Past-paper walk-through

Mechanisms of Transport ▪ 2.8

eXercise

Questions in this set

- 2024 Q3
- 2021 Q1
- 2019 Q8

Reading the mark scheme

- **B1** a mark that stands on its own – the point is either made or not.
- **M1** a *method* mark: the right approach, even if the number is wrong.
- **A1** an *answer* mark, and it usually needs its M mark first.
- **C1** a working mark on the way to the answer.
- // separates answers the examiner accepts equally.
- **ecf** = error carried forward: a later part is marked on your own earlier answer.
- **owtte** = "or words to that effect" – the wording need not match.

Question 3

2024 ▪ Q3

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

Question 3

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).

Solution 3

(a)

Mark scheme

- Active transport requires energy/ATP while passive transport does not (equivalently: in passive transport substances move from high to low concentration down their gradient, while in active transport substances move from low to high concentration against their gradient).

Solution 3

(b)

Mark scheme

- Using an equal number of red blood cells in each dish lets the scientists attribute any differences in results/glucose transport specifically to guinea pig age rather than to differing cell numbers — it eliminates cell number as a confounding variable that could otherwise affect the measured amount of glucose.

Solution 3

(c)

Mark scheme

- As guinea pig age increases, the amount of radioactively labeled glucose present inside the cells decreases.

Solution 3

(d)

Mark scheme

- If glucose-transporter gene expression decreases with age (as claimed), older guinea pigs' red blood cells will have fewer glucose transporters, so fewer glucose molecules will be moved into the cells by facilitated diffusion — consistent with the predicted decrease.

Question 1

2021 ▪ Q1

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.

Question 1

[Figure 1: Bar graph, "Number of Cells" (y-axis, 0 to 160) vs. "Ouabain (pM)" (x-axis: 0, 1, 10, 10^2, 10^3, 10^4, 10^5, 10^6, 10^7, 10^8, 10^9), grouped bars for NHK (grey) and PKD (white). Approximate values: at 0 pM both ~100; NHK stays roughly 100-110 across most concentrations dropping to ~30-40 at 10^6-10^9 pM; PKD rises to ~110 at 10^2 pM, ~125 at 10^3 pM, peaks ~148 at 10^4 pM, ~110 at 10^5 pM, then drops to ~35-45 at 10^6-10^9 pM. Error bars represent $\pm 2SE_{\bar{x}}$. Caption: "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: Line graph, "Percent Na^+/K^+ATPase Activity" (y-axis, 0 to 110) vs. "Ouabain (pM)" (x-axis: 0, 1, 10, 10^2, 10^3, 10^4, 10^5, 10^6, 10^7, 10^8, 10^9), two curves (NHK filled circles, PKD open squares) that overlap closely: both start near 95-100% at low concentrations, stay high (~90-95%) through 10^3 pM, begin declining at 10^4

Question 1

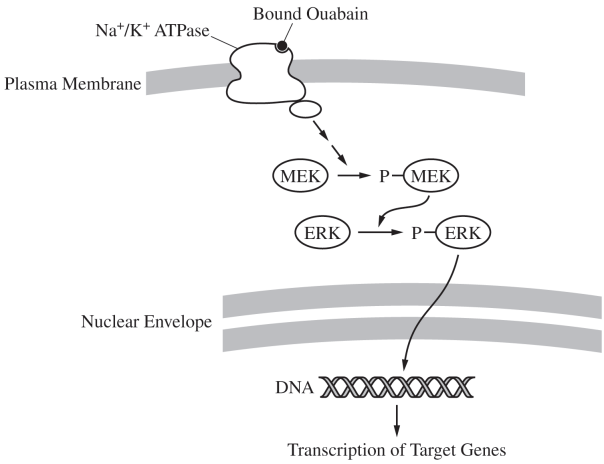
pM (~80%), drop steeply through 10^5 pM (~30%), reaching near 0% by 10^7-10^9 pM. Error bars represent $\pm 2SE_{\bar{x}}$. Caption: "Figure 2. Percent Na^+/K^+ATPase activity of NHK and PKD cells treated with increasing concentrations of ouabain. Error bars represent $\pm 2SE_{\bar{x}}$."]

[Figure 3: Diagram of a signal transduction pathway. Bound Ouabain sits on the Na^+/K^+ ATPase embedded in the Plasma Membrane. An arrow leads from the receptor down to MEK, which is converted to P-MEK (phosphorylated MEK); P-MEK activates ERK, converting it to P-ERK (phosphorylated ERK). An arrow from P-ERK crosses the Nuclear Envelope to DNA (shown as a double helix), leading to "Transcription of Target Genes." Caption: "Figure 3. Signal transduction pathway hypothesized to play a role in the increased number of PKD cells."]

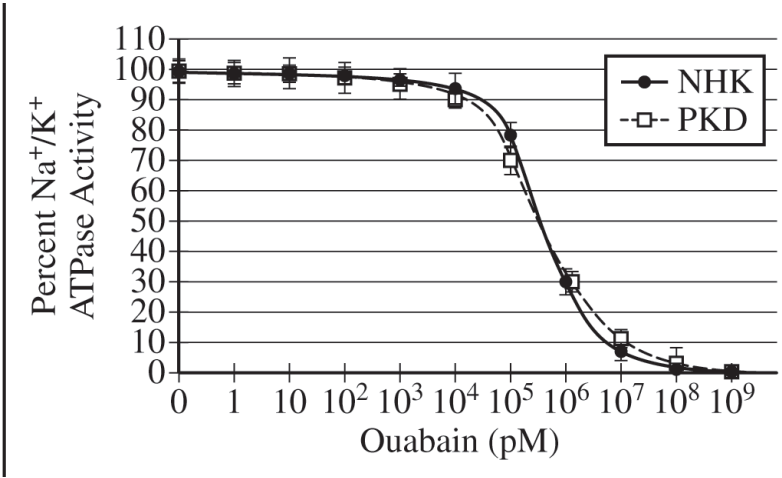
Question 1

(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.

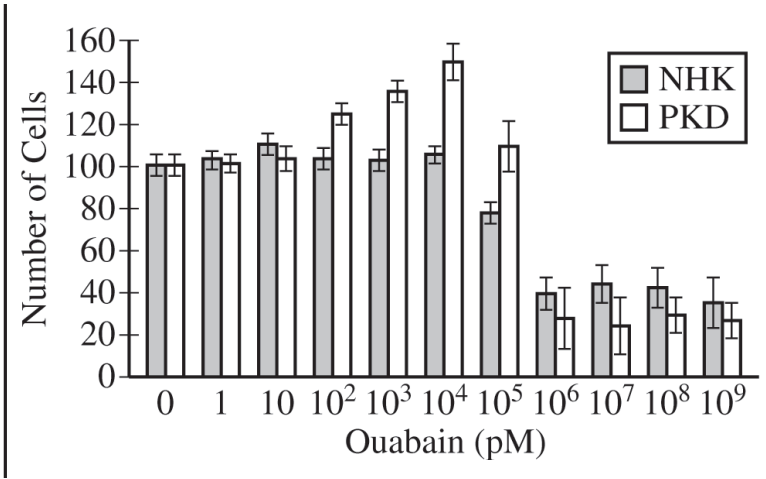
Question 1


Bound Ouabain
Na+/K+ ATPase
Plasma Membrane
MEK
P–MEK
ERK
P–ERK
Nuclear Envelope
DNA
Transcription of Target Genes

Question 1


Percent Na^+/K^+ ATPase Activity
110
100
90
80
70
60
50
40
30
20
10
0
0
1
10
10^2
10^3
10^4
10^5
10^6
10^7
10^8
10^9
Ouabain (pM)
NHK
PKD

Question 1


Number of Cells
160
140
120
100
80
60
40
20
0
NHK
PKD
0
1
10
10^2
10^3
10^4
10^5
10^6
10^7
10^8
10^9
Ouabain (pM)

Question 1

2021 ▪ Q1

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: Bar graph, "Number of Cells" (y-axis, 0 to 160) vs. "Ouabain (pM)" (x-axis: 0, 1, 10, 10^2, 10^3, 10^4, 10^5, 10^6, 10^7, 10^8, 10^9), grouped bars for NHK (grey) and PKD (white). Approximate values: at 0 pM both ~100; NHK stays roughly 100-110 across most

Question 1

concentrations dropping to ~30-40 at 10^6-10^9 pM; PKD rises to ~110 at 10^2 pM, ~125 at 10^3 pM, peaks ~148 at 10^4 pM, ~110 at 10^5 pM, then drops to ~35-45 at 10^6-10^9 pM. Error bars represent $\pm 2SE_{\bar{x}}$. Caption: "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 $\pm 2SE_{\bar{x}}$."]

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Question 1

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(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.

Question 1

2021 ▪ Q1

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(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.

Question 1

2021 ▪ Q1

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(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.

Solution 1

(a)

Mark scheme

- Describe (1 pt): Accept any one — the interior of the plasma membrane is hydrophobic/nonpolar; the phospholipid tails are hydrophobic/nonpolar; the exterior of the plasma membrane is hydrophilic/polar; the phospholipid heads are hydrophilic/polar. Na+ and K+ are charged ions, so they cannot cross the hydrophobic membrane interior by simple diffusion. Explain (1 pt): The Na+/K+ ATPase pumps ions (Na+ out, K+ in) against their concentration gradients; this active transport requires an input of (metabolic) energy, which ATP hydrolysis provides.

Solution 1

(b) Mark scheme

- Identify (1 pt): A dependent variable in the Figure 1 experiment is the number of cells. Justify NHK control (1 pt): Accept either — using normal human kidney (NHK) cells allows the scientists to determine the effect of PKD on the cells' responses to (various concentrations of) ouabain; or it allows them to compare the responses of PKD cells and normal cells (to ouabain). Justify range of ouabain concentrations (1 pt): Accept either — the scientists needed to determine whether different concentrations have different effects on cell numbers; or the scientists did not know at which concentration of ouabain there would be an effect.

Solution 1

(c)

Mark scheme

- Describe relationship (1 pt): Accept either — increasing concentrations of ouabain result in decreasing ATPase activity (in both types of cells); or there is an inverse relationship/negative correlation between the concentration of ouabain and the ATPase activity (in both types of cells). Calculate (1 pt): Given 150 units/sec at 1 pM ouabain, the expected Na+/K+ ATPase activity at 10^6 pM ouabain is 45 units/sec (accept between 40 and 50), read from the plateau/low end of the Figure 2 dose-response curve (~30% of the 1 pM baseline activity).

Solution 1

(d) Mark scheme

- Predict (1 pt): Accept either — Option 1: the ratio of ERK to pERK will increase in the cells with the (pMEK) inhibitor; or Option 2: the ratio of ERK to pERK will stay the same in the cells with the inhibitor. Justify (1 pt): Must indicate the pMEK inhibitor blocks further phosphorylation of ERK AND one of the following. For Option 1: the amount of pERK will not increase as it does without the inhibitor; or the amount of ERK will not decrease as it does without the inhibitor; or the cell continues to synthesize ERK; or phosphorylated ERK is being dephosphorylated to ERK. For Option 2: no additional ERK is synthesized/pERK is not being dephosphorylated. Explain cyclin increase (1 pt): Cell number (Figure 1) increases to a maximum at 10^4 pM ouabain. The ouabain-triggered signaling

Solution 1

pathway (Figure 3) stimulates transcription of genes involved in cell division; the target genes likely include those for cyclins, because cyclins regulate the cell cycle.

Question 8

2019 ▪ Q8

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

[Diagram, BUD: a petal cell containing a central vacuole. On the plasma membrane: a "K+ Channel" (dark circle) allowing K+ to cross; a "Proton Pump" (light gray circle) pumping H+ out of the cell (labelled H+, H+ outside). On the vacuole membrane: a "K+/H+ Transport Protein (inactive)" (black oval, inactive) with H+ and K+ labelled nearby but not being actively transported.]

Question 8

[Diagram, OPEN FLOWER: a larger petal cell/vacuole. On the plasma membrane: "K+ Channel" (dark circle) with K+ moving in; "Proton Pump" (light gray circle) pumping K+ in and H+ out (labelled K+, H+). On the vacuole membrane: "K+/H+ Transport Protein (active)" (black oval, active) transporting H+ out of the vacuole and K+ into the vacuole (labelled H+, K+, with multiple K+ ions shown accumulating inside the vacuole); H2O arrow entering the cell, labelled H2O.]

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

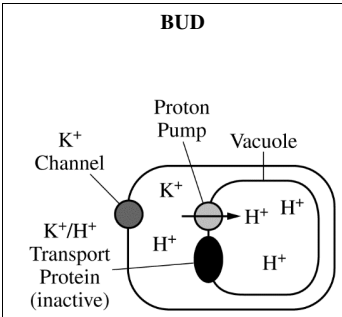
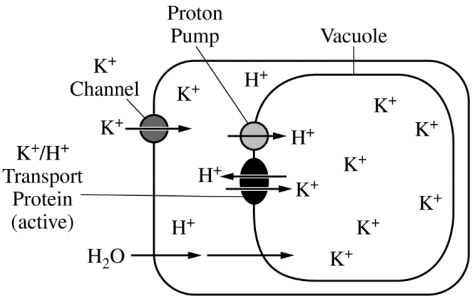
Question 8

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.

Question 8

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

Solution 8

(a)

Mark scheme

- Identification: The K+/H+ transport protein is the cellular component responsible for the increase in vacuole pH during flower opening. [1 point] Description: Once activated, the K+/H+ transport protein moves H+ out of the vacuole (in exchange for K+ moving into the vacuole), which raises the pH of the vacuole (fewer H+ ions present means a higher, more basic pH) — this pH increase is what shifts the anthocyanin pigment's color from red (more acidic vacuole, in the bud) to blue (more basic vacuole, in the open flower). [1 point]

Solution 8

(b)

Mark scheme

- Activation of the K+/H+ transport protein moves K+ into the vacuole, increasing the concentration of solute (K+) inside it. This makes the vacuole hypertonic/hyperosmotic relative to the surrounding cytoplasm (i.e., it lowers the vacuole's water potential), so water moves into the vacuole by osmosis, down its water-potential gradient — causing the vacuole (and thus the cell) to swell with water, consistent with the observed increase in cell volume as the flower opens.