Past-paper walk-through

Introduction to Signal Transduction ▪ 4.2

eXercise

Questions in this set

- 2026 Q1
- 2025 Q2
- 2019 Q4
- 2018 Q8
- 2017 Q2
- 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 1

2026 ▪ Q1

Molecules known as dinucleoside polyphosphates, a type of nucleotide, are signaling molecules that accumulate in plant cells during dry or stressful conditions.
The following information applies to parts B, C, and D.
Stomata are pores on the surface of leaves that open when exposed to light and regulate the flow of carbon dioxide, oxygen, and water vapor in and out of a plant. In response to dry environmental conditions, many plants close their stomata, which reduces water loss.
Scientists hypothesized that the dinucleoside polyphosphates Ap_4A and Cp_4C bind to DORN1 receptors on the plasma membrane of plant cells and initiate signaling cascades that cause stomata to close. The scientists exposed plants to light to open the stomata and then placed samples of the leaves in buffer alone or in buffer

Question 1

containing one of three different compounds: Ap_4A, Cp_4C, or abscisic acid (ABA), a molecule that causes stomata to close.
The scientists measured the size of the stomata in each sample and calculated their sizes relative to the size of the stomata in the sample kept in buffer alone, as shown in Figure 1.
Figure 1. Effect of Ap_4A, Cp_4C, and ABA on Relative Stomatal Size (Error Bars Represent $\pm SE_{\bar{x}}$)
[Bar graph; y-axis "Relative Size of Stomata (width/length)" from 0.0 to 1.1 in increments of 0.1; x-axis "Treatment" with four bars: Buffer, Ap_4A, Cp_4C, ABA. Approximate bar heights with error bars: Buffer $\approx 1.0 \pm 0.05$; $Ap_4A \approx 0.65 \pm 0.05$; $Cp_4C \approx 0.62 \pm 0.05$; ABA $\approx 0.70 \pm 0.05$.]
(a) Describe the three structural components of a nucleotide.

Question 1

2026 ▪ Q1

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The scientists measured the size of the stomata in each sample and calculated their sizes relative to the size of the stomata in the sample kept in buffer alone, as shown in Figure 1.

Question 1

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(b)(i) Identify the dependent variable in the scientists' first experiment.

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

(b)(iii) Justify the use of buffer alone as a control in the scientists' experiments.

Question 1

2026 ▪ Q1

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(c)(i) In a second experiment, the scientists used plants that were identical to those in the first experiment except that the gene encoding the DORN1 receptor was mutated. The scientists repeated the procedure of the first experiment. Their results are shown in Figure 2.

Figure 2. Effect of Ap_4A, Cp_4C, and ABA on Relative Stomatal Size in DORN1 Mutants (Error Bars Represent $\pm SE_{\bar{x}}$)

Question 1

[Bar graph; y-axis "Relative Size of Stomata (width/length)" from 0.0 to 1.2 in increments of 0.1; x-axis "Treatment" with four bars: Buffer, Ap_4A, Cp_4C, ABA. Approximate bar heights with error bars: Buffer $\approx 1.0 \pm 0.05$; $Ap_4A \approx 1.1 \pm 0.1$; $Cp_4C \approx 0.70 \pm 0.05$; ABA $\approx 0.60 \pm 0.05$.]

Justify the scientists' treating one sample of leaves with ABA in the experiments.

(c)(ii) Based on Figure 2, **describe** the difference between the effects of Ap_4A and Cp_4C treatments on the size of stomata in plants with mutated DORN1 receptors.

(c)(iii) Activation of DORN1 receptors induces plant cells to produce certain molecules that cause the stomata to close. Based on the data in Figures 1 and 2 for cells treated with Ap_4A, **predict** the relative production of the molecules by DORN1-mutated cells in comparison to the production by nonmutated cells.

Question 1

2026 ▪ Q1

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(d)(i) The DORN1 receptor transmits signals that result in an increase in the transcription of genes involved in plant defenses. The scientists then developed DORN1-mutant plants in which the DORN1 receptor lacked most of its intracellular domain.

In cells homozygous for this mutation, **predict** the effect of Ap_4A treatment on transcription of the genes involved in plant defenses relative to the effect of Ap_4A on nonmutated cells.

Question 1

(d)(ii) Justify your prediction.

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

Treatment	General Activity (percent of total time observed, average $\pm 2SE_{\bar{x}}$)	Oriented Activity (percent of general activity, average $\pm 2SE_{\bar{x}}$)
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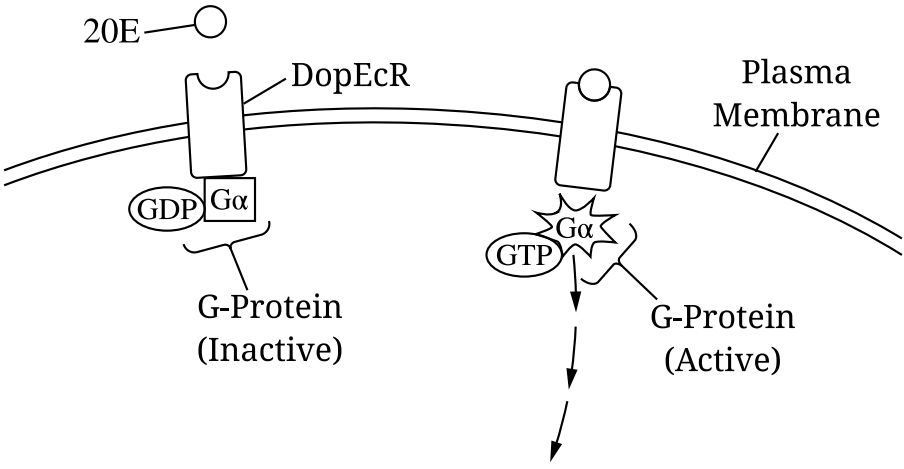
Question 2


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 4

2019 ▪ Q4

[Figure 1. Release of neurotransmitters into the synapse in response to an action potential: a diagram of a presynaptic neuron terminal releasing "Neurotransmitter" molecules (packaged in vesicles) into the "Synapse", which are received by receptor channels on the "Postsynaptic Neuron" membrane.]

[Figure 2. Model of a typical action potential in a neuron: a graph of Membrane Potential (mV) on the y-axis (labeled -70, -55, 0, 30) versus Time (milliseconds) on the x-axis (0 to 5); a dashed horizontal line at -55 mV labeled "Threshold"; the curve starts at resting potential -70 mV, rises sharply to a peak of about +30 mV around t=1.5 ms, then falls rapidly, undershoots to about -75 mV around t=3 ms, and returns gradually toward -70 mV by t=5 ms.]

Acetylcholine is a neurotransmitter that can activate an action potential in a postsynaptic neuron (Figures 1 and 2). A researcher is investigating the effect of a

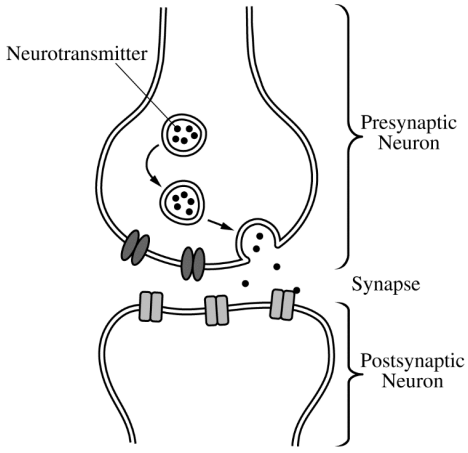
Question 4

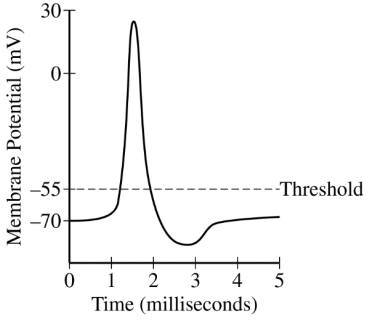
particular neurotoxin that causes the amount of acetylcholine released from presynaptic neurons to increase.

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

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

Question 4


Neurotransmitter
Presynaptic Neuron
Synapse
Postsynaptic Neuron


30
0
–55
–70
Threshold
Membrane Potential (mV)
0
1
2
3
4
5
Time (milliseconds)

Solution 4

(a) Mark scheme

- Description: The immediate effect of the neurotoxin (which increases acetylcholine released from presynaptic neurons) is to increase the number/frequency of action potentials generated in the postsynaptic neuron, since more neurotransmitter binding means the postsynaptic membrane reaches threshold more often. [1 point] Prediction: The maximum membrane potential (peak amplitude) of each postsynaptic action potential will stay the same — the toxin increases how often an action potential fires, not the peak voltage an individual action potential reaches (which is set by the same voltage-gated channels regardless of stimulus frequency). [1 point]

Solution 4

(b) Mark scheme

- Model A (AChE added to the synapse): Predicted effective. Reasoning — acetylcholine released by the presynaptic neuron acts in the synapse, so AChE present there can degrade it before it binds and overstimulates postsynaptic receptors, counteracting the neurotoxin's effect. [1 point] Model B (AChE added to the cytoplasm of the postsynaptic cell): Predicted not effective. Reasoning — acetylcholine is never present in the cytoplasm of the postsynaptic cell (it acts extracellularly, binding receptors on the postsynaptic membrane from the synaptic side), so intracellular AChE has no acetylcholine to degrade and cannot prevent the toxin's effect. [1 point]

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 2

2017 ▪ Q2

[Figure 1: Line graph titled "The effect of karrikins (KAR) and trimethylbutenolides (TMB) on seed germination in *Lactuca* plants. Error bars represent $\pm 2SE_{\bar{X}}$." Y-axis: "Seed Germination (- KAR (solid line, open squares): 0- Control (solid line, filled circles): 0- KAR + TMB (dashed line, open circles): 0- TMB (solid line, filled squares): 0All curves start at 0

Fires frequently occur in some ecosystems and can destroy all above-ground vegetation. Many species of plants in these ecosystems respond to compounds in smoke that regulate seed germination after a major fire. Karrikins (KAR) and trimethylbutenolides (TMB) are water-soluble compounds found in smoke that are deposited in the soil as a result of a fire. KAR and TMB bind to receptor proteins in a seed. In a study on the effects of smoke on seeds, researchers recorded the timing and

Question 2

percent of seed germination in the presence of various combinations of KAR and TMB. The results are shown in Figure 1.

In a second investigation into the effect of available water on seed germination after a fire, researchers treated seeds with KAR or TMB. The treated seeds were then divided into two treatment groups. One group received a water rinse and the other group received no water rinse. The seeds were then incubated along with a group of control seeds that were not treated. The results are shown in the table.

EFFECT OF CHEMICAL TREATMENT AND WATER RINSE ON GERMINATION

Treatment Group	Chemical Treatment — KAR	Chemical Treatment — TMB	Water	Germination Result
1 (control)	−	−	−	Control result
2	+	−	−	Different from control
3	−	+	−	Different from control
4 (control)	−	−	+	Control result
5	+	−	+	Different from control
6	−	+	+	Same as control

Question 2

(a) The researchers made the following claims about the effect of KAR and the effect of TMB on seed germination relative to the control treatment.

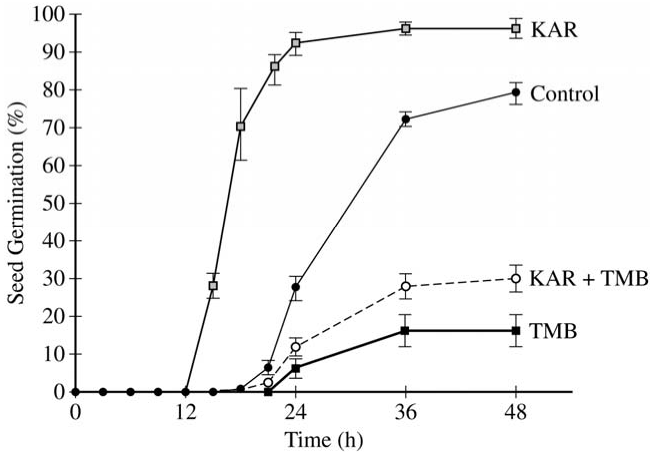
- KAR alone affects the timing of seed germination.
- KAR alone affects the percentage of seeds that germinate.
- TMB alone affects the timing of seed germination.
- TMB alone affects the percentage of seeds that germinate.

Provide support using data from Figure 1 for each of the researchers' claims.

Question 2

Treatment Group	Chemical Treatment		Water	Germination Result
	KAR	TMB		
1 (control)	–	–	–	Control result
2	+	–	–	Different from control
3	–	+	–	Different from control
4 (control)	–	–	+	Control result
5	+	–	+	Different from control
6	–	+	+	Same as control

Question 2


Seed Germination (%)
100
90
80
70
60
50
40
30
20
10
0
0
12
24
36
48
Time (h)
KAR
Control
KAR + TMB
TMB

Question 2

2017 ▪ Q2

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Fires frequently occur in some ecosystems and can destroy all above-ground vegetation. Many species of plants in these ecosystems respond to compounds in smoke that regulate seed germination after a major fire. Karrikins (KAR) and trimethylbutenolides (TMB) are water-soluble compounds found in smoke that are deposited in the soil as a result of a fire. KAR and TMB bind to receptor proteins in a seed. In a study on the effects of smoke on seeds, researchers recorded the timing and percent of seed germination in the presence of various combinations of KAR and TMB. The results are shown in Figure 1.

In a second investigation into the effect of available water on seed germination after a fire, researchers treated seeds with KAR or TMB. The treated seeds were then divided into two

Question 2

treatment groups. One group received a water rinse and the other group received no water rinse. The seeds were then incubated along with a group of control seeds that were not treated. The results are shown in the table.

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4 (control)	−	−	+	Control result
5	+	−	+	Different from control
6	−	+	+	Same as control

(b) Make a claim about the effect of rinsing on the binding of KAR to the receptor in the seed and about the effect of rinsing on the binding of TMB to the receptor in the seed. Identify the appropriate treatment groups and results from the table that, when compared with the controls, **provide support** for each claim.

Question 2

2017 ▪ Q2

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Question 2

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5	+	−	+	Different from control
6	−	+	+	Same as control

(c) There is intense competition by plants to successfully colonize areas that have been recently cleared by a fire. **Describe** ONE advantage of KAR regulation and ONE advantage of TMB regulation to plants that live in an ecosystem with regular fires.

Solution 2

(a)

Mark scheme

- Using Figure 1 data, 1 point per claim. KAR affects timing: germination starts earlier/sooner/faster/quicker with KAR than in Control. KAR affects percentage: a higher percentage of seeds germinate in the presence of only KAR than in Control. TMB affects timing: germination starts later/slower with TMB than in Control. TMB affects percentage: a lower percentage of seeds germinate in the presence of only TMB than in Control.

Solution 2

(b)

Mark scheme

- KAR claim (1 point): KAR remains bound to the receptor after rinsing (rinsing does not affect KAR binding). KAR support (1 point): both KAR-no-rinse (Group 2) and KAR-with-rinse (Group 5) give results different from the controls (Group 1 and Group 4) — rinsing does not remove the KAR effect. TMB claim (1 point): TMB does not remain bound after rinsing (rinsing affects/removes TMB binding). TMB support (1 point): TMB-no-rinse (Group 3) differs from Control (Group 1), but TMB-with-rinse (Group 6) is the same as Control (Group 4) — rinsing removes the TMB effect.

Solution 2

(c)

Mark scheme

- 1 point per row. Advantage of KAR regulation: germination occurs at times of increased resource availability, OR plants with KAR regulation can outcompete other plants (without KAR regulation), OR germination occurs when fewer competitors are present / land is barren (shortly after a fire). Advantage of TMB regulation: plants with TMB regulation do not germinate / can maintain seed dormancy until (enough) water is available, OR plants with TMB regulation do not germinate in a dry environment.

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).