1.6 Organisms Respond to Changes in their Environments

Total Marks

AQA 7402 · Calculator allowed · about 235 minutes · Write-in edition

Name: _____ Date: ____ / ____ / _____

Answer ALL questions. Show all your working.

1 Woodlice are commonly found in damp, dark places such as under logs, stones and loose bark. A student studied the behavioural response of woodlice to differences in humidity using a choice chamber divided into a dry side and a humid side (with light and temperature kept the same on both sides). For woodlice found in each side, the student recorded the mean rate at which individual woodlice changed direction (the turning rate).

(a) State what is meant by a kinesis. **(1)**

(b) The student recorded a mean turning rate of 9.6 turns per minute for woodlice in the dry side of the chamber and 1.2 turns per minute for woodlice in the humid side. Using these data, evaluate whether the turning rates alone explain woodlice accumulating in the humid side of the chamber over time. **(4)**

(c) Explain one advantage to the woodlouse of relying on a simple kinesis, rather than a taxis, to respond to changes in humidity. **(2)**

(d) State one difference between a taxis and a kinesis. **(1)**

(Total for Question 1 is 8 marks)

2 Required practical. A choice chamber was used to study how humidity affects the distribution of woodlice. The chamber had two connected sections: one containing dry silica gel and one containing damp cotton wool, with a mesh floor so woodlice could not tell the two sides apart by sight. Twenty woodlice were placed in the centre of the chamber and left for 10 minutes, after which the number on each side was counted. The procedure was repeated five times using fresh woodlice each time.

(a) Describe how the investigation should be set up to ensure that humidity is the only variable affecting the distribution of the woodlice. **(4)**

(b) Explain why the same number of woodlice should be used in each repeat, and why the count should be taken after a set, fixed period of time in every repeat. **(2)**

(c) In one repeat, 4 of the 20 woodlice were found on the dry side and the rest on the humid side after 10 minutes. Calculate the percentage of woodlice found on the humid side. **(2)**

(d) The student wants to test whether this distribution is significantly different from an even (50:50) split due to chance. Name an appropriate statistical test for this data, and state a suitable null hypothesis. **(2)**

(Total for Question 2 is 10 marks)

3 In a classic experiment, the tips of oat coleoptiles (seedling shoots) were removed and placed upside-down on blocks of agar jelly, allowing auxin (indoleacetic acid, IAA) produced by the tips to diffuse into the agar. Each agar block (now containing auxin) was then placed off-centre on top of a separate decapitated coleoptile stump, touching only one side of the cut surface. The stumps were left in the dark and their growth was monitored.

(a) Predict, with a reason, the direction in which a coleoptile stump would bend as it grew. **(3)**

(b) In an intact coleoptile exposed to unilateral (one-sided) light, explain how light brings about lateral (side-to-side) redistribution of auxin, and how this causes the shoot to curve towards the light (positive phototropism). **(4)**

(c) The coleoptile in the intact plant curved through 35 degrees over a period of 90 minutes. Calculate the mean rate of curvature, in degrees per hour. **(2)**

(d) Suggest two improvements to the experimental procedure that would increase confidence in a conclusion drawn from a single curvature measurement like this. **(2)**

(Total for Question 3 is 11 marks)

4 A resting neurone maintains a potential difference of about -70 mV across its axon membrane (inside negative relative to outside).

(a) Explain how the sodium-potassium pump and ion channels in the axon membrane maintain this resting potential. **(5)**

(b) State the term used to describe the state of the axon membrane when it is at its resting potential and not currently transmitting an impulse. **(1)**

(Total for Question 4 is 6 marks)

5 Required practical. A simple ruler-drop test was used to measure a person's reaction time. One person held a ruler vertically with the zero mark between the thumb and forefinger of a second person, who was looking at the ruler. The first person released the ruler without warning, and the second person caught it as quickly as possible. The distance the ruler fell before being caught was recorded.

(a) Describe how this test should be carried out to obtain a reliable estimate of a person's mean reaction time. **(3)**

(b) In one trial, the ruler fell 18.0 cm before being caught. Using $s = 1/2 \times g \times t^2$ (where $g = 9.81\ m/s^2$), calculate the person's reaction time in milliseconds. **(4)**

(c) Explain one variable that should be controlled when comparing reaction times between different people, and suggest one way to improve the reliability of the comparison. **(2)**

(d) The reaction time measured in this test includes the time taken for sensory processing, decision-making in the brain, and the motor response, as well as synaptic delays. Explain why this measured reaction time is much longer than the time taken for a single action potential to cross one synapse. **(2)**

(Total for Question 5 is 11 marks)

6 Blood glucose concentration is regulated by negative feedback involving the hormones insulin and glucagon, secreted by the islets of Langerhans in the pancreas.

(a) Describe how a rise in blood glucose concentration, following a meal, is detected and the sequence of events that returns it to normal. **(4)**

(b) Describe the second messenger role of cyclic AMP (cAMP) in glucagon action on liver cells. **(3)**

(c) Explain why insulin and glucagon secretion form an example of negative feedback control. **(2)**

(Total for Question 6 is 9 marks)

7 Thermoregulation in mammals is controlled by the thermoregulatory centre in the hypothalamus, which coordinates responses to both a rise and a fall in core body temperature.

(a) State the two types of receptor, and their locations, that provide the thermoregulatory centre with information about temperature. **(2)**

(b) Explain how vasodilation of arterioles supplying the skin capillaries helps to lower body temperature when core temperature rises above normal. **(3)**

(c) Explain how shivering helps to raise body temperature when core temperature falls below normal. **(2)**

(d) Explain why thermoregulation is described as an example of negative feedback control involving effectors that can produce opposite responses (antagonistic effectors). **(1)**

(Total for Question 7 is 8 marks)

8 Synaptic transmission at a cholinergic synapse can be modified by the number and pattern of impulses arriving at the presynaptic neurone(s).

(a) Explain why transmission across a cholinergic synapse can only occur in one direction (from the presynaptic to the postsynaptic neurone). **(2)**

(b) Explain the difference between spatial summation and temporal summation, and how each can help a postsynaptic neurone reach the threshold needed to generate an action potential. **(3)**

(Total for Question 8 is 5 marks)

9 Heart rate is controlled by the cardiovascular (cardiac) centre in the medulla oblongata, which receives information from receptors in the walls of the aorta and carotid arteries and sends impulses to the heart via the autonomic nervous system.

(a) Explain how baroreceptors help to reduce heart rate when blood pressure rises above normal. **(4)**

(b) Explain how chemoreceptors help to increase heart rate in response to a fall in blood pH (caused by a rise in dissolved carbon dioxide). **(4)**

(c) A person at rest has a heart rate of 68 beats per minute and a stroke volume of 72 cm^3. Using cardiac output (cm^3/min) = heart rate x stroke volume, calculate their cardiac output in dm^3 per minute. **(3)**

(Total for Question 9 is 11 marks)

10 A sarcomere is the repeating structural unit of a myofibril in a skeletal muscle fibre, containing overlapping thick (myosin) and thin (actin) filaments.

(a) Describe the roles of tropomyosin and troponin in a relaxed muscle, and explain how an increase in calcium ion concentration in the sarcoplasm triggers muscle contraction. **(5)**

(b) During contraction, a sarcomere shortens from 2.6 micrometres to 2.1 micrometres. Calculate the percentage decrease in the length of the sarcomere. **(2)**

(c) Explain why, during this contraction, the I band and the H zone both decrease in width, but the width of the A band stays the same. **(3)**

(d) Explain why the observation that the A band stays a constant width during contraction supports the sliding filament theory, rather than an alternative hypothesis in which the thick and thin filaments themselves become shorter during contraction. **(2)**

(Total for Question 10 is 12 marks)

11 Animals coordinate responses to changes in their external environment using both the nervous system and the hormonal (endocrine) system. Compare and contrast nervous and hormonal communication as means of coordinating a response to a change in the external environment.

(Total for Question 11 is 6 marks)

12 Organophosphate compounds are used as pesticides because they inhibit the enzyme acetylcholinesterase in the nervous systems of insects.

(a) Predict and explain the short-term effect of an organophosphate pesticide on transmission at a cholinergic synapse in an insect's nervous system. **(4)**

(b) A researcher placed woodlice in a choice chamber with dry and humid sides, as in Question 2. Woodlice treated with a sub-lethal dose of an organophosphate pesticide showed a significantly lower rate of turning in the dry side of the chamber compared with untreated woodlice. Suggest an explanation for this observation, and evaluate why it might reduce the survival chances of the treated woodlice population in a pesticide-treated habitat. **(5)**

(Total for Question 12 is 9 marks)

13 The table shows the membrane potential of an axon recorded every 0.5 milliseconds during a single nerve impulse.

Time (ms): 0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5
Membrane potential (mV): -70 -70 -20 +40 +30 -60 -80 -70

Time (ms)	Membrane potential (mV)
0.0	-70
0.5	-70
1.0	-20
1.5	+40
2.0	+30
2.5	-60
3.0	-80
3.5	-70

(a) Using the data, state the resting potential of the axon and identify the time interval in which depolarisation begins. **(2)**

(b) Explain the ionic basis of the rising phase (depolarisation) and the falling phase (repolarisation) of the action potential shown in the table. **(4)**

(c) Explain why the membrane potential becomes more negative than the resting potential at t = 3.0 ms (hyperpolarisation), and state the importance of the refractory period that follows an action potential. **(3)**

(d) The absolute refractory period of this axon is 1 millisecond. Calculate the maximum theoretical frequency, in Hz, at which action potentials could be generated. **(2)**

(Total for Question 13 is 11 marks)

14 A student used two pairs of electrodes placed 45 mm apart along an isolated, myelinated sensory neurone to measure the time taken for a nerve impulse to travel between them. The impulse took 0.5 milliseconds to travel from the first pair of electrodes to the second.

(a) Calculate the speed of conduction of the impulse, in m/s. Give your answer to 2 significant figures. (speed = distance / time) **(3)**

(b) Explain why myelination increases the speed of conduction of a nerve impulse. **(3)**

(c) Explain how each of the following would affect the speed of conduction of a nerve impulse: (i) an increase in axon diameter; (ii) a decrease in temperature. **(4)**

(d) A technician suggests that raising the temperature of an isolated nerve preparation above 40°C would continue to increase the speed of impulse conduction.
Evaluate this suggestion. **(2)**

(Total for Question 14 is 12 marks)

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15 Acetylcholine is the neurotransmitter released at a cholinergic synapse. Describe the sequence of events at a cholinergic synapse that leads to the generation of an action potential in the postsynaptic neurone, starting from the arrival of an action potential at the presynaptic knob.

(Total for Question 15 is 6 marks)

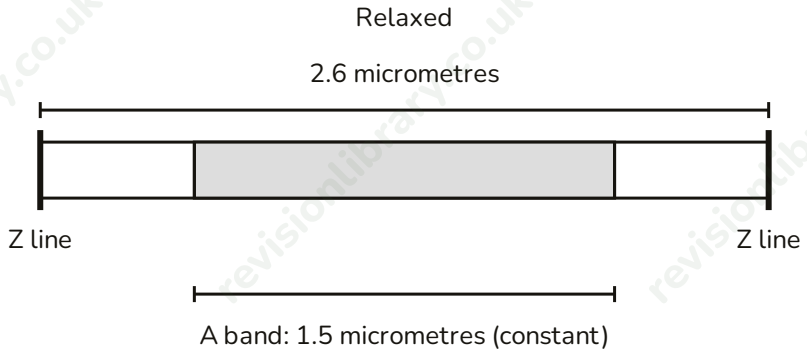
16 Skeletal muscle contraction is explained by the sliding filament theory, in which actin and myosin filaments slide past one another within each sarcomere, shortening the muscle fibre.

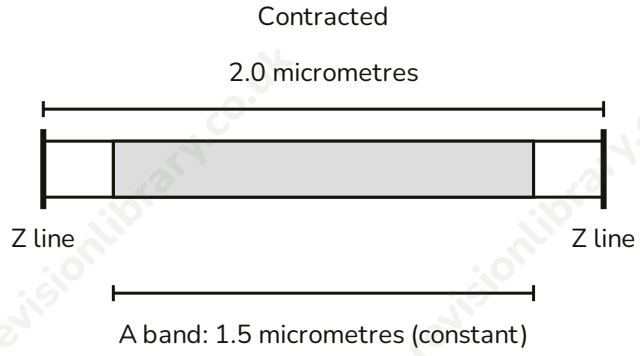
(a) Describe the role of calcium ions and troponin in initiating muscle contraction once an action potential reaches a muscle fibre. **(3)**

(b) Explain the role of ATP in both the power stroke of the myosin head and in muscle relaxation. **(3)**

(c) An electron micrograph of a relaxed sarcomere shows the whole sarcomere (Z line to Z line) is 2.6 micrometres long, and the (constant) A band is 1.5 micrometres long. During contraction the sarcomere shortens to 2.0 micrometres. Assuming the A band stays the same length, calculate the percentage decrease in the length of the I band during this contraction. (I band length = sarcomere length - A band length.) **(3)**

Schematic measurement comparison (not an electron micrograph)





I band length = sarcomere length - A band length

(Total for Question 16 is 9 marks)

17 In type 1 diabetes, the β cells of the islets of Langerhans are destroyed by an autoimmune response, so little or no insulin is produced. A patient with untreated type 1 diabetes has a fasting blood glucose concentration of 11.8 mmol/dm3 (normal fasting range is approximately 4.0-5.9 mmol/dm3).

(a) Explain why a person with untreated type 1 diabetes has a persistently high blood glucose concentration. **(2)**

(b) Calculate the percentage by which this patient's fasting blood glucose concentration (11.8 mmol/dm3) exceeds the upper limit of the normal fasting range (5.9 mmol/dm3). **(2)**

(c) When blood glucose concentration exceeds the kidney's reabsorption capacity (the renal threshold, approximately 10 mmol/dm3), glucose appears in the urine. Explain, in terms of the proximal convoluted tubule, why glucose is normally completely reabsorbed from the filtrate but appears in the urine of this patient. **(3)**

(d) Explain why untreated type 1 diabetes also causes excessive urine production (polyuria). **(1)**

(Total for Question 17 is 8 marks)

18 The loop of Henle creates a concentration gradient of sodium and chloride ions in the medulla of the kidney, which is essential for producing concentrated urine. This is known as the countercurrent multiplier mechanism.

(a) Explain how the ascending limb of the loop of Henle, which is impermeable to water, contributes to establishing a high concentration of sodium and chloride ions in the medulla. **(3)**

(b) Explain how this ion concentration gradient in the medulla enables the collecting duct to reabsorb water and produce concentrated urine, when ADH is present. **(2)**

(c) A desert-adapted rodent has unusually long loops of Henle that extend deep into the medulla, compared with an aquatic mammal such as a beaver, which has short loops of Henle. Suggest why this difference in loop length is an adaptation to each animal's habitat. **(2)**

(Total for Question 18 is 7 marks)

19 Evaluate the effectiveness of negative feedback control in maintaining a stable internal environment, using blood glucose regulation and thermoregulation as examples, and discuss circumstances in which this control can fail or be overwhelmed.

(Total for Question 19 is 6 marks)

Mark scheme · 1.6 Organisms Respond to Changes in their Environments

Question 1

(a) a non-directional response in which the rate of movement (or rate of turning) changes according to the intensity of the stimulus, not the direction of movement (oe) **B1**

(a) Answer: A kinesis is a non-directional response in which the organism's rate of movement or turning changes with the intensity of the stimulus.

(b) in the dry side, the higher turning rate (9.6 turns/min) means woodlice change direction more frequently **B1**

(b) in the humid side, the lower turning rate (1.2 turns/min) means woodlice change direction less frequently; this does not show that they remain there **B1**

(b) movement speed and the directions or angles of turns are not supplied, so the rates alone do not establish how likely woodlice are to cross between the two sides **B1**

(b) the turning rates alone do not explain accumulation in the humid side; movement speed, trajectories or time spent in each side would be needed to evaluate this explanation (oe) **B1**

(b) Answer: Woodlice turn more frequently in dry air (9.6 turns per minute) than in humid air (1.2 turns per minute). Fewer turns in humid air do not show that woodlice remain there. Without movement speeds and the directions or angles of turns, the rates alone cannot establish how often woodlice cross between the sides or explain accumulation in the humid side.

(c) a kinesis does not require the woodlouse to detect the direction of the stimulus (useful because humidity does not spread as a clear directional gradient in the way light or a chemical source might) (oe) **B1**

(c) so a kinesis can still keep the woodlouse in suitable conditions using a much simpler nervous response/less complex sensory processing, which is less costly for a simple invertebrate (oe) **B1**

(c) Answer: A kinesis does not need the direction of the humidity gradient to be detected, so it can be produced by a much simpler nervous system than a directional taxis would require.

(d) a taxis is a directional response (movement towards or away from the stimulus), whereas a kinesis is non-directional (only the rate of movement/turning changes) (oe) **B1**

(d) Answer: A taxis involves directed movement towards or away from a stimulus; a kinesis involves a change in the rate of movement or turning with no fixed direction.

Question 2

(a) use a covered/opaque chamber (or cover with foil/black paper) so that both sides receive the same, or no, light (controls light as a variable) **B1**

(a) carry out the investigation in a single location/at a constant room temperature so both sides of the chamber are at the same temperature **B1**

(a) use a mesh or perforated partition/floor (not solid, and not one that lets woodlice sense a difference other than humidity) so woodlice can move freely between sides but cannot see or smell a difference other than humidity **B1**

(a) use the same number of similarly sized/acclimatised woodlice and the same time period in each repeat, to allow a fair comparison **B1**

(a) Answer: Cover the chamber (or keep it in the dark) and keep it at a constant temperature so that light and temperature are controlled and only humidity differs between the two sides; use a mesh floor so woodlice can move freely but cannot see which side is which; use the same number and type of woodlice and the same time period for each repeat.

(b) using the same number of woodlice each time means the percentage/proportion choosing each side can be validly compared between repeats (oe) **B1**

(b) using a fixed time ensures woodlice in every repeat have had the same opportunity to move/respond, so differences between repeats are not simply due to some being given longer to move (oe) **B1**

(b) Answer: Keeping the number of woodlice constant allows fair comparison of the proportions choosing each side between repeats, and using a fixed time ensures every repeat gives woodlice the same opportunity to respond, so time is not a confounding variable.

(c) correct method: (20 - 4)/20 x 100, i.e. 16/20 x 100 **M1**

(c) 80% (cao) **A1**

(c) Answer: 80%

(d) chi-squared (chi^2) test **B1**

(d) null hypothesis: there is no significant difference between the observed distribution of woodlice and the expected (even, 50:50) distribution between the humid and dry sides; any difference is due to chance (oe) **B1**

(d) Answer: Chi-squared test; H0: there is no significant difference between the observed and expected (50:50) distribution of woodlice between the two sides of the chamber.

Question 3

(a) the stump bends away from the side where the agar block is placed (i.e. curves towards the side with no auxin block) **B1**

(a) the side of the stump in contact with the agar block receives a higher concentration of auxin **B1**

(a) auxin stimulates cell elongation, so this side elongates more than the opposite side, causing unequal growth and curvature away from the block (oe) **B1**

(a) Answer: The stump curves away from the side with the agar block, because that side receives more auxin and its cells elongate more than those on the opposite side, so unequal growth causes the stem to bend towards the side without the block.

(b) auxin (IAA) is produced in the tip of the shoot **B1**

(b) when the shoot is illuminated from one side, auxin is transported laterally towards the shaded side of the tip **B1**

(b) this results in a higher concentration of auxin on the shaded side than on the illuminated side, and auxin then moves down the shoot from the tip **B1**

(b) auxin stimulates cell elongation in the region just behind the tip; because the shaded side has more auxin it elongates more than the illuminated side, causing the shoot to bend/curve towards the light **B1**

(b) Answer: Auxin made in the tip is moved to the shaded side when light comes from one direction, giving a higher auxin concentration there; since auxin promotes cell elongation, the shaded side grows faster than the illuminated side, bending the shoot towards the light.

(c) correct method: 35/90 x 60 (or equivalent unit conversion) **M1**

(c) 23.3 degrees per hour (awrt 23) **A1**

(c) Answer: 23.3 degrees per hour

(d) repeat the experiment using several different coleoptiles (of the same age/species) and calculate a mean curvature, to reduce the effect of natural variation between individual plants (oe) **B1**

(d) include a control coleoptile with a plain agar block (containing no auxin) placed off-centre, to confirm that curvature is caused specifically by auxin and not by the presence of the agar block, gravity or handling of the stump (oe) **B1**

(d) Answer: Repeat with several coleoptiles and calculate a mean, and include a control using a plain (auxin-free) agar block to confirm the curvature is due to auxin rather than the block itself or another factor.

Question 4

(a) the sodium-potassium pump actively transports (using ATP) 3 sodium ions out of the axon for every 2 potassium ions moved into the axon **B1**

(a) this creates a concentration gradient with a higher concentration of sodium ions outside the axon and a higher concentration of potassium ions inside the axon **B1**

(a) the membrane has (some) potassium ion channels open at rest, making it more permeable to potassium ions than to sodium ions **B1**

(a) potassium ions diffuse back out of the axon down their concentration gradient through these channels (facilitated diffusion), while few sodium ions can re-enter as most sodium channels are closed **B1**

(a) the resulting net loss of positive charge from inside the axon makes the inside of the membrane negatively charged relative to the outside, maintaining the resting potential of about -70 mV **B1**

(a) Answer: The sodium-potassium pump actively moves 3 Na^+ out for every 2 K^+ in, using ATP, creating concentration gradients; because the membrane is more permeable to K^+ (via open potassium channels) than to Na^+, K^+ diffuses back out, leaving the inside relatively negative and maintaining the resting potential of about -70 mV.

(b) polarised (accept 'resting state') **B1**

(b) Answer: Polarised

Question 5

(a) repeat the test several times (e.g. at least 5-10 times) for each person **B1**

(a) discard anticipatory catches (e.g. where the person appears to guess/close their hand before release) and use random, unpredictable time intervals between repeats **B1**

(a) calculate the mean distance fallen (or mean reaction time) from the repeats, to reduce the effect of anomalous results/random variation **B1**

(a) Answer: Repeat the drop several times per person using random time intervals so the catch cannot be anticipated, discard any obvious anticipatory catches, and calculate a mean value from the repeats.

(b) rearranges correctly to $t = \sqrt{2s/g}$ **M1**

(b) correctly substitutes s = 0.180 m: $t = \sqrt{(2 \times 0.180)/9.81}$ **M1**

(b) t = 0.192 s (awrt 0.19 s) **A1**

(b) converts to 192 ms (awrt 190-193 ms) **A1**

(b) Answer: 192 ms (0.192 s)

(c) control a variable such as the hand/finger position used to catch, whether the dominant hand is used, time of day, or level of alertness/caffeine intake, with a reason why it affects reaction time (any valid confounding variable with reason) **B1**

(c) suggest a way to improve reliability, e.g. increasing the number of repeats per person and/or testing multiple people to calculate a mean, to reduce the effect of random variation between individual trials **B1**

(c) Answer: For example, the hand used to catch should be the same for every person tested (dominant hand affects reaction time); reliability can be improved by increasing the number of repeats per person and averaging the results.

(d) the measured reaction time involves impulses passing along several neurones (sensory, relay/interneurones in the brain, and motor) and crossing more than one synapse, each of which adds a synaptic delay **B1**

(d) it also includes the time needed for processing/decision-making in the brain and for the muscle to respond and physically move the hand, not just the transmission across a single synapse **B1**

(d) Answer: The overall reaction time includes conduction along several neurones, several synaptic delays (not just one), processing time in the brain, and the time for the muscle to contract and move the hand, so it is much longer than a single synaptic crossing time.

Question 6

(a) β cells in the islets of Langerhans detect the rise in blood glucose concentration directly oe **B1**

(a) β cells secrete (more) insulin into the blood oe **B1**

(a) insulin binds to specific receptors on muscle cells, causing more glucose transporters (GLUT4) to move to the cell-surface membrane, increasing glucose uptake into these cells oe **B1**

(a) insulin also stimulates conversion of glucose to glycogen (glycogenesis) in the liver/muscle, and increases the rate of glucose use in respiration, lowering blood glucose concentration back towards normal oe **B1**

(a) Answer: Beta cells detect rising blood glucose and secrete insulin, which binds to receptors on liver and muscle cells, increasing glucose uptake and stimulating glycogenesis and glucose use in respiration, lowering blood glucose back to normal.

(b) glucagon binds to a specific receptor on the cell-surface membrane of a liver cell (glucagon cannot cross the membrane as it is a protein hormone) oe **B1**

(b) this activates an enzyme (adenylate cyclase) inside the cell, which converts ATP into cyclic AMP (cAMP) oe **B1**

(b) cAMP acts as a second messenger, activating a cascade of enzymes (e.g. activating enzymes that break down glycogen to glucose, glycogenolysis) inside the cell oe **B1**

(b) Answer: Glucagon binds a surface receptor, activating adenylate cyclase to produce cAMP inside the cell, which acts as a second messenger to activate enzymes that break down glycogen to glucose.

(c) a rise in blood glucose triggers insulin release, which lowers blood glucose; a fall in blood glucose triggers glucagon release, which raises blood glucose - in each case the response counteracts/reverses the original change oe **B1**

(c) this keeps blood glucose concentration fluctuating within a narrow range around a set point, rather than continuing to rise or fall oe **B1**

(c) Answer: Each hormone's effect counteracts the change that triggered its release (insulin lowers a rise, glucagon raises a fall), keeping blood glucose within a narrow range - the defining feature of negative feedback.

Question 7

(a) thermoreceptors in the skin, which detect the temperature of the external environment/skin surface oe **B1**

(a) thermoreceptors within the hypothalamus itself, which detect the temperature of the blood flowing through it (core body temperature) oe **B1**

(a) Answer: Thermoreceptors in the skin (detecting external/skin temperature) and thermoreceptors in the hypothalamus itself (detecting core blood temperature).

(b) arterioles supplying the skin capillary network dilate (widen), allowing more blood to flow close to the skin surface, into the capillary network oe **B1**

(b) this increases the flow of warm blood near the body surface oe **B1**

(b) increasing the transfer of heat from the blood to the environment (by radiation/convection/conduction), cooling the blood and lowering body temperature oe **B1**

(b) Answer: Vasodilation lets more warm blood flow through capillaries near the skin surface, increasing heat loss to the environment by radiation and convection, cooling the blood and lowering body temperature.

(c) shivering involves rapid, involuntary contraction and relaxation of skeletal muscles oe **B1**

(c) these contractions require respiration, which releases heat as a by-product, warming the body oe **B1**

(c) Answer: Shivering causes rapid involuntary muscle contractions; the increased respiration this requires releases heat as a by-product, warming the body.

(d) a rise in temperature triggers heat-losing responses (e.g. vasodilation, sweating) while a fall in temperature triggers heat-generating/conserving responses (e.g. shivering, vasoconstriction) - each response counteracts the original deviation, and the two sets of effectors act in opposite directions to keep temperature within a narrow range oe **B1**

(d) Answer: Rising temperature triggers heat-losing responses and falling temperature triggers heat-generating responses; these opposite (antagonistic) effector actions each counteract the original change, keeping body temperature within a narrow range around the set point.

Question 8

(a) only the presynaptic neurone contains synaptic vesicles of neurotransmitter (acetylcholine) that can be released **B1**

(a) only the postsynaptic membrane has the specific receptors for the neurotransmitter, to which acetylcholine can bind and open ion channels **B1**

(a) Answer: Only the presynaptic neurone has vesicles able to release acetylcholine, and only the postsynaptic membrane has receptors for it, so signals can only pass from the presynaptic to the postsynaptic neurone.

(b) spatial summation: several different presynaptic neurones each release a small amount of neurotransmitter onto the same postsynaptic neurone at the same time, so their combined (summed) effect on depolarisation may reach threshold **B1**

(b) temporal summation: a single presynaptic neurone releases neurotransmitter repeatedly, in quick succession, so the depolarisations combine (summate) before they fade, reaching threshold **B1**

(b) in both cases, no single release of neurotransmitter is enough on its own to reach threshold, but the combined/summed depolarisations can reach threshold and trigger an action potential (oe) **B1**

(b) Answer: Spatial summation combines small depolarisations from several different presynaptic neurones acting at the same time; temporal summation combines repeated depolarisations from the same presynaptic neurone in quick succession. In both cases, individually sub-threshold signals combine to reach the threshold needed for an action potential.

Question 9

(a) baroreceptors detect the increased stretching of the artery wall caused by the rise in blood pressure **B1**

(a) they send an increased frequency of impulses along sensory neurones to the cardiovascular centre in the medulla oblongata **B1**

(a) the medulla sends an increased frequency of impulses along parasympathetic (vagus) neurones to the sinoatrial node (SAN), and a decreased frequency of impulses along sympathetic neurones **B1**

(a) acetylcholine released at the SAN reduces its rate of firing, decreasing heart rate back towards normal **B1**

(a) Answer: Baroreceptors detect the extra stretch from raised blood pressure and send more impulses to the medulla, which increases parasympathetic (vagus) and decreases sympathetic output to the SAN, releasing more acetylcholine and slowing heart rate back to normal.

(b) chemoreceptors in the aorta, carotid arteries and medulla detect the fall in blood pH (rise in CO_2 concentration) **B1**

(b) they send an increased frequency of impulses along sensory neurones to the cardiovascular centre in the medulla oblongata **B1**

(b) the medulla sends an increased frequency of impulses along sympathetic neurones to the SAN, and a decreased frequency along parasympathetic (vagus) neurones **B1**

(b) noradrenaline released at the SAN increases its rate of firing, increasing heart rate, which increases blood flow to the lungs and removal of carbon dioxide (oe) **B1**

(b) Answer: Chemoreceptors detect the fall in pH/rise in CO_2 and send more impulses to the medulla, which increases sympathetic and decreases parasympathetic output to the SAN, releasing noradrenaline and increasing heart rate to remove CO_2 faster.

(c) correct substitution: 68 x 72 **M1**

(c) 4896 cm^3/min **A1**

(c) 4.9 dm^3/min (awrt 4.9, correct conversion of cm^3 to dm^3 by dividing by 1000) **A1**

(c) Answer: 4.9 dm^3 per minute (4896 cm^3/min)

Question 10

(a) in a relaxed muscle, tropomyosin blocks the myosin-binding sites on the actin filament, and troponin is attached to both tropomyosin and actin, holding tropomyosin in this blocking position **B1**

(a) an action potential arriving at the neuromuscular junction/travelling down the T-tubules causes calcium ions to be released from the sarcoplasmic reticulum **B1**

(a) calcium ions bind to troponin, causing it to change shape **B1**

(a) this pulls the attached tropomyosin away from the myosin-binding sites on actin, exposing them **B1**

(a) myosin heads can now bind to actin, forming actomyosin cross-bridges, allowing the sliding filament mechanism (powered by ATP hydrolysis) to begin **B1**

(a) Answer: In a relaxed muscle, tropomyosin (held by troponin) blocks the myosin-binding sites on actin. A rise in calcium ion concentration causes calcium to bind troponin, changing its shape and moving tropomyosin to expose the binding sites, allowing myosin heads to attach to actin and begin the sliding filament mechanism.

(b) correct method: (2.6 - 2.1)/2.6 x 100 **M1**

(b) 19.2% (awrt 19%) **A1**

(b) Answer: 19.2%

(c) the A band represents the length of the thick (myosin) filaments, which do not change length during contraction, so the A band stays the same width **B1**

(c) the I band (where only thin/actin filaments are present, with no overlap) and the H zone (where only thick/myosin filaments are present, with no overlap) both narrow because the thin filaments are pulled further over/past the thick filaments **B1**

(c) this increases the region of overlap between the two sets of filaments, without either type of filament itself getting shorter (oe) **B1**

(c) Answer: The A band (length of the myosin filaments) does not change because the filaments themselves do not shorten. The I band and H zone narrow because the actin filaments slide further over the myosin filaments, increasing the region of overlap, without the filaments themselves shortening.

(d) the A band represents the length of the thick (myosin) filaments; if the filaments themselves were shortening, the A band would be expected to narrow along with the I band and H zone **B1**

(d) because the A band stays constant while the whole sarcomere shortens, the filaments must instead be sliding past/over each other (increasing overlap) rather than shortening, supporting the sliding filament theory **B1**

(d) Answer: If filaments themselves shortened, the A band would narrow too; since it stays constant while the sarcomere shortens, the filaments must be sliding over each other rather than getting shorter, which supports the sliding filament theory over the filament-shortening hypothesis.

Question 11

Level 3 The answer gives a well-balanced, detailed comparison covering both similarities and differences between nervous and hormonal communication, using correct scientific terminology and, where appropriate, an example to illustrate the points made. **5-6**

Level 2 The answer identifies several valid differences and/or similarities between nervous and hormonal communication, with reasonable use of terminology, but the comparison may be less detailed, one-sided, or lack an illustrative example. **3-4**

Level 1 The answer makes one or two simple, isolated correct points about nervous or hormonal communication, with little genuine comparison between the two. **1-2**

Level 0 No relevant content, or the response does not address the question. **0**

Indicative content:

- Nervous communication uses electrical impulses (action potentials) travelling along neurones; hormonal communication uses chemical messengers (hormones) carried in the blood
- Nervous transmission is much faster than hormonal transmission, which relies on the relatively slow circulation of blood
- Nervous responses tend to be short-lived/rapidly reversed once the stimulus stops; hormonal effects tend to be longer-lasting
- Nervous signals act on a specific, localised target (the effector connected by the neurone via a synapse); hormones are carried throughout the body in the blood and can affect many different target cells/organs that have the appropriate receptors
- Nervous communication produces a precise, localised response; hormonal communication can produce a widespread, generalised response affecting many organs simultaneously
- Both systems ultimately rely on a receptor/target cell having specific receptor molecules to detect the signal (electrical or chemical), and are used together in many coordinated responses
- A valid example may be used, such as detecting a sudden loud noise (nervous, rapid, localised reflex) compared with the release of adrenaline in response to a threat (hormonal, slower onset but widespread and longer-lasting effects)

Question 12

(a) acetylcholinesterase normally breaks down acetylcholine in the synaptic cleft after it has triggered a response; if it is inhibited, acetylcholine is not broken down (or is broken down much more slowly) **B1**

(a) acetylcholine therefore remains in the synaptic cleft and continues to bind to receptors on the postsynaptic membrane **B1**

(a) this causes continuous/repeated depolarisation of the postsynaptic membrane, generating action potentials continuously in the postsynaptic neurone (or continuous stimulation of a muscle fibre at a neuromuscular junction) **B1**

(a) this leads to continuous, uncontrolled stimulation, which in an insect causes convulsions, paralysis and eventually death (oe) **B1**

(a) Answer: Because acetylcholinesterase cannot break down acetylcholine, it remains bound to postsynaptic receptors, causing continuous depolarisation and repeated action potentials/continuous muscle stimulation, leading to convulsions, paralysis and death of the insect.

(b) the pesticide disrupts normal synaptic/neuromuscular transmission (as described in part (a)), which is likely to interfere with the nervous control of the kinesis response, reducing the woodlouse's normal rate of turning even in dry conditions **B1**

(b) a lower turning rate alone does not show that treated woodlice are less likely to leave the dry side; movement speeds and the directions or angles of turns are not supplied **B1**

(b) compare movement speeds, trajectories or time spent in each side for treated and untreated woodlice to establish whether treatment prolongs exposure to dry conditions **B1**

(b) if treatment causes woodlice to spend longer in dry conditions, their risk of desiccation (water loss) increases, which could reduce survival **B1**

(b) impaired nervous/muscular function from the pesticide may also reduce the woodlice's ability to escape predators or find food, further reducing survival and reproductive success, potentially reducing the population size (oe) **B1**

(b) Answer: The pesticide may disrupt synaptic or neuromuscular control of turning. A lower turning rate alone does not show that treated woodlice are less likely to leave dry areas: movement speeds and the directions or angles of turns are not supplied. Comparing trajectories and time spent in each side would test this. If treatment prolongs exposure to dry conditions, desiccation risk could increase. Impaired nervous or muscular function could also hinder feeding or escape from predators, reducing survival and reproductive success.

Question 13

(a) resting potential = -70 mV **B1**

(a) depolarisation begins after 0.5 ms and by 1.0 ms (accept 'between 0.5 and 1.0 ms'); the exact onset cannot be determined from the sampled readings **B1**

(a) Answer: Resting potential = -70 mV; depolarisation begins after 0.5 ms and by 1.0 ms. The exact onset is undetermined.

(b) a stimulus causes some sodium channels to open; if depolarisation reaches the threshold, voltage-gated sodium channels open **B1**

(b) sodium ions diffuse rapidly into the axon down their electrochemical gradient, causing rapid depolarisation and reversing the potential (inside becomes positive, e.g. reaching +40 mV) **B1**

(b) at the peak, sodium channels close (become inactivated) and voltage-gated potassium channels open **B1**

(b) potassium ions diffuse out of the axon down their concentration gradient, removing positive charge from inside and restoring a negative internal potential (repolarisation) **B1**

(b) Answer: Depolarisation: voltage-gated sodium channels open once threshold is reached, sodium ions flood in, reversing the membrane potential. Repolarisation: sodium channels close, potassium channels open, potassium ions diffuse out, restoring the negative interior.

(c) potassium channels are slower to close than they were to open, so potassium ions continue to diffuse out after the membrane has returned to -70 mV, causing a brief overshoot to a more negative potential (e.g. -80 mV) **B1**

(c) during the refractory period, sodium channels are inactivated/cannot reopen immediately, so a new action potential cannot be generated **B1**

(c) this ensures action potentials only travel in one direction (away from the previous site of depolarisation) and are discrete, separate impulses, which also limits the maximum frequency at which impulses can be generated (oe) **B1**

(c) Answer: Potassium channels stay open slightly too long, so more K^+ leaves than needed, causing a brief hyperpolarisation below resting potential. The refractory period that follows (during which sodium channels cannot reopen) ensures impulses travel in one direction only and are transmitted as discrete impulses, limiting the maximum impulse frequency.

(d) correct method: f = 1/T, using T = 1 ms = 0.001 s **M1**

(d) 1000 Hz (cao) **A1**

(d) Answer: 1000 Hz

Question 14

(a) converts distance and time to SI units: 45 mm = 0.045 m and 0.5 ms = 0.0005 s **M1**

(a) correctly substitutes into speed = distance/time = 0.045/0.0005 **dM1**

(a) 90 m/s (cao, 2 sf) **A1**

(a) Answer: 90 m/s

(b) the myelin sheath is an electrical insulator, so ion movement (and depolarisation) can only occur at the gaps between myelin cells, the nodes of Ranvier **B1**

(b) depolarisation jumps from node to node rather than travelling continuously along the whole membrane (saltatory conduction) **B1**

(b) this means fewer sections of membrane need to be depolarised over a given distance, so the impulse travels faster than in a non-myelinated (continuously conducting) neurone **B1**

(b) Answer: Myelin insulates the axon so depolarisation can only occur at the nodes of Ranvier; the impulse jumps from node to node (saltatory conduction) rather than depolarising the whole membrane, which greatly increases conduction speed.

(c) a larger diameter axon has less resistance to the flow of ions (less charge leakage relative to the volume of cytoplasm) **B1**

(c) so local currents spread further/faster along the axon before dissipating, increasing conduction speed **B1**

(c) a decrease in temperature reduces the kinetic energy of ions and slows the rate of diffusion of ions through channels (and reduces the rate of respiration providing ATP for the sodium-potassium pump) **B1**

(c) this slows the rate of depolarisation/repolarisation at each point along the axon, decreasing conduction speed **B1**

(c) Answer: A larger diameter reduces relative ion leakage so local currents spread faster, increasing speed. Lower temperature reduces ion diffusion rate and ATP-dependent pump activity, slowing depolarisation and repolarisation, decreasing speed.

(d) the suggestion is not correct/only partly correct; although conduction speed does increase with temperature up to a point, above about 40°C the proteins involved (ion channels and the sodium-potassium pump) begin to denature **B1**

(d) this would disrupt normal ion movement and could slow, or even stop, conduction rather than continuing to speed it up (oe) **B1**

(d) Answer: The suggestion is incorrect above a certain point: while conduction speed rises with temperature initially, temperatures above roughly 40°C denature the channel and pump proteins, which would slow or stop conduction rather than keep increasing its speed.

Question 15

Level 3 A logical, coherent and detailed account of the sequence of events, using correct scientific terminology throughout, covering most of the indicative content points in the correct order. **5-6**

Level 2 A generally correct account covering several stages of the sequence, with mostly appropriate terminology, but the account may be incomplete, contain minor inaccuracies, or lack full coherence/order. **3-4**

Level 1 Some relevant, isolated points are made, but with little logical sequence or correct use of scientific terminology; the answer may be a simple list. **1-2**

Level 0 No relevant content, or the response does not address the question. **0**

Indicative content:

- An action potential arrives at the presynaptic knob and depolarises its membrane
- Depolarisation causes voltage-gated calcium ion channels in the presynaptic membrane to open
- Calcium ions diffuse into the presynaptic knob down their concentration gradient
- The influx of calcium ions causes synaptic vesicles (containing acetylcholine) to move to and fuse with the presynaptic membrane
- Acetylcholine is released into the synaptic cleft by exocytosis
- Acetylcholine diffuses across the synaptic cleft
- Acetylcholine binds to specific (cholinergic) receptors on ligand-gated sodium ion channels in the postsynaptic membrane
- Binding causes the sodium ion channels to open, and sodium ions diffuse into the postsynaptic neurone
- This depolarises the postsynaptic membrane, producing an excitatory postsynaptic potential (EPSP)
- If the depolarisation reaches the threshold, an action potential is generated in the postsynaptic neurone
- Acetylcholine is broken down by acetylcholinesterase into choline and ethanoic acid, which are reabsorbed by the presynaptic neurone, preventing continuous stimulation

Question 16

(a) the action potential travels down the T-tubules, causing the sarcoplasmic reticulum to release calcium ions into the sarcoplasm oe **B1**

(a) calcium ions bind to troponin, causing it to change shape, pulling the attached tropomyosin away from the myosin-binding sites on the actin filament oe **B1**

(a) this exposes the binding sites, allowing myosin heads to bind to actin, forming actin-myosin cross-bridges oe **B1**

(a) Answer: Calcium ions released from the sarcoplasmic reticulum bind troponin, which moves tropomyosin off the actin binding sites, allowing myosin heads to bind actin and form cross-bridges.

(b) ATP hydrolysis (by ATPase on the myosin head) provides the energy for the myosin head to change angle (power stroke), pulling the actin filament along the myosin, oe **B1**

(b) a new ATP molecule must then bind to the myosin head to allow it to detach from actin, oe **B1**

(b) ATP is also needed to actively pump calcium ions back into the sarcoplasmic reticulum, allowing tropomyosin to block the binding sites again and the muscle to relax oe **B1**

(b) Answer: ATP hydrolysis powers the myosin head's power stroke; a fresh ATP molecule is needed for the myosin head to detach from actin; and ATP is used to actively pump calcium back into the sarcoplasmic reticulum, allowing the muscle to relax.

(c) I band before = 2.6 - 1.5 = 1.1 micrometres; I band after = 2.0 - 1.5 = 0.5 micrometres **M1**

(c) percentage decrease = (1.1 - 0.5)/1.1 x 100 **M1**

(c) 54.5% (accept 54-55%), awrt **A1**

(c) Answer: Approximately 54.5% decrease.

Question 17

(a) without functioning β cells, little or no insulin is secreted in response to rising blood glucose oe **B1**

(a) so glucose uptake by cells and conversion of glucose to glycogen are not stimulated, and blood glucose remains high after eating (and between meals) oe **B1**

(a) Answer: Without insulin, cells cannot increase their glucose uptake or convert glucose to glycogen normally, so blood glucose concentration stays persistently high.

(b) correct substitution: (11.8 - 5.9)/5.9 x 100 **M1**

(b) 100% (exactly double the upper normal limit), cao **A1**

(b) Answer: 100%

(c) glucose is normally reabsorbed from the filtrate in the proximal convoluted tubule by active co-transport with sodium ions, via specific glucose-sodium co-transporter proteins oe **B1**

(c) these co-transporter proteins have a limited/finite number, giving a maximum rate at which glucose can be reabsorbed oe **B1**

(c) when blood (and therefore filtrate) glucose concentration is very high, as in this patient, the amount of glucose filtered exceeds this maximum reabsorption capacity, so the excess glucose remains in the filtrate and is excreted in the urine oe **B1**

(c) Answer: Glucose is normally reabsorbed by a limited number of co-transporter proteins in the proximal convoluted tubule; when filtrate glucose concentration is very high, as in this patient, this reabsorption capacity is exceeded and the excess glucose passes into the urine.

(d) glucose remaining in the filtrate lowers the water potential of the filtrate, so less water is reabsorbed by osmosis from the nephron into the blood, increasing the volume of urine produced oe **B1**

(d) Answer: Glucose left in the filtrate lowers its water potential, so less water is reabsorbed by osmosis, increasing urine volume.

Question 18

(a) sodium and chloride ions are actively transported (pumped) out of the filtrate in the ascending limb, into the surrounding medulla tissue oe **B1**

(a) because the ascending limb is impermeable to water, water cannot follow the ions out, so this builds up a high concentration of ions in the medulla tissue without diluting it oe **B1**

(a) because the loop is long and the process happens repeatedly along its length, a large concentration gradient (increasing towards the tip of the loop, deep in the medulla) is built up and maintained oe **B1**

(a) Answer: Sodium and chloride ions are actively pumped out of the water-impermeable ascending limb into the medulla, building a high, undiluted ion concentration that increases towards the tip of the loop.

(b) the collecting duct passes back down through the medulla, alongside the loop of Henle, and its wall (with ADH present) is permeable to water via aquaporins oe **B1**

(b) as fluid in the collecting duct passes through regions of increasingly low water potential (high ion concentration) in the medulla, water is progressively reabsorbed by osmosis into the surrounding tissue and blood, concentrating the urine oe **B1**

(b) Answer: As the collecting duct passes through the medulla, water moves out by osmosis into the increasingly concentrated surrounding tissue, progressively concentrating the fluid inside and producing concentrated urine.

(c) a longer loop of Henle allows a greater/steeper ion concentration gradient to be built up in the medulla, enabling more water to be reabsorbed and much more concentrated urine to be produced, conserving water - an advantage in a desert where water is scarce oe **B1**

(c) an aquatic mammal has ready access to water, so producing highly concentrated urine (and conserving water) is less important, and a shorter loop (with less energy spent on active transport) is sufficient oe **B1**

(c) Answer: Long loops build a steeper medullary gradient, allowing the desert rodent to produce very concentrated urine and conserve scarce water; the beaver has abundant water available, so a shorter loop (needing less energy) is sufficient.

Question 19

Level 3 A detailed, well-structured evaluation that explains the general principle of negative feedback with correct reference to both blood glucose regulation and thermoregulation, discusses why the system is normally highly effective (rapid detection, antagonistic effectors, hormonal amplification), and gives at least two well-explained circumstances in which control can fail (e.g. type 1 diabetes, extreme environmental temperature, prolonged/severe stimuli), reaching a supported overall judgement.	**5-6**
Level 2 A reasonably clear evaluation referencing at least one of the two named systems correctly, with some discussion of why the system is normally effective and at least one valid example of when it can fail, but the discussion is not fully developed or one system is not properly addressed.	**3-4**
Level 1 Limited evaluation; describes negative feedback only in general terms with little or no correct reference to blood glucose or thermoregulation, and little or no discussion of when control can fail.	**1-2**

Indicative content:

- Negative feedback works by detecting a deviation from a set point and triggering a response that counteracts (reverses) that deviation, returning the factor towards normal.
- In blood glucose regulation, beta and alpha cells of the pancreas act as both receptors and (via hormone secretion) as the trigger for effector responses in the liver/muscle (insulin/glucagon), providing rapid, hormone-mediated correction.
- In thermoregulation, the hypothalamus integrates information from skin and internal thermoreceptors and coordinates antagonistic effector responses (e.g. vasodilation/vasoconstriction, sweating/shivering) via the nervous system, allowing very rapid correction.
- Both systems are normally highly effective because they involve continuous monitoring, rapid detection, and effectors capable of acting in either direction depending on which way the factor has deviated.
- Control can fail when a receptor or effector itself is damaged or absent, e.g. in type 1 diabetes the beta cells are destroyed, so no insulin can be secreted regardless of how high blood glucose rises, and blood glucose regulation fails.
- Control can be overwhelmed when the environmental stimulus is too extreme or prolonged for the effectors to compensate, e.g. in extreme heat or cold, vasodilation/vasoconstriction and sweating/shivering may be insufficient to prevent dangerous changes in core body temperature (heat stroke or hypothermia).
- A balanced evaluation notes that negative feedback is very effective within the normal physiological range the system evolved to handle, but is not infallible outside that range or when a component of the pathway is damaged.