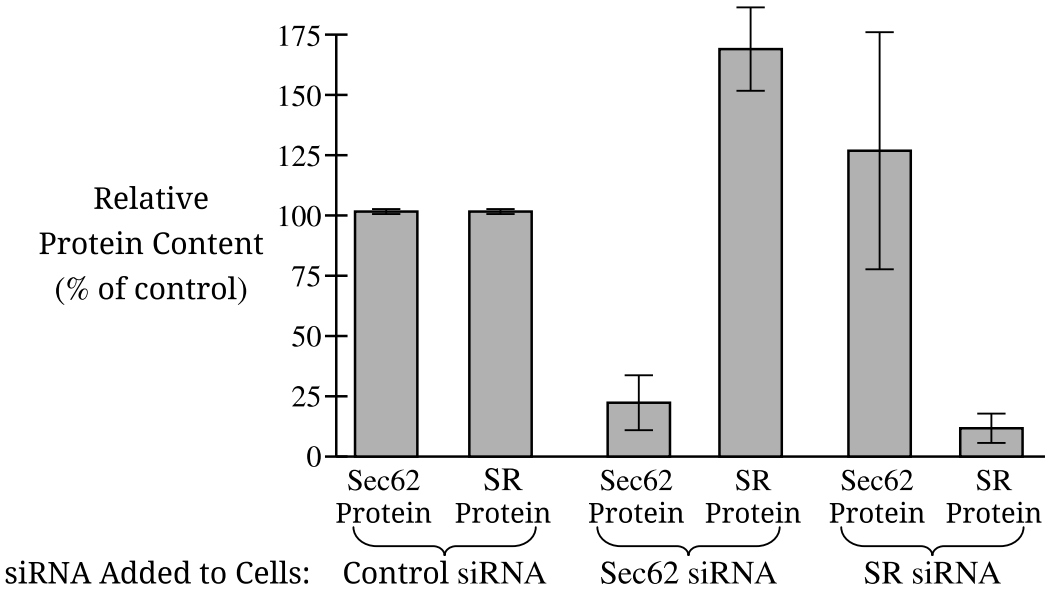
**1.** Most proteins that are secreted from a cell must be transported to the endoplasmic reticulum (ER) either during translation or after translation.

**A. Describe** the function of ribosomes.

For proteins transported during translation, this process begins in the cytosol and pauses when a specific sequence of amino acids is translated. The translation complex is then transported to the surface of the ER where translation continues. Proteins that are transported after translation are translated entirely in the cytosol and then transported to the ER. In both instances, the translated proteins enter the ER through a protein channel in the membrane of the ER.

Researchers studying the two types of protein transport identified that the ER membrane protein SR is necessary for transport during translation, while the ER membrane protein Sec62 is necessary for transport after translation. To investigate which transport mechanism is used for different proteins, researchers first created small interfering RNAs (siRNAs) that reduce expression of either SR or Sec62. They then treated groups of cells with either the SR siRNA or the Sec62 siRNA and determined the relative amount of SR and Sec62 protein in each group of cells compared with cells treated with a control siRNA (Figure 1).

**Figure 1. Average relative amounts of Sec62 and SR proteins in cells treated with control siRNA, Sec62 siRNA, or SR siRNA. Error bars represent $\pm SE_{\bar{x}}$.**




**B.**

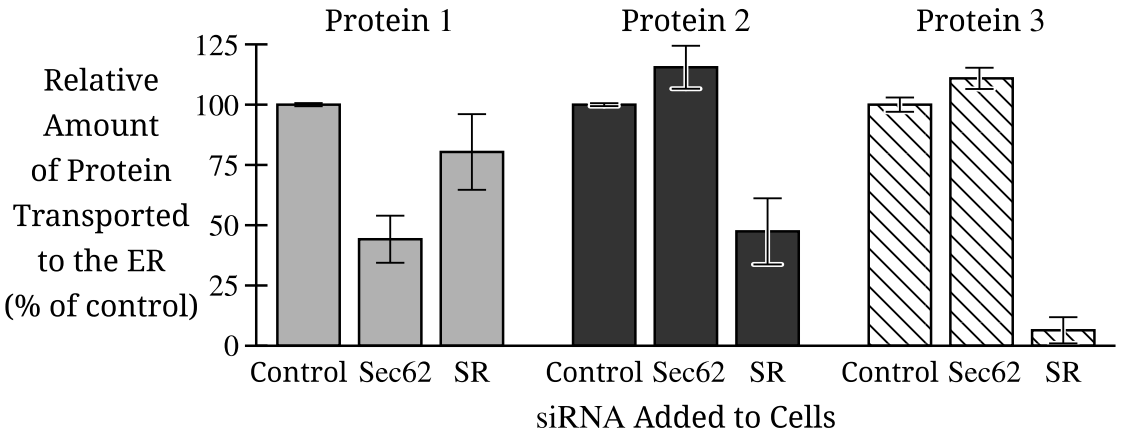
i. **Identify** the dependent variable in the experiments shown in Figure 1.

ii. **Justify** why the researchers included the control of measuring the relative amounts of both Sec62 and SR proteins in cells that were treated with Sec62 siRNA only (data shown in Figure 1).

iii. Based on Figure 1, **describe** the effect on the production of SR protein when cells are treated with Sec62 siRNA.

The researchers then measured the amount of each of three different proteins that was transported to the ER in cells treated with Sec62 siRNA or SR siRNA. The researchers calculated the percent transported relative to the cells treated with control siRNA (Figure 2).

**Figure 2. Average relative amounts of three proteins that were transported to the ER when treated with control siRNA, Sec62 siRNA, or SR siRNA. Error bars represent $\pm SE_{\bar{x}}$.**




**C.**

i. **Identify** the independent variable in the researchers' second experiment (data shown in Figure 2).

ii. Based on Figure 2, **identify** the protein(s) that when treated with Sec62 siRNA showed an increase in percent transport to the ER compared with the control.

iii. Protein 1 is encoded by 234 nucleotides, while protein 2 is encoded by 495 nucleotides. Assuming all nucleotides for both proteins encode amino acids, **calculate** the difference in the number of amino acids between the two proteins.

**D.**

i. Researchers claim that protein 1 is the only tested protein that is transported to the ER following its complete translation in the cytosol. Using data from Figure 2, **support** the researchers' claim.

ii. For any protein that enters the ER, researchers claim that amino acids close to the protein's amino terminus determine how likely the protein is to pass through the protein channel within the ER membrane. **Justify** the researchers' claim based on your understanding of factors that affect the transport of proteins across membranes.

2. Elevated levels of $CO_2$ increase the rate of photosynthesis and growth in plants. Scientists studying the mechanisms involved in these increases examined a variety of species and found that when plants are exposed to elevated levels of $CO_2$, there is an increase in the number of chloroplasts per cell. To investigate whether the elevated levels of $CO_2$ have a similar effect on the number of mitochondria in plant cells, the scientists then selected six of these species to quantify the number of mitochondria per cell when the plants were exposed to both normal and elevated levels of $CO_2$ (Table 1).

TABLE 1. AVERAGE NUMBER OF MITOCHONDRIA IN PLANTS EXPOSED TO NORMAL AND ELEVATED LEVELS OF $CO_2$

| Species | Mitochondria at Normal $CO_2$ (per 100 $\mu m^2$ of cell area) $\pm 2SE_{\bar{x}}$ | Mitochondria at Elevated $CO_2$ (per 100 $\mu m^2$ of cell area) $\pm 2SE_{\bar{x}}$ |
|---|---|---|
| 1 | 1.0 ± 0.10 | 1.6 ± 0.10 |
| 2 | 0.4 ± 0.05 | 0.9 ± 0.08 |
| 3 | 0.5 ± 0.07 | 0.9 ± 0.10 |
| 4 | 0.3 ± 0.03 | 0.6 ± 0.06 |
| 5 | 0.7 ± 0.06 | 1.5 ± 0.22 |
| 6 | 1.3 ± 0.15 | 2.4 ± 0.22 |

(a) **Describe** the role of the inner mitochondrial membrane in cellular respiration.

(b) Using the template in the space provided for your response, **construct** an appropriately labeled graph that represents the data in Table 1. **Determine** which species show(s) a difference in the number of mitochondria between normal and elevated levels of $CO_2$.

(c) Based on the data in Table 1, **describe** the relationship between the level of $CO_2$ and the average number of mitochondria per unit area of a cell.

(d) The leaves of a particular plant species are typically green, but scientists notice a plant in which the leaves have white stripes. They determine that the stripes result from a mutation in mitochondrial DNA that interferes with the development of chloroplasts. The scientists crossed plants using pollen from the plant with white-striped leaves and ovules from a plant with green leaves. **Predict** the phenotype(s) of the leaves of offspring produced from this cross. Provide reasoning to **justify** your prediction. **Explain** why plants with the same genotype are able to differ in the structure and/or number of certain organelles in response to changes in atmospheric levels of $CO_2$.

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

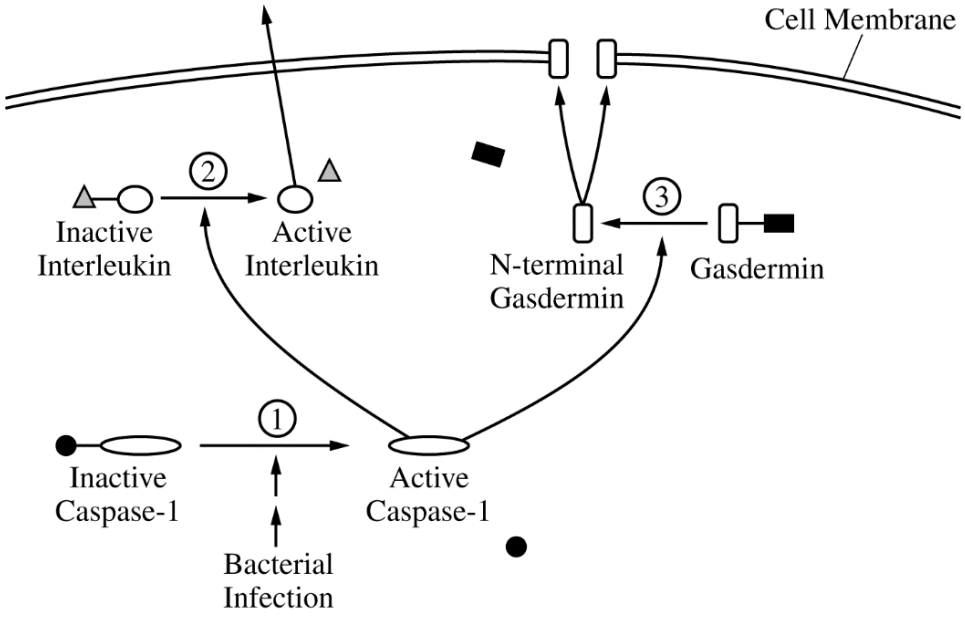



Figure 1. Cellular response to infection by pathogenic bacteria

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-$\kappa$B protein is located in the cytoplasm until the protein is needed for transcription. **Justify** the student's claim with evidence. **Identify TWO** fractions where N-terminal gasdermin would be found in cells infected with pathogenic bacteria.

(d) **Describe** the most likely effect of gasdermin pore formation on water balance in the cell in a hypotonic environment.

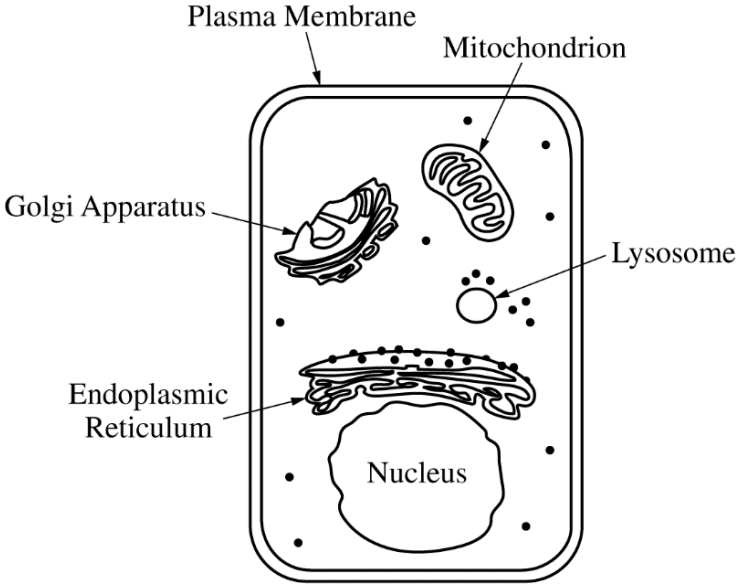
(e) **Explain** how gasdermin pore formation AND interleukin release contribute to an organism's defense against a bacterial pathogen.

6. Cystic fibrosis is a genetic condition that is associated with defects in the CFTR protein. The CFTR protein is a gated ion channel that requires ATP binding in order to allow chloride ions ($Cl^-$) to diffuse across the membrane.

(a) In the provided model of a cell, **draw** arrows to describe the pathway for production of a normal CFTR protein from gene expression to final cellular location.

(b) **Identify** the most likely cellular location of the ribosomes that synthesize CFTR protein.

(c) **Identify** the most likely cellular location of a mutant CFTR protein that has an amino acid substitution in the ATP-binding site.



AP BIOLOGY • EXERCISE SHEET

# 2.10 The Origins of Cell Compartmentalization

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

**KEY WORDS** endosymbiotic theory 内共生学说 • mitochondria 线粒体 • organelles 细胞器 • chloroplasts 叶绿体 • nucleus 细胞核

## Objective

Build the skills to answer exam questions on the **origins of cell compartmentalization** — the endosymbiotic theory.

**You must be able to:**

- state the **endosymbiotic theory** 内共生学说
- give the evidence (own DNA, double membrane, own ribosomes, binary fission)
- identify which organelles it explains

## 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 endosymbiotic theory

**Mitochondria** and **chloroplasts** are thought to have originated when a larger cell **engulfed** a free-living prokaryote, which then lived inside it (**endosymbiosis**) rather than being digested.

### The evidence

- they have their **own DNA** (circular, like bacteria);
- they have their **own ribosomes**;
- they are surrounded by a **double membrane**;
- they reproduce by **binary fission**, like bacteria.

### Which organelles

The theory explains **mitochondria** (from an aerobic bacterium) and **chloroplasts** (from a photosynthetic bacterium) — both double-membraned, DNA-containing organelles.

> **A worked reasoning**
>
> A mitochondrion's own circular DNA and ability to divide independently are strong signs it descended from a once free-living bacterium.

## 2 Practice

Now apply the methods above.

**2.1** Which two organelles does the endosymbiotic theory explain? [2]

**2.2** State one piece of evidence for the theory. [1]

**2.3** How do mitochondria reproduce? [1]

## 3 Exam-style questions

**3.1** Evidence that mitochondria were once free-living bacteria includes that they have [1]

- **A** no DNA
- **B** their own circular DNA and ribosomes
- **C** a single membrane only
- **D** the same DNA as the nucleus

**3.2** A student examines a chloroplast.

(a) State two features that support the endosymbiotic theory. [2]

(b) Explain what the theory proposes about the chloroplast's origin. [2]

**3.3** Explain why having its own DNA and dividing by binary fission suggests a mitochon-

drion had a bacterial ancestor. [2]

## Solutions

**2.1** Mitochondria and chloroplasts.

**2.2** Any one: own (circular) DNA, own ribosomes, double membrane, reproduce by binary fission.

**2.3** By binary fission (dividing like bacteria).

**3.1 B** — their own circular DNA and ribosomes.

**3.2** (a) Any two: own DNA, own ribosomes, double membrane, binary fission. (b) It proposes the chloroplast arose when a cell engulfed a photosynthetic bacterium that survived and lived inside it.

**3.3** These are bacterial traits — free-living bacteria have their own DNA and reproduce by binary fission — so their presence in mitochondria points to a bacterial ancestor.

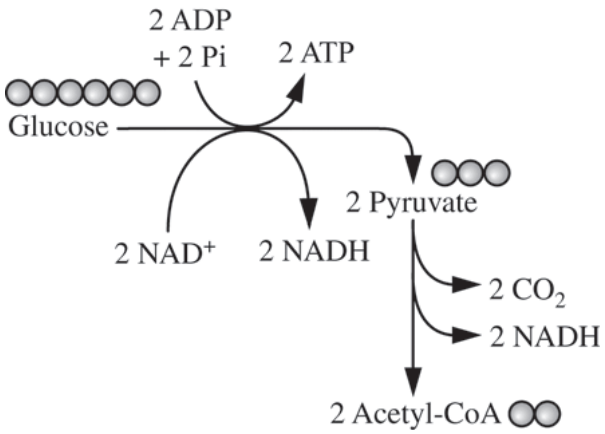



Figure 1. Glycolysis and pyruvate oxidation

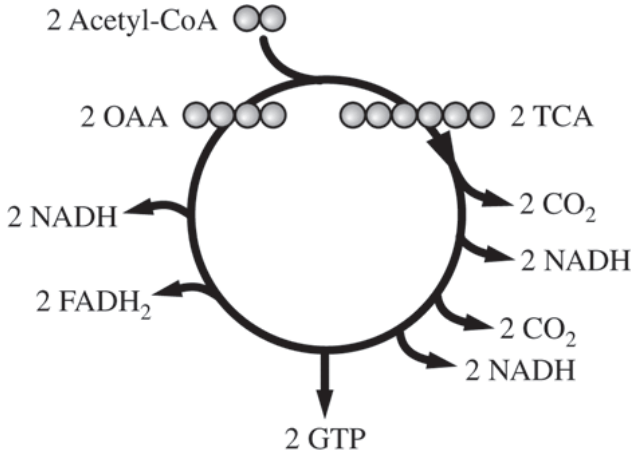



Figure 2. Krebs cycle

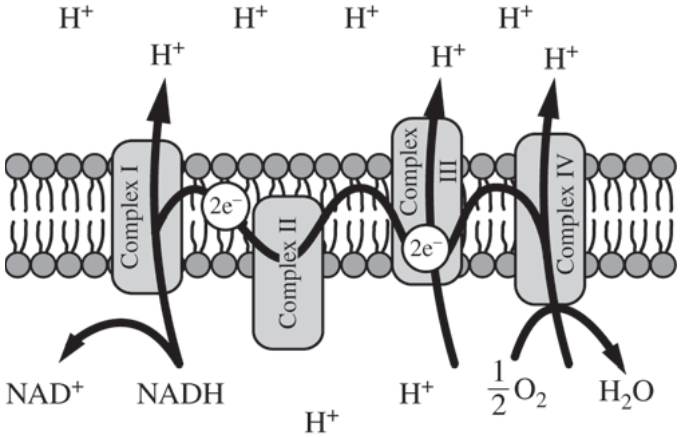



Figure 3. Electron transport chain

2. Cellular respiration includes the metabolic pathways of glycolysis, the Krebs cycle, and the electron transport chain, as represented in the figures. In cellular respiration, carbohydrates and other metabolites are oxidized, and the resulting energy-transfer reactions support the synthesis of ATP.

   (a) Using the information above, **describe** ONE contribution of <u>each</u> of the following in ATP synthesis.

   - Catabolism of glucose in glycolysis and pyruvate oxidation
   - Oxidation of intermediates in the Krebs cycle
   - Formation of a proton gradient by the electron transport chain

   (b) Use each of the following observations to **justify** the claim that glycolysis first occurred in a common ancestor of all living organisms.

   - Nearly all existing organisms perform glycolysis.
   - Glycolysis occurs under anaerobic conditions.
   - Glycolysis occurs only in the cytosol.

(c) A researcher estimates that, in a certain organism, the complete metabolism of glucose produces 30 molecules of ATP for each molecule of glucose. The energy released from the total oxidation of glucose under standard conditions is 686 kcal/mol. The energy released from the hydrolysis of ATP to ADP and inorganic phosphate under standard conditions is 7.3 kcal/mol. **Calculate** the amount of energy available from the hydrolysis of 30 moles of ATP. **Calculate** the efficiency of total ATP production from 1 mole of glucose in the organism. **Describe** what happens to the excess energy that is released from the metabolism of glucose.

(d) The enzymes of the Krebs cycle function in the cytosol of bacteria, but among eukaryotes the enzymes function mostly in the mitochondria. **Pose** a scientific question that connects the subcellular location of the enzymes in the Krebs cycle to the evolution of eukaryotes.