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**Pearson Edexcel
Level 3 GCE**

Centre Number

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Monday 15 June 2020

Morning (Time: 2 hours)

Paper Reference **9BN0/03**

Biology A (Salters Nuffield)

Advanced

Paper 3: General and Practical Applications in Biology

You must have:

Calculator, HB pencil, ruler and a copy of the scientific article adapted from *Scientific American* (enclosed)

Total Marks

Instructions

- Use **black** ink or ball-point pen.
- **Fill in the boxes** at the top of this page with your name, centre number and candidate number.
- Answer **all** questions.
- Show your working in any calculation questions and include units in your answer where appropriate.
- Answer the questions in the spaces provided
– *there may be more space than you need.*

Information

- The total mark for this paper is 100.
- The marks for **each** question are shown in brackets
– *use this as a guide as to how much time to spend on each question.*
- You may use a scientific calculator.
- In questions marked with an **asterisk** (*), marks will be awarded for your ability to structure your answer logically, showing how the points that you make are related or follow on from each other where appropriate.

Advice

- Read each question carefully before you start to answer it.
- Try to answer every question.
- Check your answers if you have time at the end.

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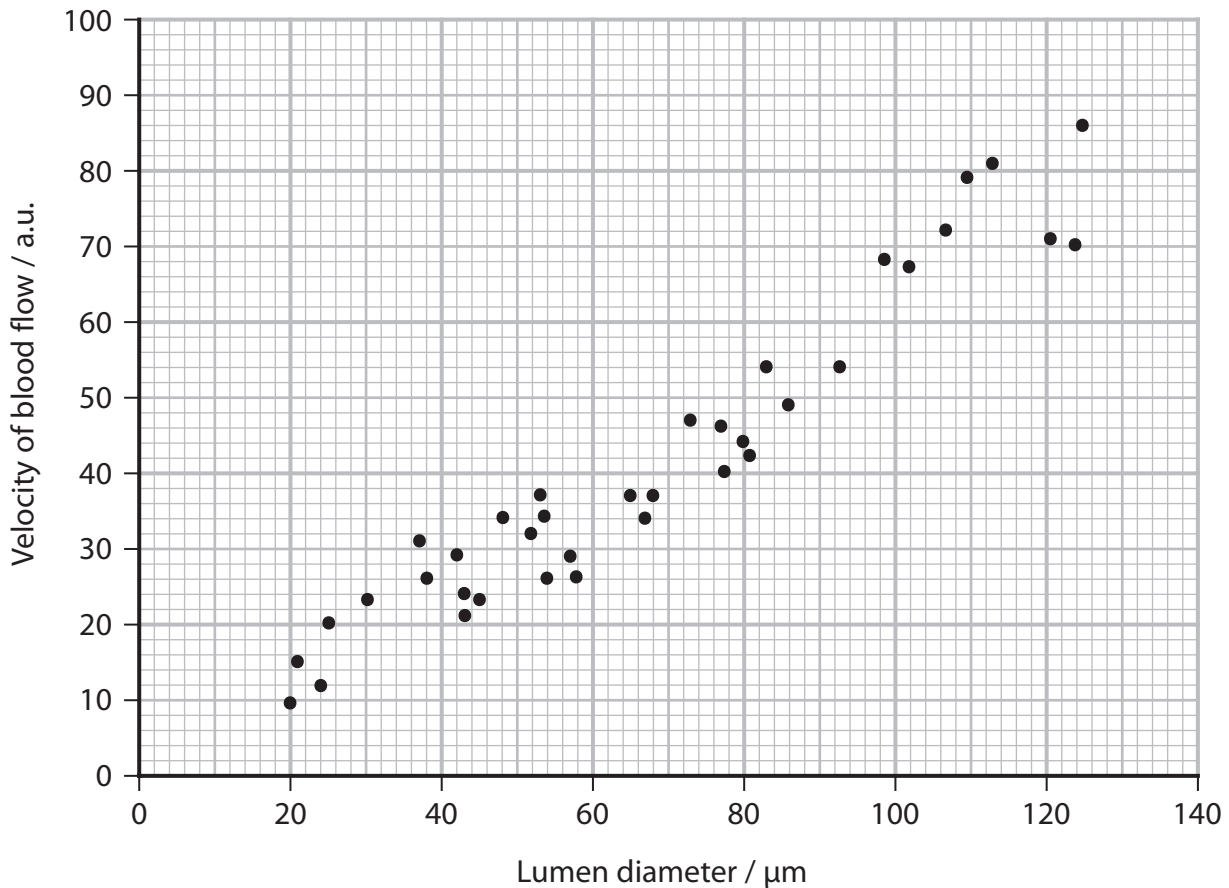
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Answer ALL questions.

Write your answers in the spaces provided.

- 1 The diameter of the inside of a blood vessel (lumen diameter) affects the speed of blood flow.

The graph shows the relationship between the lumen diameter of blood vessels and the velocity of blood flow.



- (a) State the relationship shown in the graph.

(1)

There is a (strong) positive correlation: as lumen diameter increases, the velocity of blood flow increases.



- (b) (i) Explain how the development of cardiovascular disease (CVD) could affect the velocity of blood flow.

(2)

In CVD, atheroma (plaques) forms in the artery walls, which narrows (reduces the diameter of) the lumen of the arteries.

Therefore the velocity of blood flow is reduced.

- (ii) Explain why a change in the velocity of blood flow will affect the function of the heart muscle.

(2)

Slower blood flow in the coronary arteries reduces the supply of oxygen to the heart muscle.

This results in less aerobic respiration (more anaerobic respiration), so weaker heart muscle contraction or death of heart tissue.

- (c) Explain the importance of the relationship, shown in the graph, to capillary function.

(2)

Capillaries have a very small lumen diameter, so blood flow through them is slow.

This allows time for diffusion, i.e. exchange of substances between the blood and the tissue fluid.

(Total for Question 1 = 7 marks)



2 The banded snail *Cepaea nemoralis* occupies many habitats.

The thrush is a major predator of the banded snail.

The thrush and the banded snail, shown in the photograph, occupy different niches.



Source: © Dave Watts/Alamy

(a) Describe the difference between the terms niche and habitat.

(2)

A niche is the role of an organism in its habitat, i.e. the way it interacts with its environment (both living and non-living).

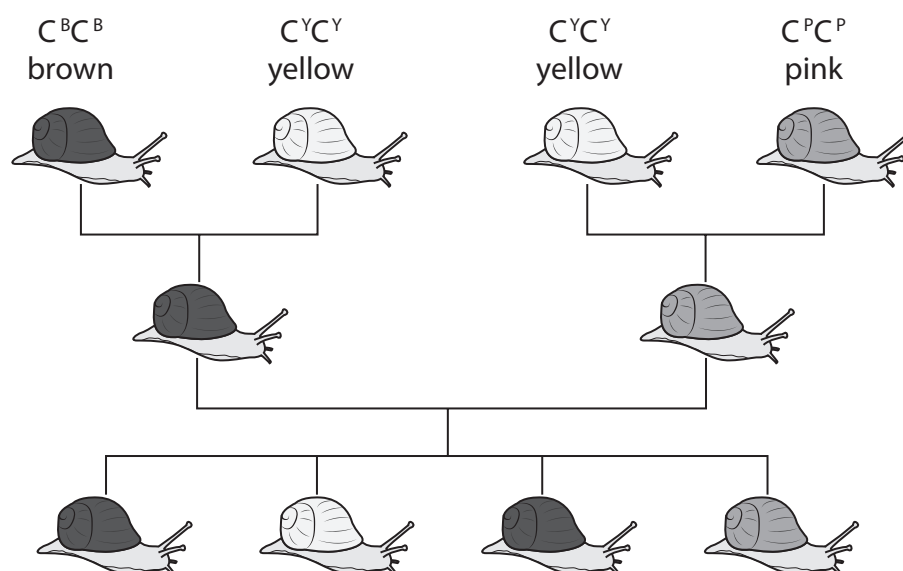
A habitat is the place, with a distinct set of conditions, where an organism (or a community of organisms) lives.

(b) The shell colour of the banded snail can be yellow, pink or brown.

A single gene controls shell colour in the banded snail.

There are three alleles for this gene, C^Y , C^P , and C^B .

The effects of these alleles on shell colour is shown in the genetic pedigree diagram.



Deduce the dominance of the alleles for shell colour.

(2)

C^B (brown) and C^P (pink) are dominant to C^Y (yellow), which is recessive.

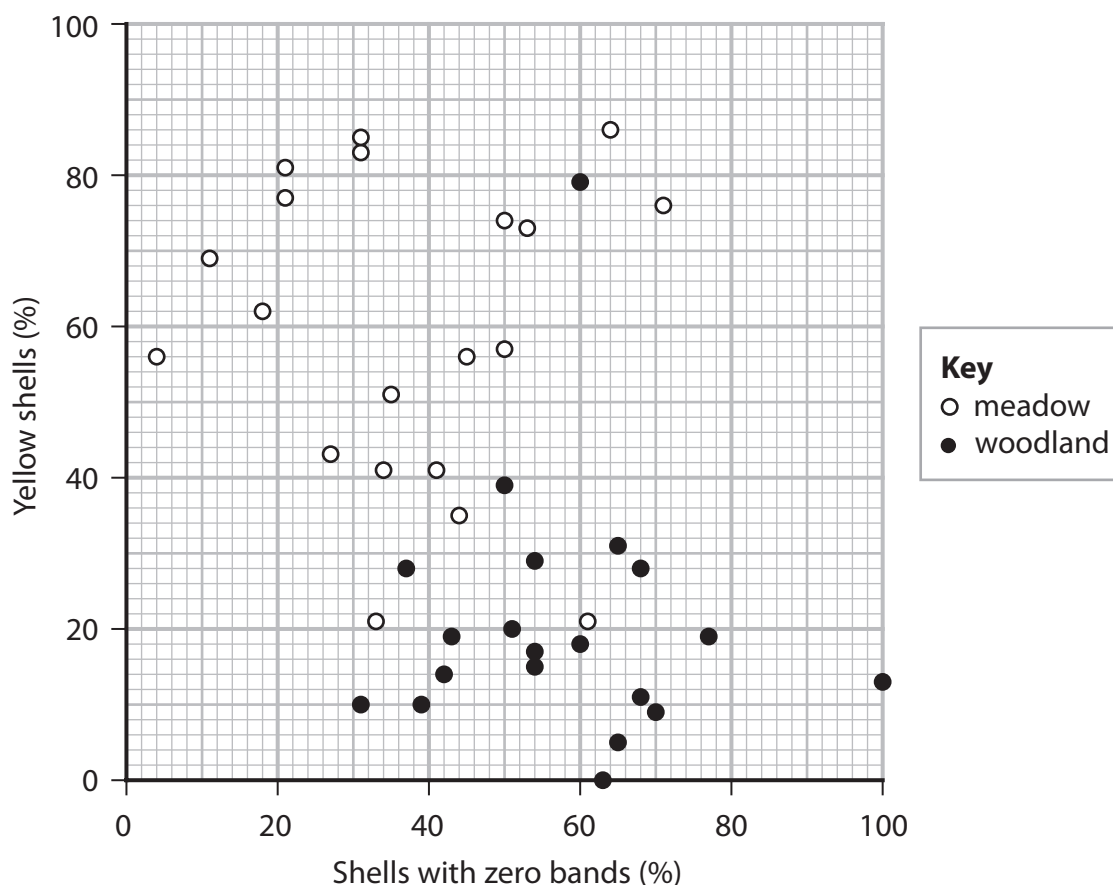
C^B is dominant to C^P , so the order of dominance is $C^B > C^P > C^Y$.



- (c) The shells of the banded snail can have from zero to five black bands.

The populations of banded snails in 20 meadow habitats and 20 woodland habitats were investigated.

At each location the percentage of snails with yellow shells was recorded. The percentage of snails with shells with zero bands was also recorded.



- (i) Explain the importance of the different shell patterns in these two habitats.

(3)

The different frequencies of shell patterns in the two habitats are an example of adaptation: woodland has more banded, darker (non-yellow) shells and meadows have more yellow shells.

Each pattern provides camouflage appropriate to its habitat, so the snails are less visible to thrushes, reducing predation.

Therefore snails with the camouflaged pattern have an increased chance of surviving to reproduce and pass on their alleles.



- (ii) Explain how a statistical test could be used to determine if the number of shells with zero bands is significantly different in these two habitats.

(2)

Use a statistical test such as the Student's t-test to compare the mean percentage of shells with zero bands in the two habitats.

If the calculated test value is greater than the critical value at $p = 0.05$ (with the appropriate degrees of freedom), the difference is significant.

(Total for Question 2 = 9 marks)



3 Photosynthesis in green plants involves light-dependent reactions and the Calvin cycle.

(a) The Calvin cycle uses the products of the light-dependent reactions.

(i) State the location of the Calvin cycle.

(1)

In the stroma of the chloroplast.

(ii) Describe the roles of the products of the light-dependent reactions in the Calvin cycle.

(3)

The products are ATP and reduced NADP.

Reduced NADP provides hydrogen (electrons) to reduce GP to GALP (glyceraldehyde 3-phosphate).

ATP provides the energy for converting GP to GALP and phosphate (and energy) for regenerating RuBP from GALP.

(b) Photosynthesis contributes to the productivity of ecosystems.

(i) State what is meant by the term ecosystem.

(1)

All the organisms (community) in an area together with the non-living components (abiotic factors) and their interactions.



(ii) The table shows information about two types of ecosystem.

Ecosystem	Gross productivity / g m ⁻² day ⁻¹	Net productivity / g m ⁻² day ⁻¹	Percentage of gross productivity used in respiration (%)	Total surface area of Earth occupied / km ²
Tropical rainforest	16.7	5.5	67.1	510 × 10 ⁶
Salt marsh	10.5		34.3	5.5 × 10 ⁴

Calculate the net productivity of the salt marsh ecosystem.

(2)

$$\text{respiration} = 10.5 \times (34.3 \div 100) = 3.6$$

$$\text{net productivity} = 10.5 - 3.6 = 6.9$$

..... 6.9 g m⁻² day⁻¹

(iii) Comment on the impact of these different types of ecosystem on global warming.

(3)

Tropical rainforests use a greater percentage of gross productivity in respiration (67.1% compared with 34.3% in salt marsh).

Tropical rainforests also occupy a much larger surface area of the Earth (510 × 10⁶ km² compared with 5.5 × 10⁴ km²).

Therefore tropical rainforests release more carbon dioxide from respiration in total.

Carbon dioxide is a greenhouse gas, so rainforests make a greater contribution to global warming, although their large net productivity also removes a lot of carbon dioxide; salt marsh releases a smaller proportion of the carbon it fixes.



(c) Explain the importance of RUBISCO to the productivity of an ecosystem.

(2)

RUBISCO is the enzyme that fixes inorganic carbon; it combines carbon dioxide with RuBP in the Calvin cycle.

This allows the formation of organic molecules such as GP, GALP, glucose and amino acids.

These organic molecules are converted into biomass, allowing the transfer of energy to the next trophic level.

(Total for Question 3 = 12 marks)



- 4 Global warming can affect abiotic factors that determine the distribution of organisms.

The presence of sodium chloride in soil is an abiotic factor that affects the germination of seeds.

The effects of sodium chloride solution and gibberellin on the germination of rice seeds have been investigated.

Gibberellin regulates developmental processes in plants.

Fifty seeds were placed in each of three Petri dishes containing different solutions.

The seeds were incubated for 96 hours and the number that germinated in each Petri dish was counted.

Treatment	Solution	Number of seeds germinating
Control	Distilled water	48
Sodium chloride	120 mmol dm ⁻³ of sodium chloride	33
Sodium chloride and gibberellin	120 mmol dm ⁻³ sodium chloride and 50 µmol dm ⁻³ gibberellin	45

- (a) (i) Give a null hypothesis for this experiment.

(1)

Treatment of seeds with sodium chloride, or with sodium chloride and gibberellin, has no effect on the number of seeds that germinate.

- (ii) Calculate the chi-squared (χ^2) value for these results, using the formula provided.

(3)

$$\chi^2 = \sum \frac{(O - E)^2}{E}$$

$$E = (48 + 33 + 45) \div 3 = 42$$

$$(O - E)^2 = 36, 81 \text{ and } 9$$

$$\chi^2 = (36 + 81 + 9) \div 42 = 126 \div 42 = 3$$

Answer 3.0



- (iii) In a second experiment, using the same three treatments, the chi-squared (χ^2) value was found to be 6.635.

The table gives the critical values for the chi-squared (χ^2) test at different probability levels.

Degrees of freedom	Probability level		
	0.05	0.01	0.001
1	3.841	6.635	10.83
2	5.991	9.210	13.82
3	7.815	11.34	16.27
4	9.488	13.28	18.47

Deduce the statistical significance of the results of the second experiment.

(2)

6.635 is greater than the critical value of 5.991 at $p = 0.05$ with 2 degrees of freedom

(3 treatments - 1), but less than 9.210 at $p = 0.01$.

So the results are significant at $p = 0.05$; the null hypothesis is rejected.



(b) Gibberellins can activate the gene for amylase in rice seeds.

Amylase is an enzyme that hydrolyses starch in the rice seeds.

Devise an investigation to demonstrate the effect of gibberellin on amylase activity in rice seeds treated with sodium chloride.

(4)

Soak equal numbers of the same type and size of rice seeds in sodium chloride solution, and in sodium chloride solution with gibberellin (or a range of gibberellin concentrations).

Control temperature using a water bath, e.g. 25 °C, and keep the time the same.

Extract the amylase by grinding the seeds, using the same mass of seeds and the same volume of seed extract each time.

Add the extract to starch solution and test samples with iodine solution at intervals; time how long it takes until the iodine no longer turns blue-black (or use a colorimeter, or Benedict's test for reducing sugars).

If gibberellin increases amylase activity, the time for the starch to disappear will be shorter. Repeat and compare means.

(Total for Question 4 = 10 marks)



5 Blood clotting is a process that is affected by genes.

Some people are at an increased risk of a condition called deep vein thrombosis (DVT). Blood clots form in the veins of people with DVT.

There are two alleles in a population, a wild type allele and G20210A.

- (a) The table shows the risk of DVT for people with different genotypes in this population.

Genotype	Risk of DVT / number of people with DVT per 1000 individuals
Homozygous wild type	1.0
Heterozygous for G20210A	2.5
Homozygous for G20210A	20.0

- (i) Determine the effect of the allele G20210A on the risk of an individual developing DVT in this population.

(2)

The G20210A allele increases the risk of developing DVT; having two copies of the allele increases the risk more.

One allele gives a 2.5 fold increase in risk and two alleles a 20 fold increase in risk compared with homozygous wild type (an 8 fold increase compared with one allele).



- (ii) The frequency of the G20210A allele in a population of 10 000 individuals was investigated.

In this population, 50 individuals were homozygous for G20210A.

Calculate the number of individuals in the population who were heterozygous for the G20210A allele, using the Hardy-Weinberg equation:

$$p^2 + 2pq + q^2 = 1.0 \quad (3)$$

$$q^2 = 50 \div 10\,000 = 0.005$$

$$q = \sqrt{0.005} = 0.0707 \quad p = 1 - 0.0707 = 0.9293$$

$$2pq = 2 \times 0.9293 \times 0.0707 = 0.1314$$

$$0.1314 \times 10\,000 = 1314$$

Answer 1314



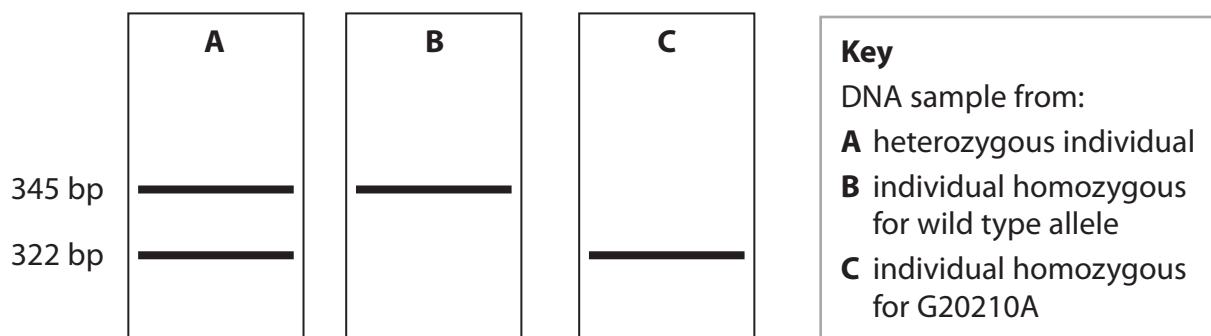
- (b) Individuals with a family history of DVT may be offered a genetic test for the G20210A allele.

In this test, a sequence of 345 base pairs (bp) from this gene is amplified using the polymerase chain reaction (PCR).

A specific restriction enzyme is then added to the amplified DNA.

The DNA fragments produced are then separated using gel electrophoresis.

The diagram shows the results of gel electrophoresis for three individuals, A, B and C.



- (i) Explain the role of DNA primers in the production of the amplified 345bp sequence.

(2)

Primers are short single strands of DNA with a specific base sequence.

They bind (anneal) to complementary bases at either end of the 345 bp sequence to be amplified.

Therefore they provide a starting site for DNA polymerase to bind and build the complementary strand, so only this sequence is copied.



- (ii) Explain why the amplified DNA fragments for the G20210A allele and the wild type allele are different.

(3)

The base sequences of the two alleles are different (G20210A has a base substitution).

The restriction enzyme recognises and cuts at a specific DNA base sequence (restriction site) that is only present in the G20210A allele.

Therefore a shorter fragment (322 bp) is produced for the G20210A allele, while the wild type stays 345 bp.

- (iii) Devise an investigation to determine the optimum number of cycles for the polymerase chain reaction used to amplify the DNA for this test.

(4)

Set up PCR tubes with the same volume of DNA sample, and DNA polymerase, primers and free nucleotides provided in excess.

Control the conditions: the same temperatures in each cycle (95 °C to separate strands, 55 °C for primers to anneal, 72 °C for extension) and the same duration of each step.

Change the number of cycles, e.g. 5, 10, 15, 20, 25, 30, 35 cycles.

Separate the products using gel electrophoresis, with the same volume of each sample loaded, stain the DNA and compare the band for the 345 bp fragment.

Choose the smallest number of cycles that produces a clear, observable band (the clearest band, after which there is no further increase).

(Total for Question 5 = 14 marks)



6 Cells use ions in many different processes.

(a) Explain why ions can dissolve in blood.

(2)

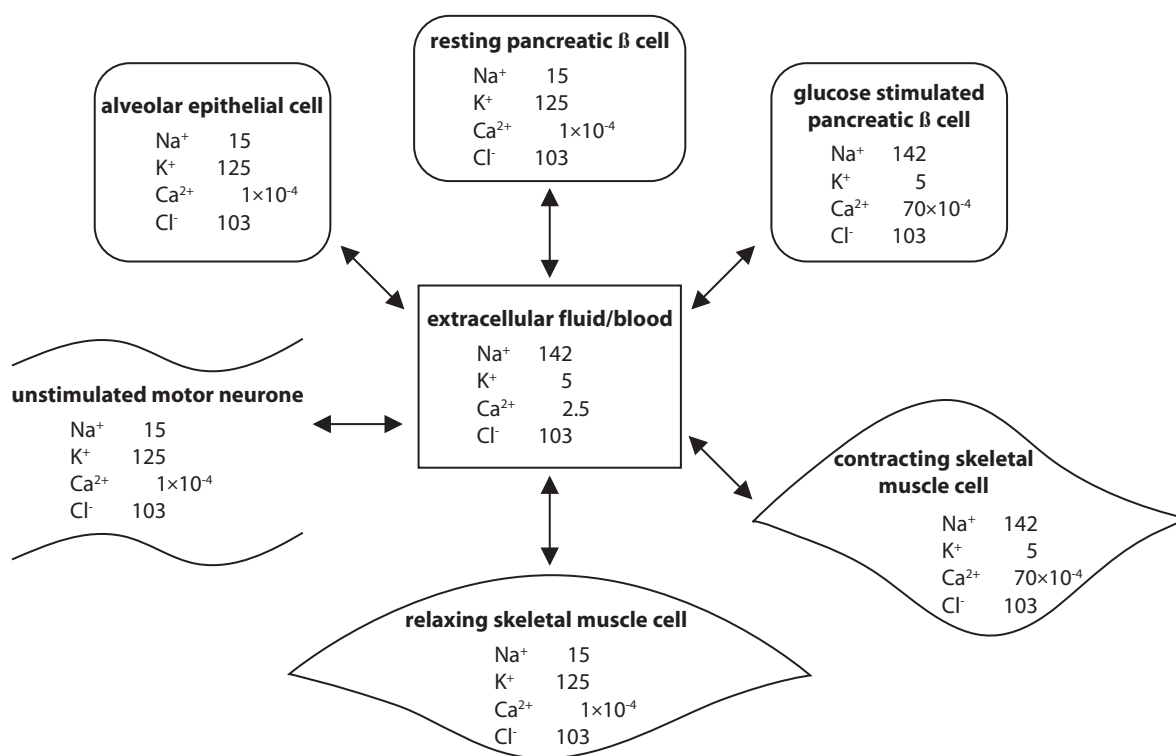
Ions are charged, and water is the main component of blood (plasma).

Water is a polar (dipole) molecule, so water molecules are attracted to and surround the ions, so they dissolve.

*(b) Ion transport across cell membranes is a fundamental property of all living cells.

The diagram shows some typical ion concentrations in healthy human cells and in the extracellular fluid.

All values are in mmol dm^{-3} .



The tables show information about the human genome and types of transport channel in humans.

Some information about the human genome	
Number of genes in the human genome	approximately 20 000
Number of genes coding for membrane proteins	approximately 5 400
Number of genes coding for proteins involved in the transport of ions across cell membranes	more than 350
Number of diseases associated with mutations in genes involved in the transport of ions across cell membranes	more than 28
Organs and systems in which ion channel mutations cause disease	central nervous system, heart, lungs, pancreas and skeletal muscle

Type of transport channel	Number of each type of transport channel
Voltage gated ion channels	147
Chloride channels	17
Active transport	81

Discuss the importance of ion transport across membranes in human health and disease.

(9)

Ion transport is fundamental to health because cells keep very different ion concentrations inside and outside, e.g. Na^+ 15 mmol dm⁻³ inside most cells but 142 outside, and K^+ 125 inside but 5 outside. These gradients are maintained by active transport against the concentration gradient using ATP (sodium potassium pump), while ions also move passively by facilitated diffusion through specific channel proteins. Nerve conduction: in the unstimulated motor neurone the gradients give a resting potential. When voltage gated Na^+ channels open, Na^+ diffuses in, causing depolarisation and an action potential; voltage gated K^+ channels then open for repolarisation. There are 147 types of voltage gated channel, showing how important this is.



At the synapse, depolarisation opens Ca^{2+} channels in the presynaptic knob; Ca^{2+} diffuses in (2.5 outside but 1×10^{-4} inside) and causes release of neurotransmitter by exocytosis.

Muscle contraction: Ca^{2+} concentration rises in the contracting muscle cell (70×10^{-4} compared with 1×10^{-4} when relaxing). Ca^{2+} released from the sarcoplasmic reticulum binds to troponin, moving tropomyosin so myosin heads can bind to actin; Ca^{2+} is then actively pumped back for relaxation.

In glucose stimulated pancreatic β cells, the change in ion movements (Na^+ 142 , Ca^{2+} 70×10^{-4}) depolarises the cell and Ca^{2+} entry triggers insulin secretion, controlling blood glucose.

Ions moving down a gradient can also do work: H^+ ions diffusing through ATP synthase in chemiosmosis make ATP in mitochondria and chloroplasts, and Na^+ gradients drive cotransporters, e.g. glucose absorption in the ileum.

Disease: more than 350 genes code for ion transport proteins, so there are many genes that can mutate, and more than 28 diseases are caused by such mutations, affecting the CNS, heart, lungs, pancreas and skeletal muscle. For example in cystic fibrosis a mutation in the CFTR chloride channel (one of 17 chloride channels) means Cl^- is not transported out of alveolar epithelial cells, so water does not follow by osmosis and thick sticky mucus forms in the lungs and pancreas.

Channels are specific to particular ions and their opening is controlled (voltage or ligand gated), so a change in a channel's tertiary structure can cause disease.

(Total for Question 6 = 11 marks)



7 The scientific article you have studied is from *Scientific American*.

Use the information from the scientific article and your own knowledge to answer the following questions.

(a) Describe how 'eyes relay visual information' to the brain (paragraph 2).

(5)

Light is detected by rod cells in the retina: light breaks down rhodopsin into retinal and opsin.

Opsin causes Na^+ channels to close, so the rod cell membrane is hyperpolarised.

This stops the release of the inhibitory neurotransmitter glutamate onto the bipolar neurone.

So the bipolar neurone is depolarised and releases neurotransmitter, generating an action potential in a ganglion neurone.

The impulse is transmitted along the optic nerve to the visual cortex of the brain (occipital lobe).

(b) 'Most drugs cannot easily penetrate the brain' (paragraph 3).

Explain how the treatment of Parkinson's disease overcomes the difficulty of drugs passing from the blood into the brain.

(2)

Patients are given L-dopa, a precursor of dopamine, which can cross the blood-brain barrier (dopamine itself cannot).

In the brain L-dopa is converted into dopamine. Alternatively, MAO inhibitors that stop dopamine breakdown can cross.



- (c) 'Innate immunity initiates the inflammatory response, in which white blood cells swarm the site of infection' (paragraph 5).

Explain how white blood cells 'swarm' to accumulate at the site of inflammation.

(4)

Cells at the site of infection (e.g. mast cells) release chemicals such as histamine and cytokines.

These cause vasodilation of the arterioles, increasing blood flow to the site of inflammation.

They also increase the permeability of the capillaries.

So white blood cells (e.g. phagocytes) can migrate from the blood into the tissue space.

Cytokines attract more white blood cells to the site, so they accumulate.

- (d) The protein $\alpha 4 \beta 1$ integrin projects out from the cell surface membrane of white blood cells.

Deduce how molecules such as $\alpha 4 \beta 1$ integrin help immune cells cross the blood-brain barrier (paragraph 8).

(2)

The integrin binds to complementary receptor proteins on the surface of the capillary endothelial cells.

This holds the immune cell in place, stopping it moving with the blood, so it has time to squeeze between the endothelial cells into the brain.



(e) The immune system plays a role in recovery following spinal cord injuries.

Give **two** ethical arguments to support the use of rats and mice with spinal cord injuries in these experiments (paragraph 10).

(2)

1 *The benefits of the research outweigh any harm done to the animals, as spinal cord injuries are difficult to treat and have a serious impact on people's lives.*

2 *Experiments need to be carried out on animals with a well-developed CNS; experiments on tissues or invertebrates would not be sufficient.*

(f) 'The lymphatic vessels also ferry antigens—substances capable of inducing an immune response—from the tissues into tissue-draining lymph nodes, where they are presented to immune cells' (paragraph 15).

Describe how these antigens are presented to immune cells.

(3)

Phagocytes (macrophages) engulf the antigens and digest them.

The antigen is presented on the surface of the cell (with MHC proteins), so it becomes an antigen presenting cell (APC).

T lymphocytes with receptors (CD4 receptors) specific and complementary to that particular antigen bind to the APC.



- (g) 'A cytokine produced by immune cells in the meninges can change the activity of neurons, thereby altering the function of the circuit' (paragraph 20).

Cytokine has been found to affect neurotransmitter systems in the brain.

Explain how a cytokine could modify the activity of a neural circuit.

(4)

The cytokine can bind to receptors on the postsynaptic (synaptic) membrane.

This has an effect on an ion channel, e.g. opening chloride ion channels, so affecting the movement of ions across the membrane, e.g. Cl^- ions moving in or K^+ ions moving out.

This affects depolarisation of the membrane (e.g. hyperpolarisation, so threshold potential is not reached).

Therefore fewer (or more, if stimulatory) action potentials are generated in the neural circuit.

- (h) Compare and contrast the structure of a sensory neurone and a motor neurone (paragraph 21).

(4)

Similarities: both have a cell body containing a nucleus; both have an axon; both have dendrites at one end of the neurone and terminal branches at the other end.

Difference: the location of the cell body; in a motor neurone the cell body is at one end of the axon, whereas in a sensory neurone the cell body is located along the axon (part way between the dendron and axon).



- (i) Sight is a sense that develops during a critical period, 'providing a basis on which the brain can compute the activity needed for self-preservation.' (paragraph 22).

Describe what is meant by a critical period.

(2)

A period of time during early development when the nervous system must obtain specific experiences (e.g. the retina must be exposed to light) to develop properly.

During it, stimulated synapses are strengthened and unstimulated synapses are removed.

- (j) It has been suggested that there is a critical period for the development of the hard wiring of the immune response into the brain (paragraphs 22 and 23).

Explain how this critical period could be investigated using animal experiments.

(2)

Immunise or infect groups of animals (e.g. mice) at different times during early development, or compare animals with intact and deficient immune systems.

Investigate the animals later in life for effects on learning or the development of neurological conditions.



(k) Describe how bacteria can be genetically modified to produce a cytokine for the treatment of neurological and mental disorders (paragraph 24).

(4)

Isolate the gene for the cytokine from human DNA (or make it from mRNA using reverse transcriptase).

Use a bacterial plasmid as a vector.

Cut the human DNA and the plasmid using the same restriction enzyme, producing complementary sticky ends.

Splice the gene and plasmid together using DNA ligase to form recombinant DNA.

Put the modified plasmids into bacterial cells, e.g. using heat shock, and grow lots of bacteria expressing the cytokine gene in a fermenter, then extract the cytokine.



- (l) An immune system that interacts adversely with the CNS might be described as 'flawed' (paragraph 24).

Explain why a bone marrow transplant can be used to replace a flawed immune system.

(3)

Bone marrow is provided by a healthy donor (after the patient's own bone marrow is destroyed).

Bone marrow contains stem cells.

These stem cells can divide and differentiate into all types of white blood cells, e.g. lymphocytes (T cells and B cells), so a new immune system is produced.

(Total for Question 7 = 37 marks)

TOTAL FOR PAPER = 100 MARKS



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