Surname	StemUp Model Solution	Centre Number	Candidate Number
Other Names			2

GCE A LEVEL – NEW

A400U30-1

S17-A400U30-1

BIOLOGY – A level component 3
Requirements for Life

MONDAY, 26 JUNE 2017 – MORNING

2 hours

	For Examiner's use only		
	Question	Maximum Mark	Mark Awarded
Section A	1.	15	
	2.	15	
	3.	11	
	4.	11	
	5.	19	
	6.	9	
Section B	Option	20	
	Total	100	

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ADDITIONAL MATERIALS

In addition to this examination paper, you will need a calculator and a ruler.

INSTRUCTIONS TO CANDIDATES

Use black ink or black ball-point pen. Do not use gel pen. Do not use correction fluid.

Write your name, centre number and candidate number in the spaces at the top of this page.

Answer **all** questions.

Write your answers in the spaces provided in this booklet. If you run out of space, use the continuation pages at the back of the booklet, taking care to number the question(s) correctly.

INFORMATION FOR CANDIDATES

This paper is in 2 sections, **A** and **B**.

Section A: 80 marks. Answer **all** questions. You are advised to spend about 1 hour 35 minutes on this section.

Section B: Options; 20 marks. Answer **one option only**. You are advised to spend about 25 minutes on this section.

The number of marks is given in brackets at the end of each question or part-question.

The assessment of the quality of extended response (QER) will take place in question **6**.

The quality of written communication will affect the awarding of marks.

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Section A

Answer **all** *questions.*

1. The surface area to volume ratio of an organism is related to its ability to exchange gases with the environment. Heat can also be lost or gained through the body surface. As organisms increase in mass their surface area to volume ratio decreases. However, most large organisms do not rely on their external body surfaces for gas exchange.

(a) Describe and explain the common adaptations of the gas exchange surfaces found in fish and mammals. [3]

Thin (one cell thick, e.g. alveolar epithelium and gill lamellae), to reduce the diffusion distance.

Moist, so that gases can dissolve before diffusing across.

Rich blood supply (extensive capillary network) which carries gases away, maintaining a steep diffusion (concentration) gradient.

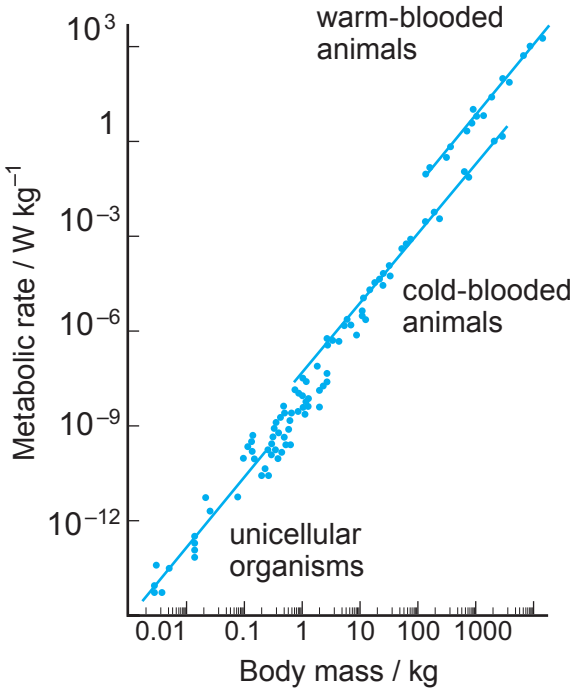
Large number of alveoli / folded into many gill filaments and lamellae, to increase the surface area.

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The graph below shows how the metabolic rates of three different groups of organisms vary with body mass. All readings were taken at an external environmental temperature of 20 °C.



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(b) (i) Describe the general relationship between body mass and metabolic rate. [1]

The greater the body mass, the greater the metabolic rate (positive correlation).

(ii) The body temperature of cold-blooded animals, e.g. fish, varies with the temperature of the environment. Suggest why warm-blooded animals which have a constant body temperature, e.g. mammals, have a higher metabolic rate. [2]

Their body temperature is not dependent on that of the environment, so energy is needed to generate heat to maintain body temperature (at 20 °C they lose heat).

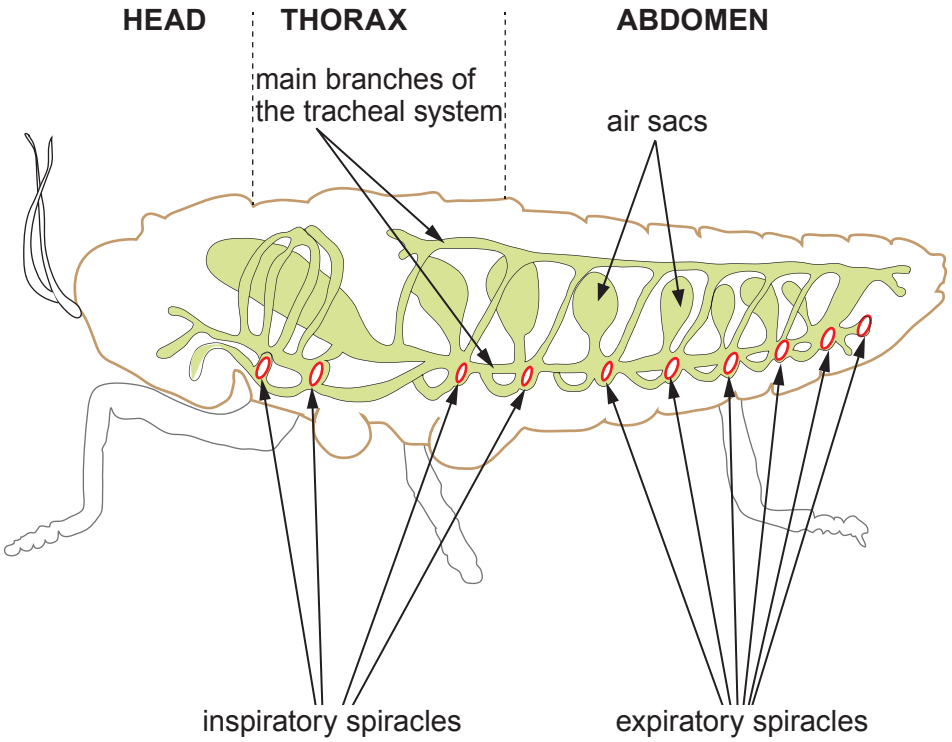
Constant body temperature provides the optimum temperature for enzymes, so the rate of metabolic reactions is higher.

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(c) Insects are terrestrial animals that have an exoskeleton. Air is delivered directly to the tissues through a network of tubes called tracheae. The tracheal system is ventilated by contractions of the abdomen. During flight, contractions of muscles in the thorax produce the same effect. Valves regulate the flow of air so that air enters through the first four pairs of spiracles and exits through the last six pairs. The diagram below shows the main branches of the tracheal system of an insect (left side only).



(i) Explain the advantage to the insect of closing the spiracles. [1]

To reduce (limit) water loss by evaporation from the tracheal system.

(ii) Suggest a role of the air sacs. [1]

To provide a reservoir (store) of air / oxygen when the spiracles are closed, and to aid ventilation of the tracheal system.

(iii) Explain the advantage to the insect of having a ventilation system. [1]

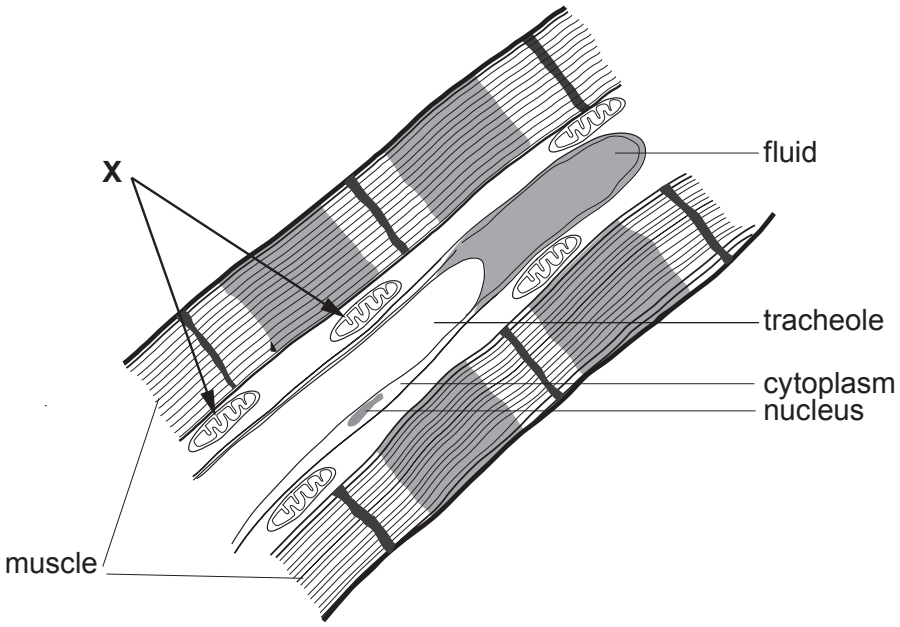
It maintains a concentration gradient: stale air with a high carbon dioxide concentration is replaced with fresh, oxygen rich air.

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(d) The tracheae are lined with a thin strip of chitin and have a layer of waxy cuticle covering their interior surface. The ends of the tracheae are called tracheoles. These penetrate between cells and are not lined with either chitin or cuticle. Their ends are filled with a fluid.
The diagram below shows the position of a tracheole in a muscle cell.



(i) The chitin in the walls of the tracheae has a similar chemical bonding and function as cellulose in plant cell walls. Explain how the chemical bonding in chitin enables it to carry out this function in insects. [3]

Chitin is made of β monomers joined by β glycosidic bonds, so alternate monomers are rotated by 180°, giving long straight chains.

This allows bonding (cross-linking) between neighbouring chains, forming microfibrils (fibres).

This provides strength and makes the tracheae tough, preventing them from collapsing.

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(ii) Identify organelles **X** in the diagram on page 5 and explain why they are found close to the tracheoles. [3]

X are mitochondria.

They are the site of aerobic respiration (ATP synthesis), which requires oxygen; muscle contraction needs a lot of ATP.

The tracheole is the site of gas exchange: oxygen diffuses from the tracheole into the muscle cell, so the diffusion distance to the mitochondria is short.

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2. Tomatoes *(Lycopersicon esculentum)* are an important greenhouse crop. Plant growers need to control conditions in their greenhouses to achieve a high yield of tomato production.

An investigation was carried out to determine the effect of light intensity ($W\,m^{-2}$) on the density of stomata in the leaves of tomato plants.

(a) (i) Outline a method by which the density of stomata could have been determined. [3]

Coat the lower surface of the leaf with clear nail varnish, leave to dry and peel it off with sellotape (to make an epidermal impression). Examine the impression using a light microscope (e.g. ×400 magnification). Count the number of stomata in the field of view (a known area, calculated using a stage micrometer), repeat several times and calculate the number per cm^2.

(ii) The plants used in the investigation were grown either under $100\,W\,m^{-2}$ or $20\,W\,m^{-2}$ light sources for 8 hours each day at 20°C.
State **two *other*** environmental factors that should have been controlled in this investigation. [2]

Humidity

Concentration of carbon dioxide (CO_2)

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(b) The hypothesis tested was: *'the higher the light intensity, the higher the density of stomata on the lower leaf surface'*.
The results of the investigation are shown in the table below.

Tomato plant	Mean density of stomata per plant / number cm^{-2}			
	100 $W m^{-2}$		20 $W m^{-2}$	
	upper leaf surface	lower leaf surface	upper leaf surface	lower leaf surface
1	3.33	6.31	0.09	7.88
2	2.91	9.96	0.11	7.98
3	2.84	9.67	0.08	9.35
4	2.86	8.18	0.07	7.56
5	2.92	9.38	0.10	8.52
6	1.91	7.87	0.15	7.70
7	3.20	9.51	0.04	9.25
8	2.74	8.45	0.14	8.80
9	2.24	7.95	0.02	8.26
10	4.10	7.02	0.06	8.12
Overall mean	2.91	8.43	0.09	8.34
Standard deviation	0.56	1.14	0.04	0.59

(i) Using the table below, calculate the standard deviation for the density of stomata on the lower leaf surface at 100 $W m^{-2}$. **Enter the standard deviation into the table of results above**. State your answer to three significant figures. [3]

lower leaf surface at 100 $W m^{-2}$		
x	$x - \bar{x}$	$(x - \bar{x})^2$
6.31	–2.12	4.49
9.96	1.53	2.35
9.67	1.24	1.54
8.18	–0.25	0.06
9.38	0.95	0.90
7.87	–0.56	0.31
9.51	1.08	1.17
8.45	0.02	0.00
7.95	–0.48	0.23
7.02	–1.41	1.99
$\bar{x}$ 8.43		Σ 13.04

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The formula for standard deviation is:

$$\sqrt{\frac{\sum(x-\bar{x})^2}{N}}$$

SD = √(13.04 ÷ 10)
= √1.304 = 1.1419
= 1.14 (3 s.f.)

Where

x = individual result
$\bar{x}$ = mean result
N = number of trials
$\sum$ = sum of

(ii) What information do the standard deviations shown in the table of results opposite provide regarding the reliability of the results of this experiment? [3]

SD shows the variation (spread) of the data around the mean, i.e. how reliable the mean is.

100 W m^{-2} lower surface (SD 1.14) is least reliable; 20 W m^{-2} upper (SD 0.04) is most reliable; 100 W is less reliable than 20 W.

(iii) To what extent do these results support the hypothesis stated in *(b)*? [3]

The results do not support the hypothesis: it is incorrect.

There is very little difference between the means for the lower surfaces (8.43 at 100 W m^{-2} and 8.34 at 20 W m^{-2}, only 0.09); the difference is less than one SD so the data overlap.

The SD at high light intensity is higher (1.14 compared with 0.59), so it is less reliable.

(iv) Based on these results, suggest an alternative hypothesis for the effect of light intensity on stomatal density in tomato plants. [1]

At higher light intensity the density of stomata on the upper leaf surface increases, but light intensity has no effect on the density of stomata on the lower leaf surface.

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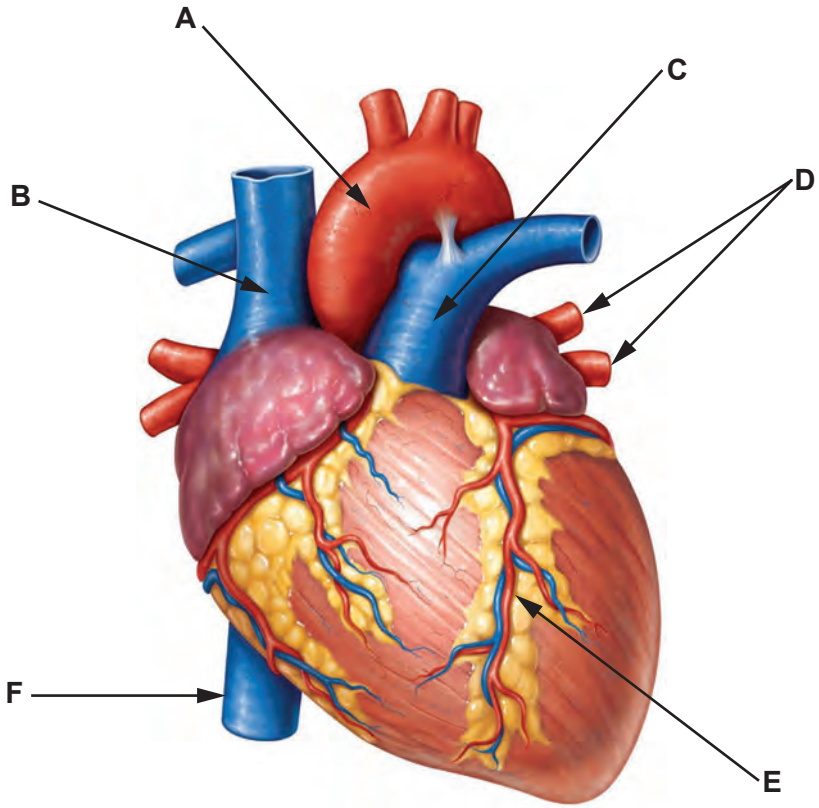
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3. In the UK, coronary heart disease accounts for nearly 73 000 deaths per year and it is estimated that approximately 2.3 million people suffer from a condition called angina. This form of heart disease develops when the blood vessels supplying the heart muscle become narrowed due to the build-up of fatty substances on the inside wall of the vessels. The fatty deposits are called atheroma and cause a condition called atherosclerosis.

The image below shows a model of the human heart together with some of its associated blood vessels.



(a) (i) In which of the blood vessels labelled **A** to **F** on the image could an atheroma develop that could cause angina? Name this blood vessel. [2]

Letter E **Name** coronary artery

(ii) Explain why narrowing of these blood vessels could lead to the heart not contracting. [2]

Oxygen and glucose do not reach the cardiac (heart) muscle, so the muscle is unable to respire aerobically and less ATP is produced for contraction.

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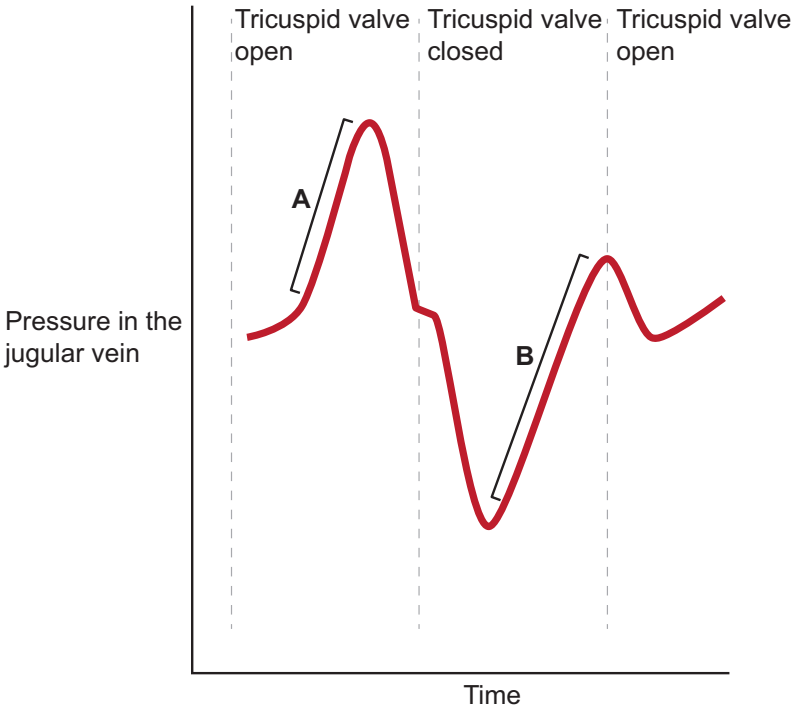
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(b) The jugular vein carries blood from the head back to the heart via the vena cava. There are no valves between the jugular vein and the heart. Therefore, the pressure in the jugular vein can be used as an indication of the ability of the heart to pump blood around the body.

(i) Which of the blood vessels labelled **A** to **F** on the image of the heart opposite will return blood from the jugular vein to the heart? [1]

Letter ..... B .....

The graph below shows how the pressure in the jugular vein changes during the course of one cardiac cycle.



(ii) State the name of the stages in the cardiac cycle during which the tricuspid valve is: [2]

I. **open** ..... atrial diastole / atrial systole (contraction) .....

II. **closed** ..... ventricular systole .....

(iii) Suggest what causes the increase in pressure in the jugular vein in the regions labelled **A** and **B** on the graph. [4]

Jugular pressure rises due to increased atrial pressure, as there are no valves between the jugular vein and atrium (backflow into the jugular).

A: atrial systole (the atria contract). B: the atria fill with blood; the ventricle contracts, closing the tricuspid (AV) valve, and high ventricular pressure pushes back on the atrium.

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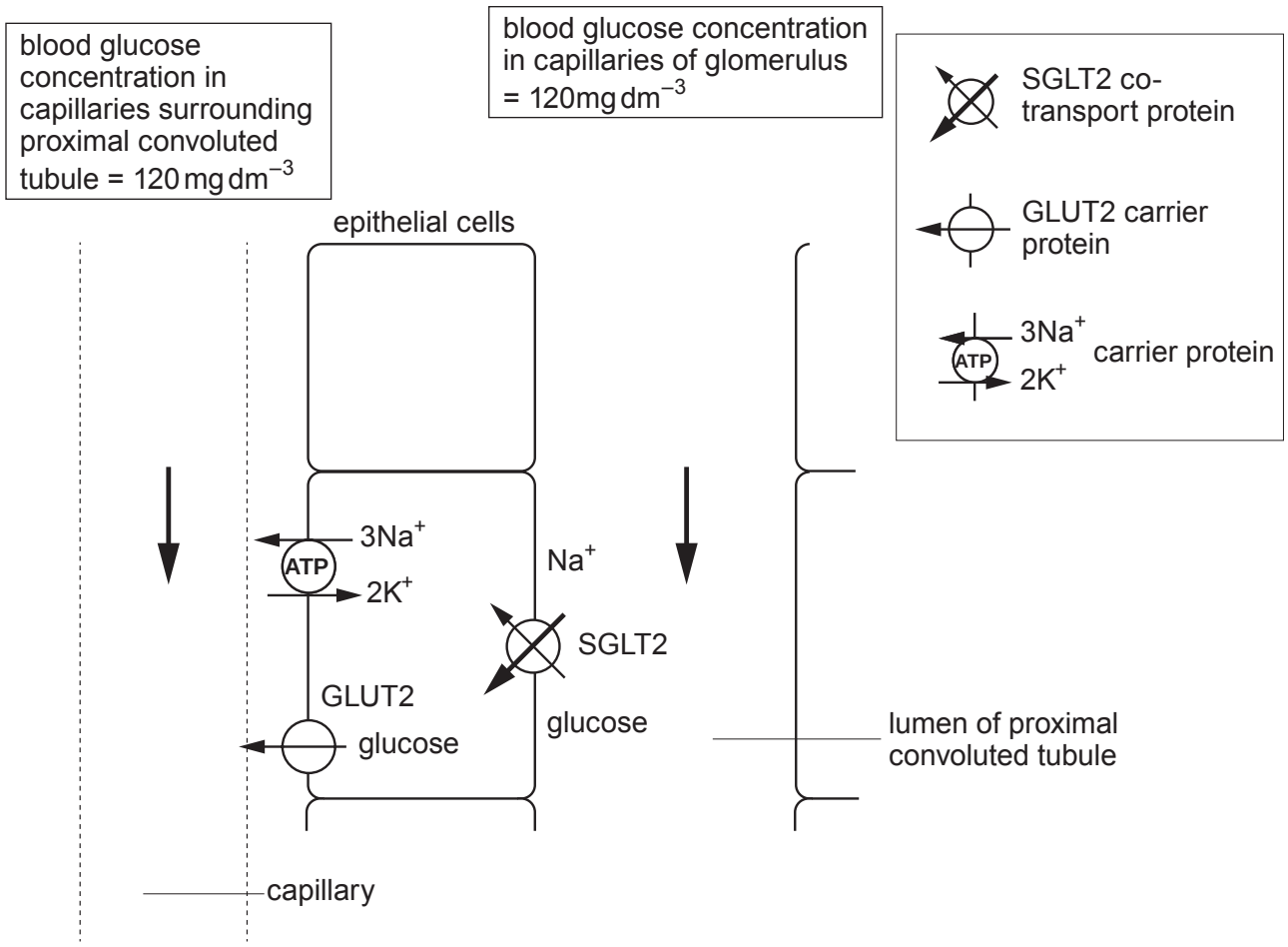
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4. Type 2 diabetes affects nearly three million adults in the UK and is particularly prevalent in obese people. Under normal conditions, almost all of the filtered glucose is reabsorbed and returned to the circulation in the proximal convoluted tubule of the nephron but in people with type 2 diabetes, glucose starts to appear in the urine when blood glucose concentration exceeds 180 – 200 mg dm^{-3}.

The diagram below shows how glucose is reabsorbed in the first part of the proximal convoluted tubule.



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(a) (i) Describe a biochemical test that could demonstrate the presence of glucose in urine and explain why this test can only provide semi-quantitative results. [3]

Add Benedict's reagent to the urine and heat in a boiling water bath (or use a Clinistix test strip).

A colour change from blue to green, yellow, orange or brick red shows glucose is present (for Clinistix, compare the colour with the colour chart).

The colour change only indicates approximate values of glucose, and judging the colour is subjective.

(ii) Explain how glucose is reabsorbed from the filtrate into the blood even at very high blood glucose levels. [4]

Na^+ ions are actively pumped (transported) out of the epithelial cell into the blood by the Na^+/K^+ pump using ATP.

This lowers the Na^+ concentration inside the epithelial cell, so Na^+ in the filtrate is at a higher concentration than inside the cell.

Na^+ diffuses into the cell through the SGLT2 protein and is co-transported with glucose into the epithelial cell.

The glucose concentration in the epithelial cell becomes higher than in the blood plasma, so glucose moves out into the blood by facilitated diffusion through GLUT2.

Circulation of blood maintains the plasma glucose concentration below that in the epithelial cells, maintaining the concentration gradient.

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(b) Reabsorption of glucose into the blood of people with Type 2 diabetes can increase the risk of hyperglycaemia (dangerously high glucose levels). Under these conditions damage can be caused to the retina and other tissues. Scientists are trialling the use of an inhibitor of the SGLT2 co-transport protein as a possible method of controlling blood glucose levels.

(i) Using the information provided above and on page 12, explain how an SGLT2 inhibitor could be used to treat Type 2 Diabetes and control blood glucose levels. [2]

The inhibitor would reduce co-transport by SGLT2, reducing the level of glucose reabsorbed into the blood, so more glucose would be lost in the urine, lowering the blood glucose concentration.

(ii) Suggest how the use of an SGLT2 inhibitor could also be used to help obese people lose weight. [2]

Less glucose is available for respiration, so other respiratory substrates such as stored fat in the body are used up in respiration. Less excess glucose is present to be converted to and stored as fat.

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5. Rennet is a mixture of enzymes that are produced by young ruminants to help improve the effectiveness of the digestion of casein (milk protein). Chymosin is the main enzyme in the mixture and is responsible for breaking a specific chemical bond in k-casein, one of the proteins found in casein. This enables digested k-casein to coagulate the other proteins found in milk and form a semi-solid mass.

(a) Chymosin is secreted as a precursor molecule by cells in gastric glands found in the abomasum (true stomach). Pepsinogen and hydrochloric acid are also secreted by these glands. Explain the role of these **three** secretions in digesting milk protein. [3]

HCl (H^+) activates the enzyme precursors, converting pepsinogen into pepsin and the precursor into chymosin; it also provides the optimum (acidic) pH.

Pepsin hydrolyses (breaks) peptide bonds in the milk proteins.

Chymosin causes coagulation of the milk proteins, which increases the time they take to pass through the stomach, allowing more digestion.

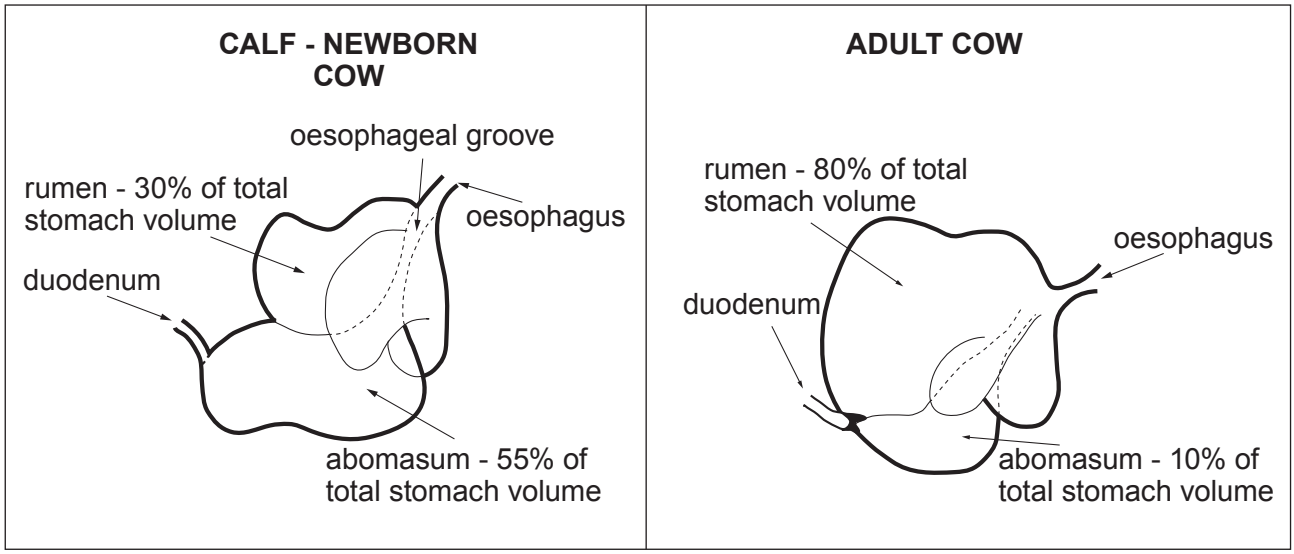
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In the ruminant gut, the relative proportions of the compartments of the stomach called the rumen and abomasum (true stomach) change as the animal grows older. The relative proportions of the rumen and abomasum of a newborn cow and adult cow are shown in the diagram below.



(b) With reference to their diets, explain the changes in the proportions of the rumen and abomasum as a calf grows older and its diet changes from milk to grass. [5]

Calf: the diet is milk, which is rich in protein. The abomasum is involved in protein digestion (secretes pepsin and chymosin), therefore the abomasum is larger (55%).

Adult: the diet is mainly grass, which is cellulose rich and difficult to digest. The rumen contains bacteria that can digest cellulose (mammals do not produce cellulase), therefore the rumen is larger (80%).

The grass diet is low in protein, and the abomasum mainly digests bacterial protein passed on from the rumen, so the abomasum becomes relatively smaller (10%).

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(c) Animal chymosin (the form of rennet used in traditional cheese production) is obtained from the stomachs of dead calves. Supplies of chymosin from this source are limited and make the cheese produced unsuitable for vegetarians. Most of the rennet now used in the cheese industry is produced from genetically engineered bacteria and yeasts.

(i) Suggest why it is generally considered that the use of GM chymosin is more ethically sound than using chymosin from animal rennet. [1]

Animals (calves) are not killed or harmed to obtain the chymosin.

(ii) Bacteria of the species *Escherichia coli* were genetically engineered to contain the gene for chymosin. Due to the presence of multiple introns in the chymosin gene, bacteria may not be able to carry out the RNA splicing. Therefore they may not be able to produce the functional mRNA molecule needed to synthesise the chymosin protein.
Outline how an intron free DNA molecule containing the chymosin gene could have been produced. [3]

Extract mRNA for chymosin from the calf stomach (abomasum) cells, because the introns have already been removed (spliced out) from it.

Use reverse transcriptase to synthesise single-stranded DNA from the mRNA template.

Then use DNA polymerase to synthesise double-stranded DNA, which is intron free.

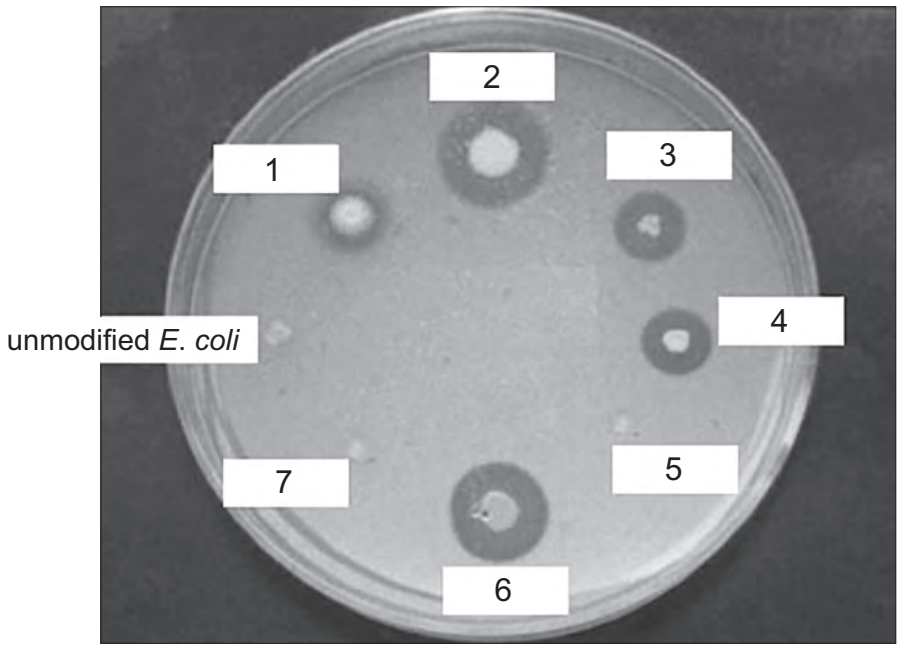
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Seven different genetically engineered *E.coli* strains were tested for their ability to synthesise and secrete chymosin. Pure cultures of each strain were grown on milk agar plates for 24 hours at a temperature of 37 °C.

The results of one test are shown in the image below. Unmodified *E.coli* was also grown on the same plate.



(iii) Suggest why the bacteria were cultured at 37 °C and explain why an unmodified strain of *E.coli* was included. [2]

37 °C is the body temperature of most mammals (humans). Unmodified E. coli is a control, to show E. coli does not naturally make a protease that acts on milk protein.

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(iv) The agar contained 0.02 g cm^{-3} milk protein. The clear zone surrounding bacterial colonies was due to the digestion of milk protein.

The clear zone surrounding strain **3** was found to be 13 mm in diameter using a 3 mm depth of agar.

I. Calculate the volume of the agar in the clear zone. Express your answer to one decimal place. [2]

[π = 3.142; volume of a cylinder = $\pi r^2 h$; h = depth of agar]

$r = 13 \div 2 = 6.5$ mm $= 0.65$ cm; $h = 3$ mm $= 0.3$ cm

$V = 3.142 \times 0.65^2 \times 0.3$

$= 3.142 \times 0.4225 \times 0.3 = 0.3982$ cm^3

Volume of agar in clear zone = ... 0.4 ..... cm^3

II. Calculate the mass of milk protein digested and hence the rate of protein digestion by the chymosin secreted by *E.coli* strain **3**. Express your answer in standard form. [3]

mass digested $= 0.4$ cm^3 $\times$ 0.02 g cm^{-3} $= 0.008$ g

time = 24 hours

rate $= 0.008 \div 24 = 0.000333$ g hour^{-1}

$= 3.33 \times 10^{-4}$

Rate of milk protein digestion = 3.33 x 10^{-4} ..... g hour^{-1}

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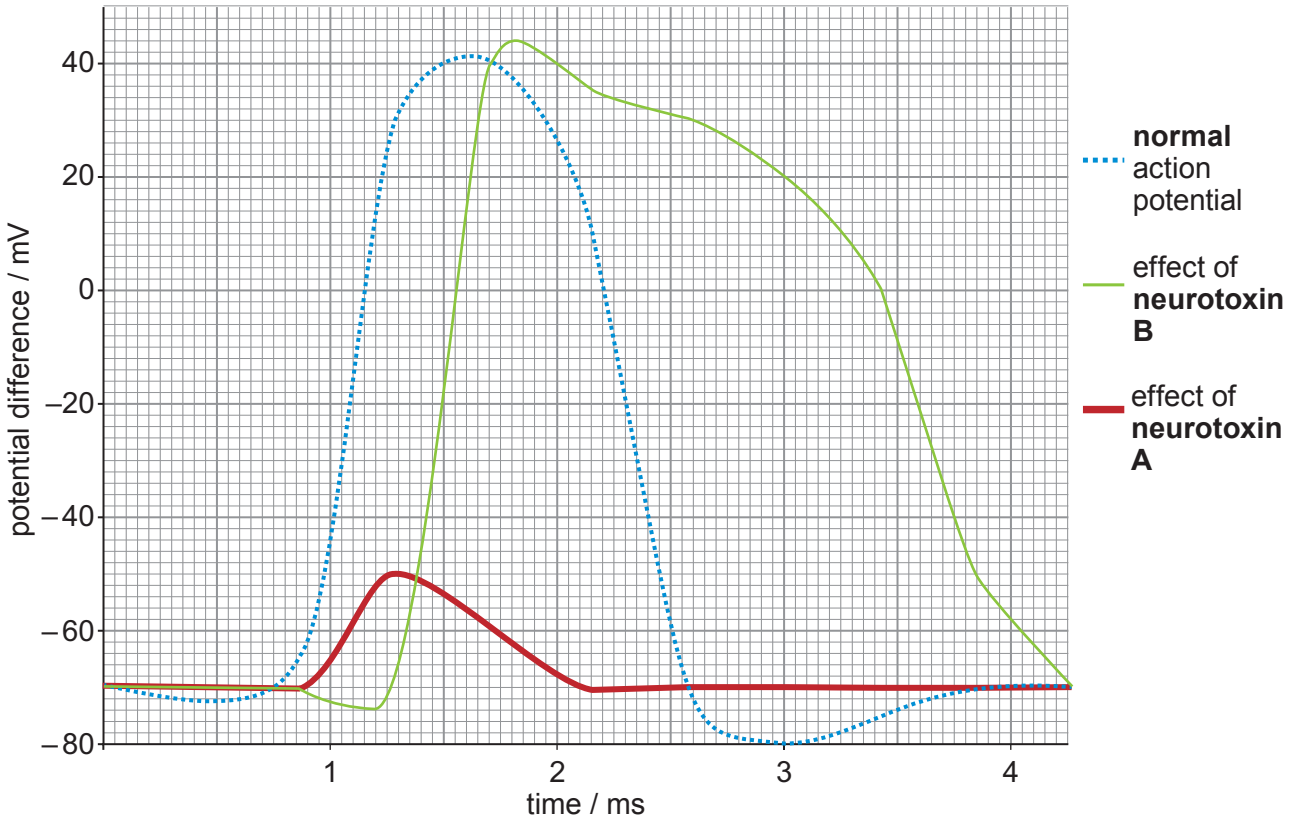
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6. Neurotoxins are chemicals produced by many organisms as a defence against predators. Most neurotoxins cause paralysis of muscles and eventually death. Different neurotoxins affect the transmission of a nervous impulse from the central nervous system to muscles in different ways.

Effect of neurotoxins A and B on an action potential



Effect of neurotoxin C:
Neurotoxin C has **no effect** on the generation or transmission of an action potential in an axon but prevents the generation of an action potential in a post-synaptic membrane.

	Ion concentration in the terminal of a presynaptic neurone / mmol dm^{-3}					
	At rest		Immediately after stimulation			
			Without neurotoxin C		With neurotoxin C	
Ion	**Inside neurone**	**Outside neurone**	**Inside neurone**	**Outside neurone**	**Inside neurone**	**Outside neurone**
Na^+	14	145	130	15	125	25
K^+	155	5	15	145	20	135
Ca^{2+}	0.001	5	3.9	1.1	0.008	4.9

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Using the information provided and your knowledge and understanding of the transmission of nervous impulses, explain how each of the neurotoxins **A**, **B** and **C** could cause muscle paralysis. [9 QER]

Neurotoxin A: the graph shows only a small depolarisation, to about −50 mV, which does not reach the threshold potential, so no action potential is generated.

Neurotoxin A must block the voltage-gated Na^+ channels in the axon membrane, so Na^+ ions cannot flood into the axon and depolarisation is small. Because action potentials are all or nothing, no action potential is generated, the impulse cannot travel along the motor neurone and cannot reach the muscles, so the muscles will not contract and are paralysed.

Neurotoxin B: an action potential is still generated (peak about +40 mV) but there is a delay in depolarisation, as Na^+ cannot flood in as quickly, and repolarisation takes far too long (about 4 ms instead of about 1 ms).

Neurotoxin B must block the voltage-gated K^+ channels, preventing K^+ from flooding out of the axon, which would normally restore the negative charge inside.

So the neurone does not return, or takes too long to return, to its resting potential (−70 mV) and the refractory period is extended. There is a delay in generating the next action potential, so impulses take too long to reach, or do not reach, the muscles and the muscles cannot contract properly.

Neurotoxin C does not affect the generation of an action potential in the axon, so Na^+ and K^+ movements are normal: after stimulation Na^+ inside rises (14 to 125 to 130) and K^+ inside falls (155 to 15 to 20) with or without the toxin.

However, without neurotoxin C the Ca^{2+} concentration inside the presynaptic terminal rises from 0.001 to 3.9 mmol dm^{-3}, but with neurotoxin C it only

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rises to 0.008, and outside stays high (4.9). So neurotoxin C must block the voltage-gated Ca^{2+} channels in the presynaptic membrane, preventing Ca^{2+} from entering the neurone.

Without Ca^{2+} influx the synaptic vesicles do not move to and fuse with the presynaptic membrane, so no neurotransmitter (acetylcholine) is released by exocytosis into the synaptic cleft.

So no neurotransmitter binds to receptors on the post-synaptic membrane (neuromuscular junction), no action potential is generated there and synaptic transmission is prevented. The impulse cannot reach the muscle, so the muscle cannot contract and is paralysed.

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SECTION B: OPTIONAL TOPICS

Option A: **Immunology and Disease** ☑

Option B: **Human Musculoskeletal Anatomy** ☐

Option C: **Neurobiology and Behaviour** ☐

Answer the question on **one topic only**.

Place a tick (✓) in **one** of the boxes above, to show which topic you are answering.

You are advised to spend about 25 minutes on this section.

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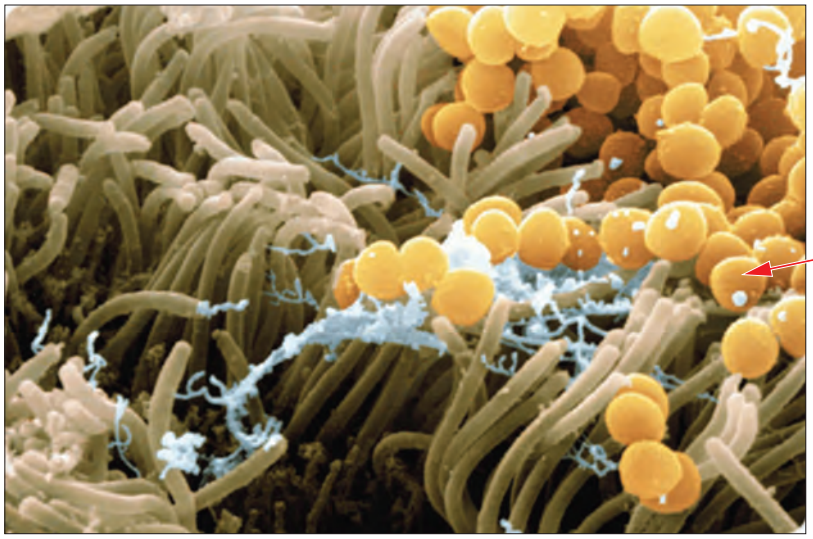
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OPTION A: IMMUNOLOGY AND DISEASE

7. *Neisseria meningitidis* is an airborne pathogenic bacterium that can cause one type of meningitis.

The photomicrograph below of an airway's lining shows an example of the body's natural barriers to infection by pathogenic bacteria.



(a) With reference to the photograph, describe this first line of defence. [1]

Mucus (from goblet cells) traps the bacteria and the cilia move (waft) the mucus away, up to the throat.

(b) *Pseudomonas aeruginosa* is a Gram-negative bacterium that can be easily spread by hands as a type of direct contact. *P. aeruginosa* infections can be treated with a bactericidal antibiotic called Colistin that binds to lipopolysaccharides and phospholipids in the outer cell layer of Gram-negative bacteria.

Using your knowledge of bacterial structure and antibiotics explain how penicillin acts and why it cannot be used to treat *P. aeruginosa*. [3]

Penicillin inhibits the formation of cross linkages between peptidoglycan molecules in the cell wall.

The wall is weakened, so when osmotic changes occur (water enters) the cells lyse (burst).

Gram-negative P. aeruginosa has an extra outer layer of lipopolysaccharide (lipoprotein) covering the peptidoglycan, so penicillin cannot reach it.

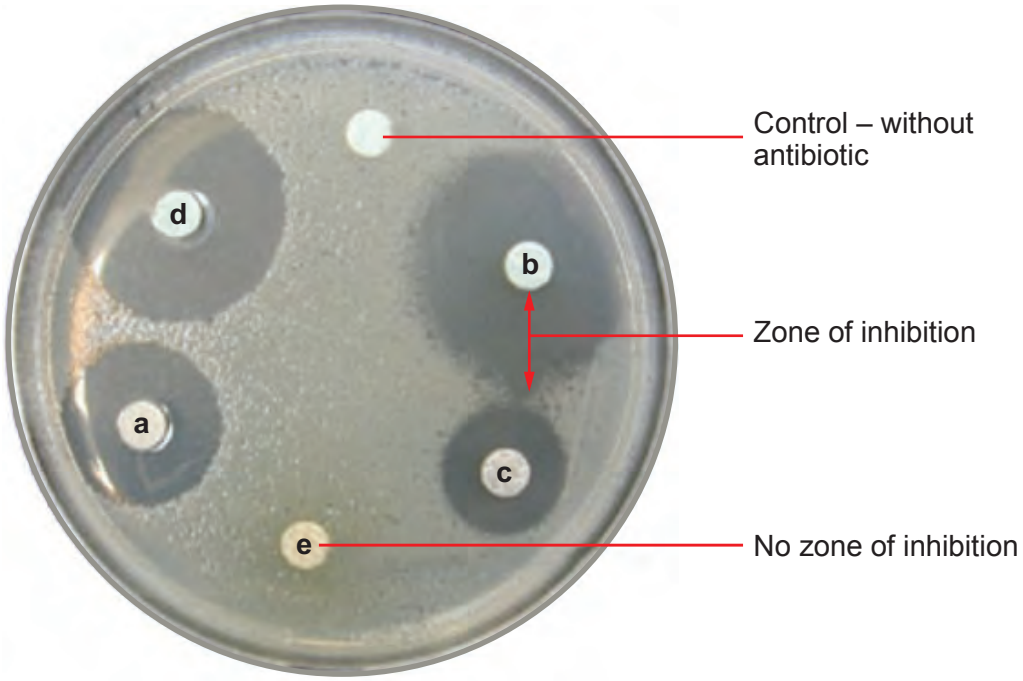
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Colistin is known as a "last resort" antibiotic, increasingly used to treat infections that resist every other antibiotic. However, in November 2015, bacteria were found resistant to this antibiotic. Microbiologists are constantly researching new antibiotic compounds.

The illustration below shows zones of inhibition around filter paper discs. The discs are all the same size and saturated with the same concentration of different antibiotic compounds and placed on bacteria growing on agar. The antibiotic will diffuse out of the filter paper. The radius of the zone of inhibition is a measure of the effectiveness of the antibiotic compound.



(c) Since this method depends on diffusion of the antibiotic, it is important to keep several factors constant.

(i) State **two** variables that should be controlled. [2]

The temperature of incubation

The thickness (depth) of the agar in the plates

(ii) Explain how you could identify which antibiotic worked the best. [1]

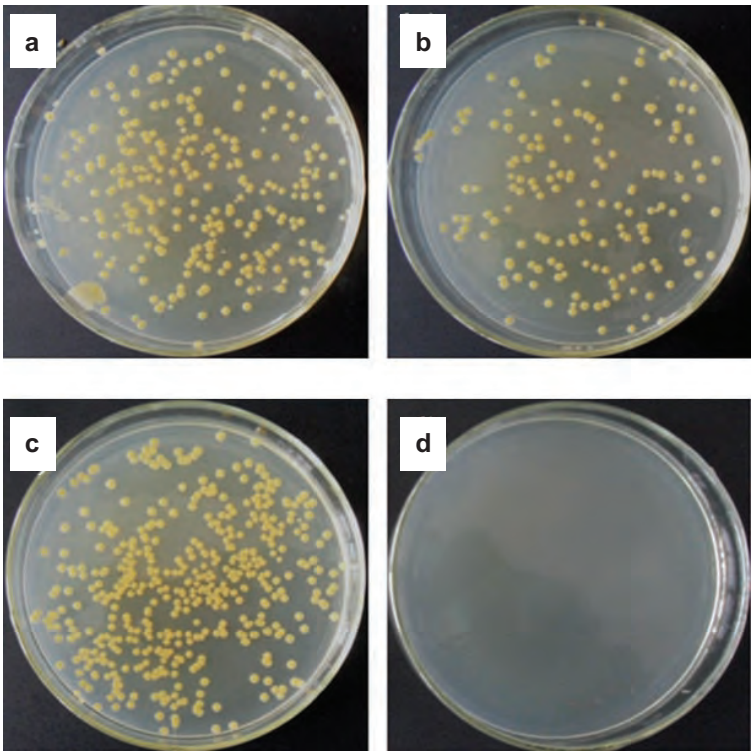
The antibiotic with the largest zone of inhibition (largest radius / diameter of clear zone) worked best.

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(iii) A sample of bacteria was removed from each zone of inhibition generated by the working antibiotics. These bacteria were then re-plated without the antibiotics and cultured.
The images below show the results for antibiotics **a** to **d**.



Conclude the mode of action of each of these antibiotics. Explain how you reached this conclusion. [2]

a, b and c are bacteriostatic and d is bactericidal: with a, b and c there is growth when re-plated, so bacteria were only inhibited; with d there is no growth, so they were killed.

(d) Antibiotics have no effect on viruses. Chickenpox is a highly infectious airborne disease caused by the varicella-zoster virus. The virus spreads easily in the air when an infected person coughs or sneezes. Airborne viruses have antigens that can attach to the surface membrane of cells lining the trachea.

Explain why the varicella-zoster virus needs to enter the cells of the trachea and the effect this has on the cells. [2]

Viruses have no organelles or metabolic pathways of their own, so they need a host cell and use its metabolic pathways to reproduce.

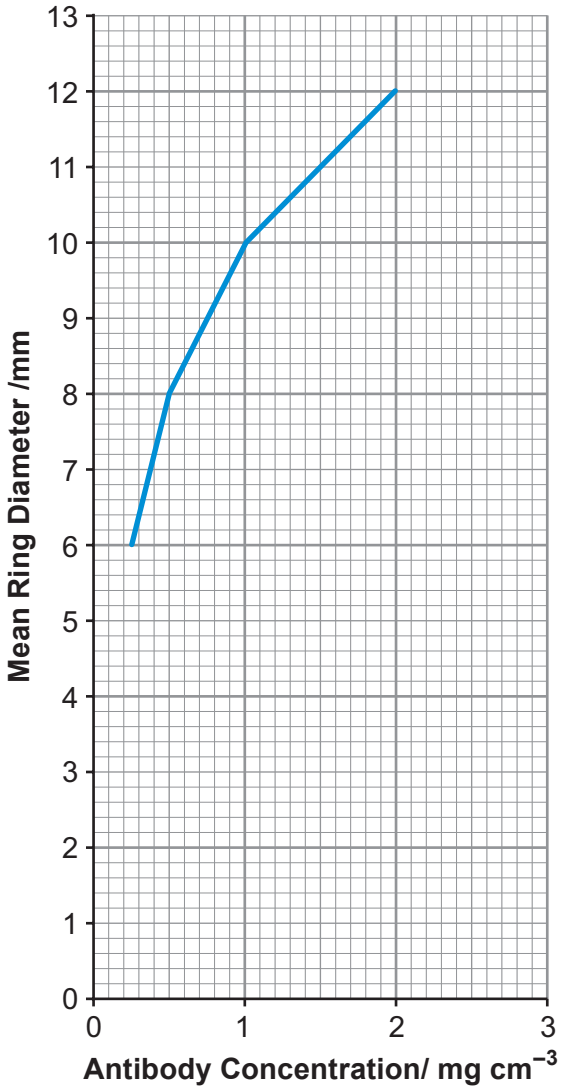
This kills the cell, by cell lysis when new viruses are released or by production of toxic substances.

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(e) Radial Immuno Diffusion is a quantitative technique used to estimate antibody concentration. Agar plates are set up with a known concentration of antibody included in the agar. Pure antigens are added to the centre of each plate. The antigens diffuse through the agar and form antigen-antibody complexes which can be seen as a precipitation ring. The diameter of the ring is used to plot a calibration curve to estimate the concentration of antibodies in the blood samples as shown below.



(i) Use the graph to estimate the antibody concentration of the sample taken before vaccination and after. **Write your answers in the table below**. [1]

Sample	Ring diameter / mm	Antibody Concentration / mg cm^{-3}
Before Vaccination	7	0.37
Following Vaccination	11	1.5

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(ii) Using your knowledge of the humoral response, explain the concentration of antibodies after the vaccination. [3]

The antigen in the vaccine is recognised: antigen presentation activates the specific B cell (clonal selection).

The B cell divides by mitosis (clonal expansion) and differentiates into plasma cells, which secrete large amounts of the specific antibody, so antibody concentration rises from 0.37 to 1.5 mg cm^{-3}.

(iii) To assess the effectiveness of the vaccine the technique was repeated with several blood samples taken from a number of volunteers. A statistical test was used to assess the significance of the differences in the antibody levels before and after vaccination.
State the null hypothesis. [1]

There is no significant difference in the concentration of antibodies in the blood samples before and after vaccination.

(iv) The test gave a value greater than the critical value at a probability of 0.05.
State whether you would accept or reject the null hypothesis and explain why. [1]

Reject the null hypothesis: there is a significant difference in antibody concentration, with less than 5% probability that it is due to chance.

(v) A protective antibody response to a vaccine requires at least a fourfold increase in antibody concentration. **Using the table opposite**, calculate the minimum antibody concentration that would be required to be protective. [1]

$4 \times 0.37 = 1.48$ mg cm^{-3}

increase in antibody concentration = 1.48 mg cm^{-3}

(vi) State whether the results shown opposite indicate a successful vaccination and explain why annual vaccination programmes against influenza are not always effective. [2]

Yes, successful: 1.5 is at least a fourfold increase (above 1.48).

Influenza mutates (antigenic variability), changing the shape of its surface antigens, so existing antibodies do not match and new ones must be produced.

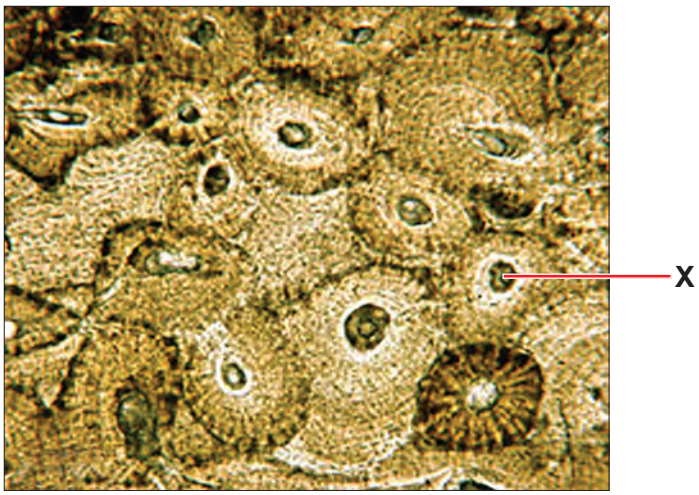
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OPTION B: HUMAN MUSCULOSKELETAL ANATOMY

8. Limb bones have a strong outer shell of compact bone, surrounding a softer, spongier core called trabecular bone making them light and strong. The electron micrograph shows a cross section through compact bone.



(a) (i) Name structure **X** and describe its role in bone. [2]

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(ii) State the percentages of organic and inorganic material in compact bone. [1]

Organic ..... Inorganic .....

Bone mineral density (BMD) is a useful measure of bone health. Bones undergo continuous remodelling; through the daily removal of small amounts of bone mineral, and equal deposition of new mineral. This process must be balanced if bone strength is to be preserved.

As we age, the bone mineral balance tips toward excessive removal and bones weaken. Over time they can become brittle and prone to fracture, leading to a disease called osteoporosis.

The table below shows the effect of four osteoporosis treatments.

Drugs	Bone mineral density gain (%)	Fracture reduction (%)
Bisphosphonate	**3-5**	**30-45**
Denosumab	**3-6**	**55-70**
Oestrogen	**3-5**	**35**
Calcitonin	**1-1.5**	**20-30**

Data adapted from Department of Pharmacology, Al-Ameen College of Pharmacy, Bangalore-560027, India.

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(b) Denosumab is a drug that binds to receptors on osteoclasts and inhibits their activity. With reference to the mineral composition of compact bone and the cells found in the lacunae, describe how bone remodelling takes place in a healthy adult and suggest how Denosumab can be used as a treatment for osteoporosis. [4]

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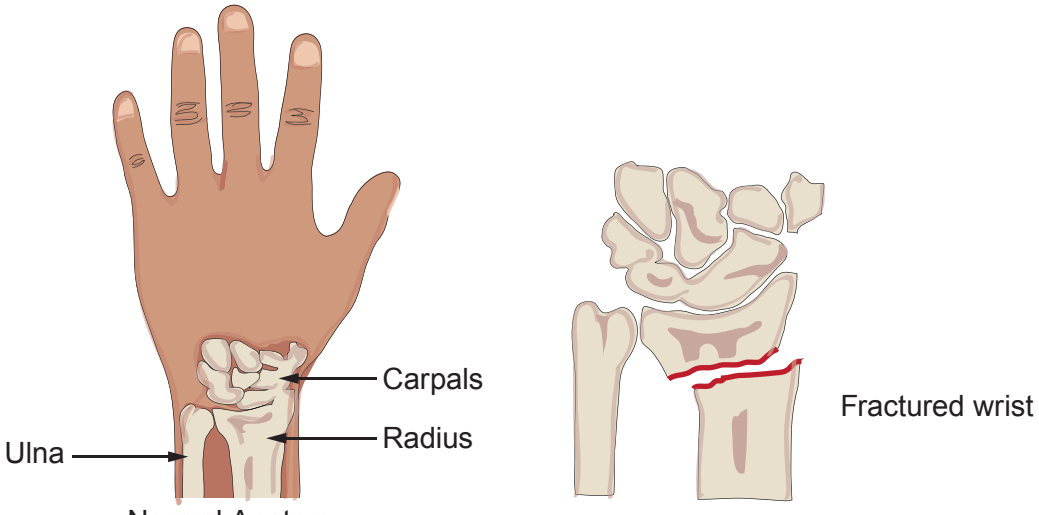
(c) With reference to data provided, conclude whether Denosumab or oestrogen is the most effective treatment for osteoporosis. Give a reason for your answer. [2]

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(d) Wrist fractures are very common in women in their 50s, typically after a fall onto an outstretched arm. This can be the first sign of underlying osteoporosis.



(i) The image above depicts a displaced fracture of the wrist. Suggest **one** possible treatment for this. [1]

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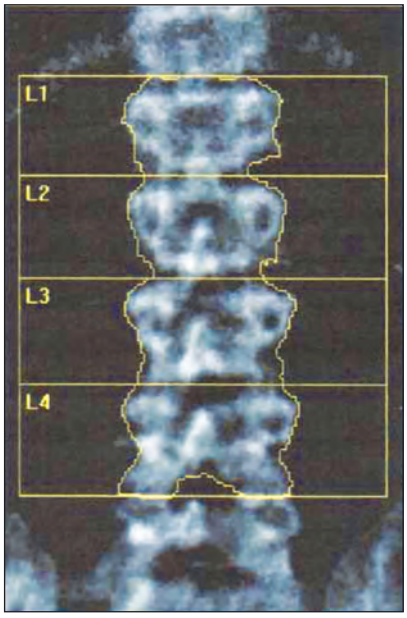
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(ii) Ideally, doctors need to identify and treat patients with osteoporosis before a fracture occurs. A radiograph of the vertebral column can be used to diagnose osteoporosis. A scan identifies the bone area, bone mineral composition (BMC) and bone mineral density (BMD). The results are then compared to the mean results for young adults to calculate a *T- score*, which can then be used to predict fracture risk.
The lumbar spine scan of a 60 year old woman is shown below.



Scan Report:

Scan Date: July 30, 2015

Scan Type: Lumbar Spine

Region	Area (cm^2)	BMC (g)	BMD (g/cm^2)	Young adult BMD Mean (g/cm^2)	Young adult BMD Standard deviation (g/cm^2)
L1	11.54	7.41	0.642	1.0	0.1
L2	12.14	9.28	0.765		
L3	12.21	9.93	0.813		
L4	14.80	12.09	0.817		
Mean	12.67	9.68	0.759		

The T score is calculated as:

$$\text{T Score} = \frac{\text{Patient mean BMD} - \text{Young Adult mean BMD}}{\text{Standard Deviation Young Adult BMD}}$$

Calculate the T score for the patient. [1]

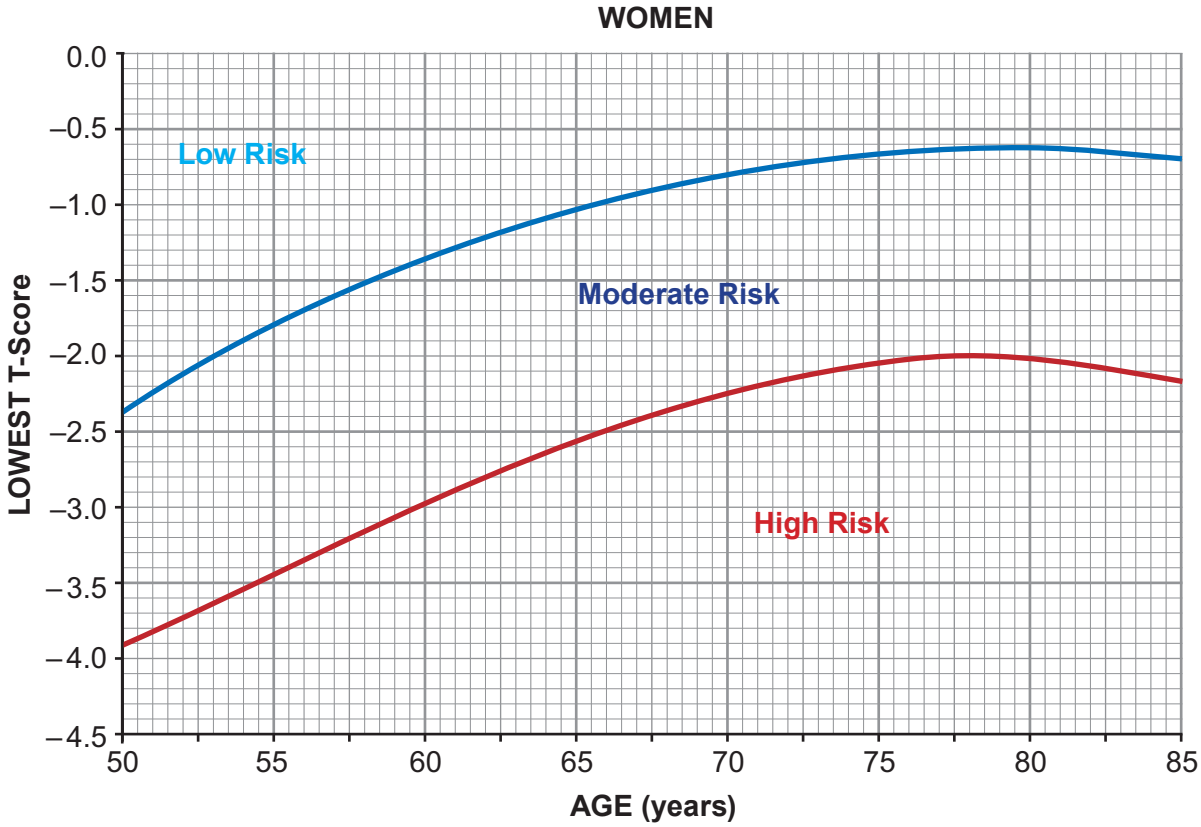
T score = ...

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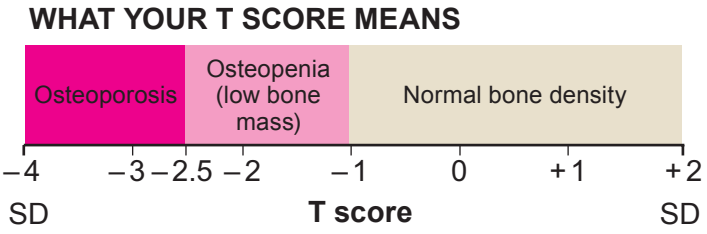
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The graph below can be used to estimate the future fracture risk in women.



The scale below can be used to interpret the T score.



Key: SD = Standard deviation

(iii) Use the T score and the information provided to diagnose her condition and fracture risk. [2]

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(e) Arthritis affects joints, particularly those in the hands and wrists.



Finger Joint Arthritis

(i) Compare and contrast the structure and movement of the wrist joint with those found in the fingers. [4]

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(ii) A patient presents symptoms of pain, stiffness and swelling in their joints. Physical examination reveals an increase in temperature at the swollen areas. Is this patient likely to be suffering from osteoarthritis or rheumatoid arthritis? Explain your conclusion. [3]

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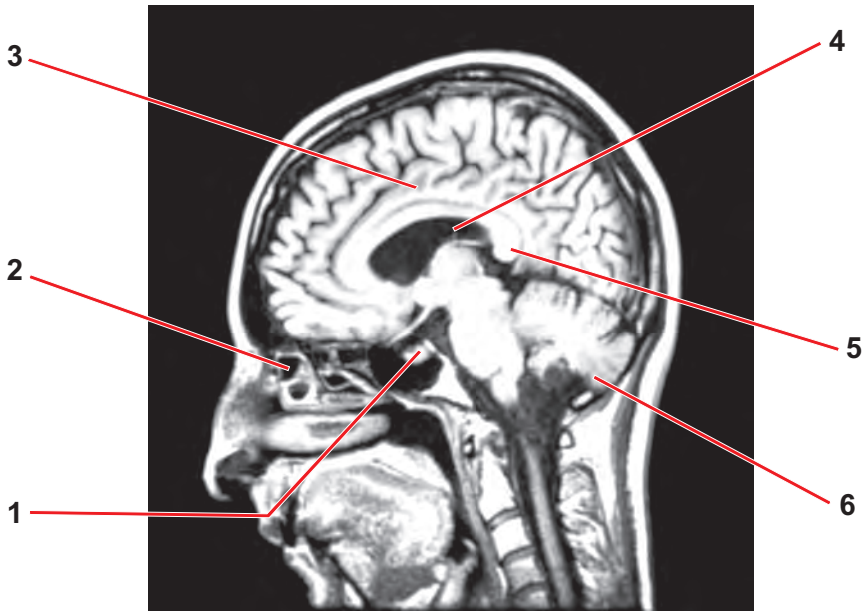
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OPTION C: NEUROBIOLOGY AND BEHAVIOUR

9. Scientists carried out research into possible changes that occur in the brains of taxi drivers, as a result of learning. To qualify as a London taxi driver, they have to learn every street name, landmark and direction of traffic flow. MRI images can be analysed to measure the volume of specific brain structures.

(a) (i) The following image depicts an MRI scan of a human brain. Which number **(1-6)** shows the hippocampus? [1]

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(ii) Suggest why the scientist studied the hippocampus region of the brain. Give reasons for your answer. [2]

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(iii) The independent variable in this research was being a male taxi driver. The dependent variable was the volume of the hippocampus as seen using MRI. Male non-taxi drivers were used as controls in this study. Suggest **two** *other* factors regarding these individuals that should be controlled. [1]

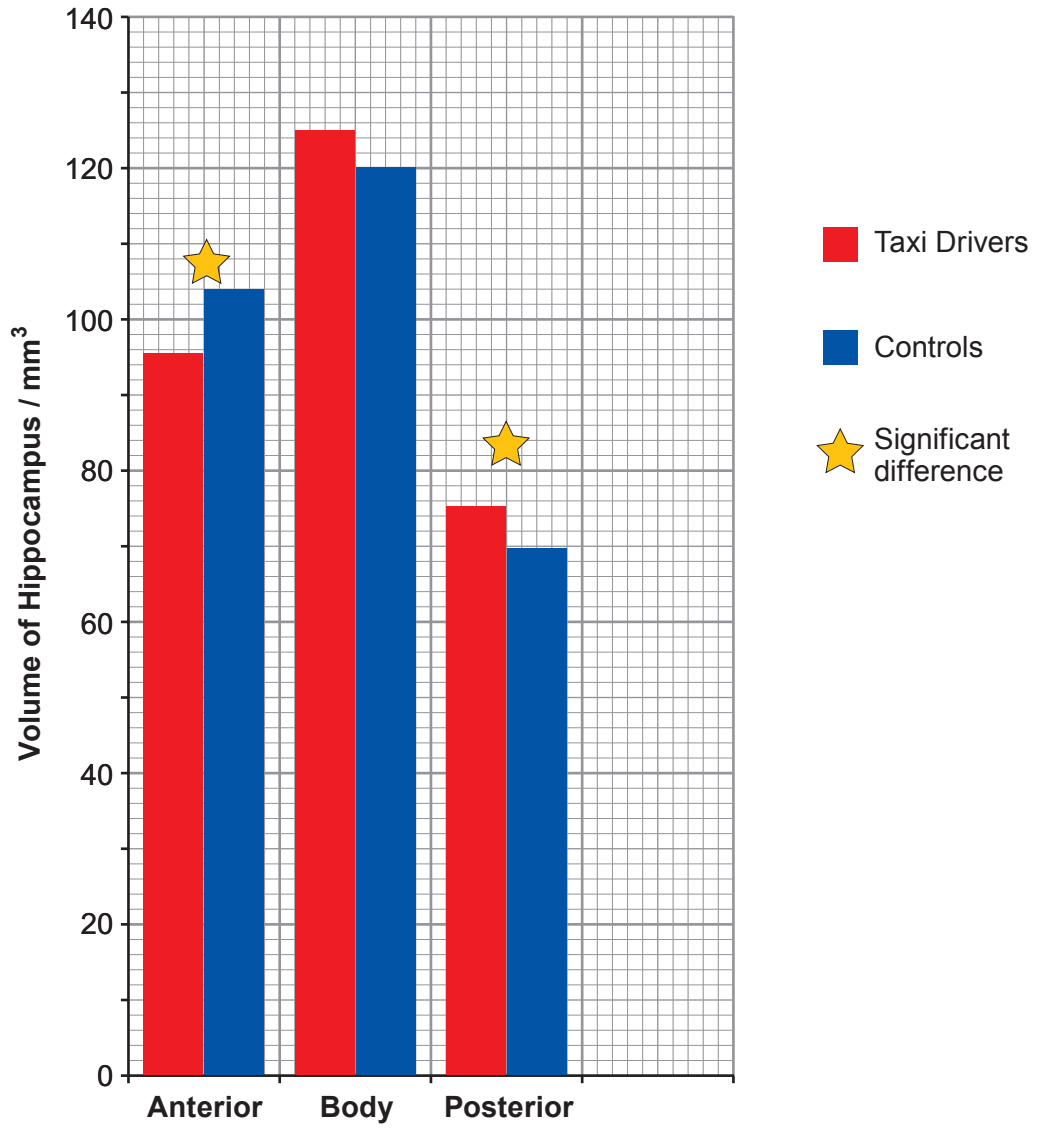
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(b) The MRI scanned the anterior, body (middle) and the posterior regions of the hippocampus. The results from the research are shown below.



(i) The scientist's hypothesis stated, "the regions of hippocampi in London taxi drivers will be structurally different to the hippocampi in non-taxi drivers".
Using the results given, can the hypothesis be accepted? Justify your conclusion.
[4]

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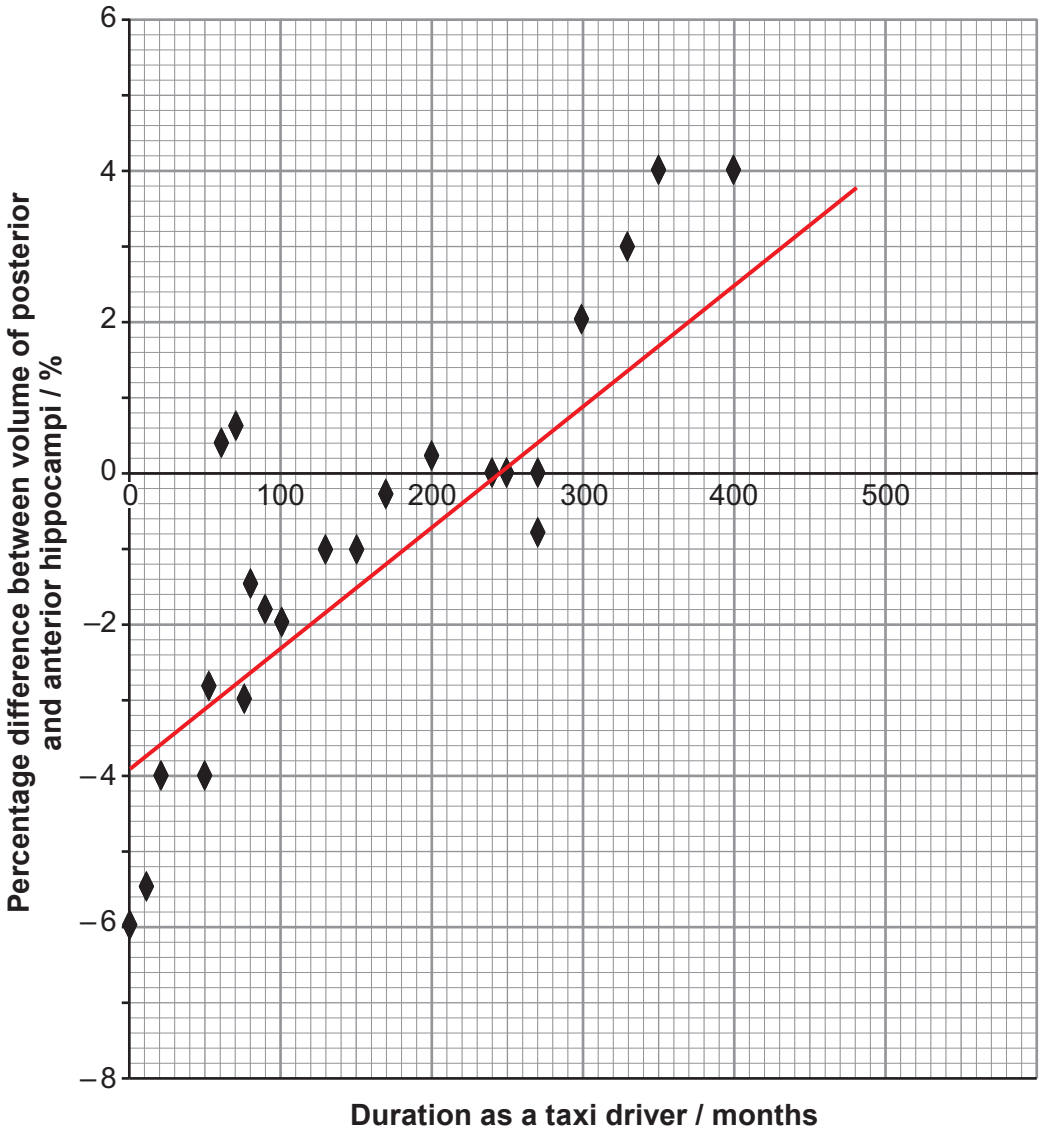
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The percentage differences between the volumes of the posterior and anterior hippocampi were plotted against the duration of time spent as a taxi driver.



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(ii) The line shown on the graph is a correlation line. Using the trend shown and your knowledge of brain structure and neuroplasticity, what conclusions can be drawn? [4]

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(iii) A further investigation is to be carried out to look at changes in brain activity during a map reading exercise whilst driving the taxi. Suggest a brain imaging technique that could be used and explain why it would be more suitable than MRI. [2]

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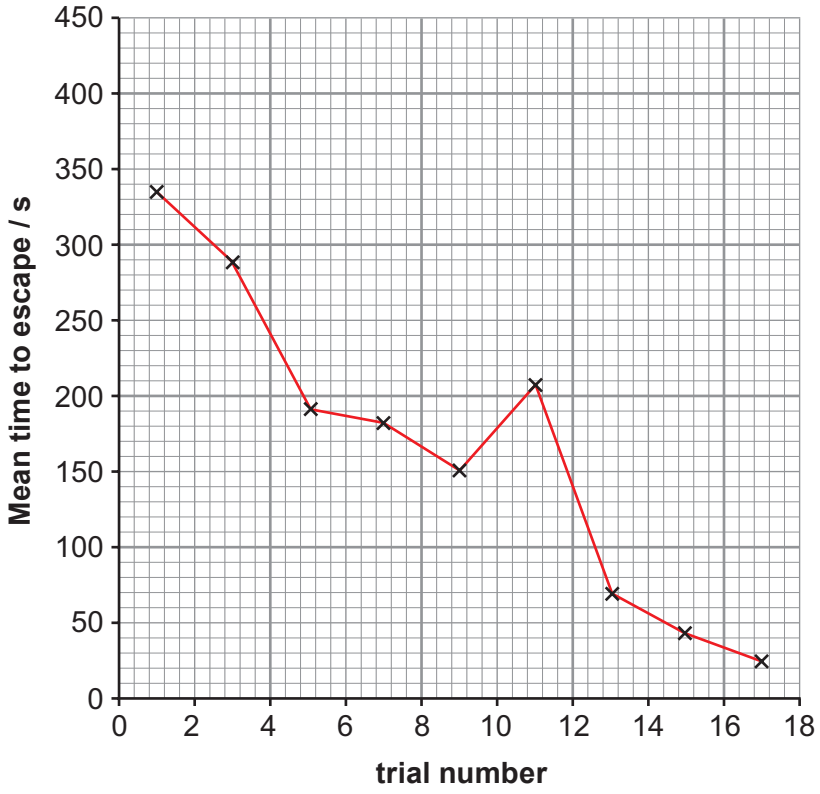
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(c) In order to better understand learning in animals, researchers presented spotted hyenas *(Crocuta crocuta)* with a problem-solving task. Hyenas were placed in a puzzle box and were encouraged to escape to reach food placed outside. Researchers timed how long it took the hyenas to escape. The experiment was repeated several times.



(i) Calculate the percentage change in mean time to escape between the start and end of the trials. [2]

percentage change in mean time = ...

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(ii) State and explain the type of behaviour exhibited by the hyenas. [2]

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(iii) Explain why the time taken to escape from the box decreases. [1]

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(iv) Suggest how the experiment could be modified to improve the reliability of the conclusion. [1]

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