Past-paper walk-through

Plasma Membrane ▪ 2.3

eXercise

Questions in this set

- 2025 Q2
- 2021 Q1
- 2018 Q8
- 2017 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 2

2025 ▪ Q2

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

Question 2

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

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

Question 2

Figure 1. A simplified model of a signaling pathway activated by the binding of 20E to its receptor, DopEcR
[Diagram of a signaling pathway across a plasma membrane. On the left: a molecule labeled "20E" (circle) approaches a membrane receptor labeled "DopEcR" embedded in the "Plasma Membrane" (drawn as two parallel wavy lines). Below the receptor inside the membrane, an inactive "G-Protein (Inactive)" complex is shown as an oval labeled "Gα" bound to "GDP". On the right: after 20E binds DopEcR, a second receptor is shown with an active "G-Protein (Active)" complex, labeled "Gα" bound to "GTP" (shown as a jagged/starburst shape indicating activation), with an arrow pointing down to the text "Increased Expression of Genes Associated with Oriented Activity in Male Moths".]

Question 2

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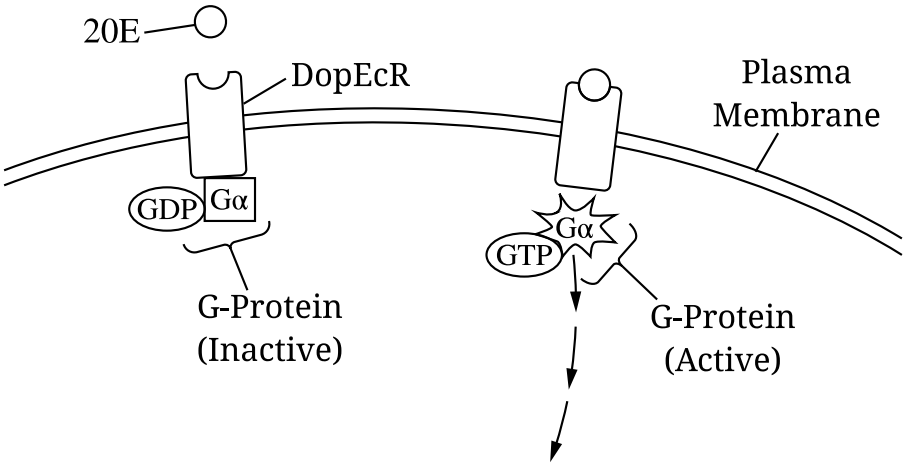
Question 2


20E
DopEcR
Plasma
Membrane
GDP
Gα
G-Protein
(Inactive)
Gα
GTP
G-Protein
(Active)

Question 2

2025 ▪ Q2

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.

(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.

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

Question 2

2025 ▪ Q2

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.

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

(c)(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.

Question 2

2025 ▪ Q2

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.

(d)(i) 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. Use evidence from the information provided to support the scientists' claim.

(d)(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.

Solution 2

(a)

Mark scheme

- The portion of the receptor inside the membrane is nonpolar/hydrophobic, consistent with the hydrophobic interior of the phospholipid bilayer it spans.

Solution 2

(b)(i) Mark scheme

- Construct an appropriate graph of the Table 1 data; 3 points total, one for each of: (1) choosing an appropriate graph type — a bar graph or modified/grouped bar graph showing General Activity and Oriented Activity (percent) for both the saline/control and siRNA treatment groups; (2) accurately plotting the data with error bars — Saline: General 95 ± 5, Oriented 60 ± 4; siRNA: General 90 ± 8, Oriented 25 ± 6 (using the table's $\pm 2SE_{\bar{x}}$ values); (3) appropriately labeling the graph — axis titles/units (e.g., percent), a legend or clear grouping distinguishing treatment and activity type. Grade a student's described or drawn graph against these three criteria.

Solution 2

(b)(ii)

Mark scheme

- Oriented activity was the type of activity affected by inhibiting DopEcR expression (it dropped from 60% to 25% of general activity), while general activity was comparatively unaffected (95% vs 90%).

Solution 2

(c)(i)

Mark scheme

- The control/saline-treated group (male moths injected with saline/control solution): oriented activity (60%) was greater than 50% of general activity (95%) in that group, whereas the siRNA group's oriented activity (25%) was well under 50% of its general activity (90%).

Solution 2

(c)(ii)

Mark scheme

- The moths will show decreased oriented activity. Because the mutation prevents GTP from displacing GDP on the G protein, the G protein cannot become active, so the downstream signaling pathway that increases expression of genes associated with oriented activity is not activated.

Solution 2

(d)(i)

Mark scheme

- Any one line of evidence is sufficient: increased DopEcR expression will increase oriented activity (and thus the moths' ability to find a mate); an increase in DopEcR expression will enable binding of 20E to more receptors; an increase in DopEcR expression will make males more sensitive to pheromones released by females — all consistent with higher DopEcR expression at sexual maturity improving mate-finding.

Solution 2

(d)(ii)

Mark scheme

- An inhibitor of the DopEcR pathway will reduce oriented activity / reduce expression of genes associated with oriented activity, and therefore decrease mating success and population growth of the moths — reducing crop damage by lowering the pest population.

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

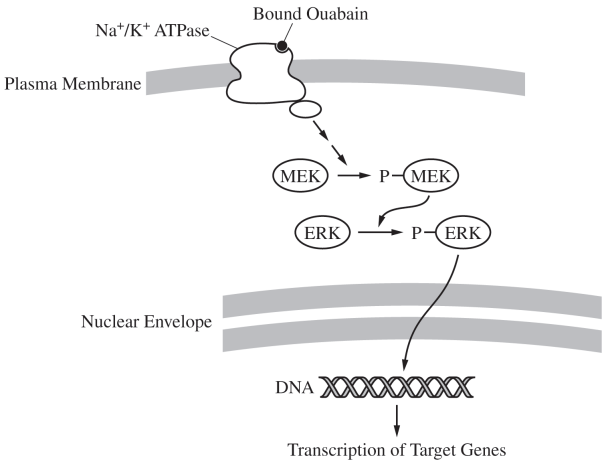
pM (~80%), drop steeply through 10^5 pM (~30%), reaching near 0% by 10^7-10^9 pM. Error bars represent $\pm 2SE_{\bar{x}}$. Caption: "Figure 2. Percent Na^+/K^+ATPase activity of NHK and PKD cells treated with increasing concentrations of ouabain. Error bars represent $\pm 2SE_{\bar{x}}$."]

[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."]

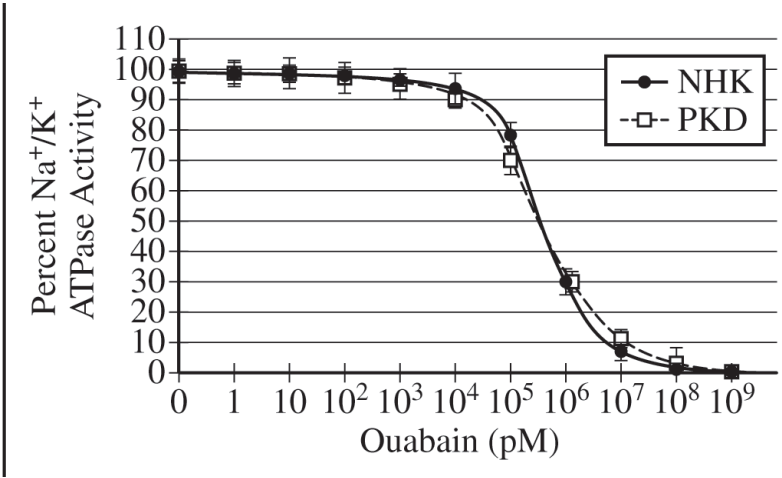
Question 1

(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.

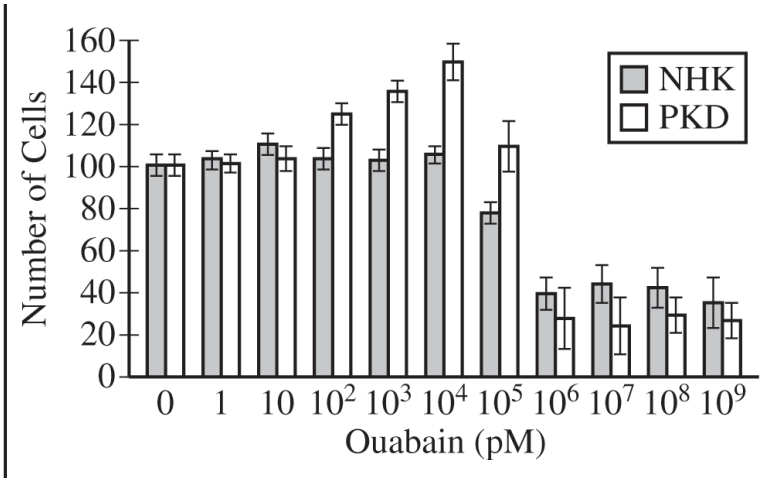
Question 1


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

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."]

(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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Question 1

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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

2018 ▪ Q8

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.

Question 8

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	+	–

Question 8

- 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.

Question 8

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

+ indicates activation
– indicates no activation

Solution 8

(a) Mark scheme

- Structure (1 pt, any one of, from Table 1 where type 1 responds to both ACh (+) and nicotine (+) but type 2 responds to ACh (+) only and not nicotine (–)): binding sites on type 1 and type 2 differ in shape/specificity/number; OR there is differential binding of molecules to type 1 vs type 2 receptors; OR the receptors are activated by one (ACh) or both (ACh and nicotine) molecules. Function (1 pt, matched to the same row/structure statement): differential binding of molecules to type 1 and type 2 receptors; OR activated by one or both molecules; OR no difference in response once activated (both open a sodium channel, cause depolarization, and cause muscle contraction). Fullest correct pairing: structurally the receptors' binding sites differ (type 2 can't bind nicotine, type 1 can);

Solution 8

functionally, once either IS activated there is no difference in the resulting muscle-cell response. Points may be earned from only one row of the table — don't mix statements across rows.

Solution 8

(b)

Mark scheme

- Acetylcholinesterase normally breaks down acetylcholine in the synapse to end receptor activation. If it is inhibited, acetylcholine is not broken down and remains in the synapse, causing continued/prolonged activation of AChR type 2 (1 pt) — leading to repeated opening of sodium channels, repeated depolarization, and/or muscle spasms.

Question 8

2017 ▪ Q8

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.

Solution 8

(a)

Mark scheme

- The plasma membrane's phospholipid bilayer is hydrophobic/nonpolar, which small hydrophobic/nonpolar estrogen molecules can cross directly; alternatively, the space between phospholipids allows small hydrophobic hormones like estrogen to passively diffuse through the membrane.

Solution 8

(b)

Mark scheme

- Antibodies are large, hydrophilic proteins that are unable to enter/cross into the cell (1 point). Because estrogen receptors are intracellular (in the cytoplasm), the (extracellular) antibodies never reach and cannot bind to the (intracellular) estrogen receptors, so they cannot block estrogen signaling and are ineffective at treating the estrogen-dependent cancer (1 point).