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Biology A (Salters-Nuffield)

Advanced

Unit 3: General and Practical Applications in Biology

Monday 26 June 2017 – Morning

Time: 2 hours

Paper Reference

9BN0/03

Candidates must have:

Calculator, HB pencil, ruler and a copy of the scientific article adapted from *The Energy of Life* (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.*
- 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.

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.*

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.

Turn over ►

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Answer ALL questions.

Write your answers in the spaces provided.

1 Plant fibres and oil-based plastics have both been used to make ropes.

(a) Describe one advantage and one disadvantage of using ropes made from plant fibres rather than ropes made from oil-based plastics.

(2)

Advantage: ropes made from plant fibres are biodegradable, so they decompose, and they come from a renewable, sustainable source as more plants can be grown.

Disadvantage: plant fibre ropes are less strong (lower tensile strength) than oil-based plastic ropes of the same diameter.

(b) Ropes used in climbing need to have high tensile strength.

State what is meant by the term **tensile strength**.

(1)

The maximum (pulling) force that a rope or fibre can withstand before it breaks.

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- (c) Climbing ropes can be made from manila (a plant fibre) or nylon (an oil-based plastic). Various factors affect the tensile strength of these ropes, including diameter and storage conditions.

The table shows the effect of rope diameter on tensile strength.

Diameter of rope / mm	Tensile strength / kN	
	Manila rope	Nylon rope
6	2.4	7.5
8	4.2	12.1
10	5.7	16.3
12	10.6	28.4

It is claimed that the ideal storage conditions for rope are 18 °C and 60% relative humidity.

Devise a valid investigation to determine the effect of storage temperature on the tensile strength of manila rope and nylon rope.

(4)

Cut pieces of manila rope and of nylon rope that are all the same length and the same diameter (e.g. 10 mm).

Store the pieces at a range of temperatures above and below 18 °C, e.g. 0, 6, 12, 18, 24 and 30 °C, using fridges and incubators.

Keep the relative humidity at 60% for every temperature and store all the ropes for the same period of time, e.g. 4 weeks.

Clamp each rope vertically and add masses (increase the force) until the rope breaks; record the force at breaking as the tensile strength in kN.

Calculate the change in tensile strength compared with unstored rope. Repeat with 3 pieces at each temperature, calculate a mean and compare manila with nylon.



(d) Tissues that contain lignin provide strength to plant fibres.

Describe the positions in the stem of those tissues that contain lignin.

(2)

Sclerenchyma fibres are found on the outer side of each vascular bundle, outside the phloem.

Xylem vessels are on the inner side of the vascular bundle, towards the centre of the stem. The vascular bundles form a ring near the outside of the stem.

(Total for Question 1 = 9 marks)

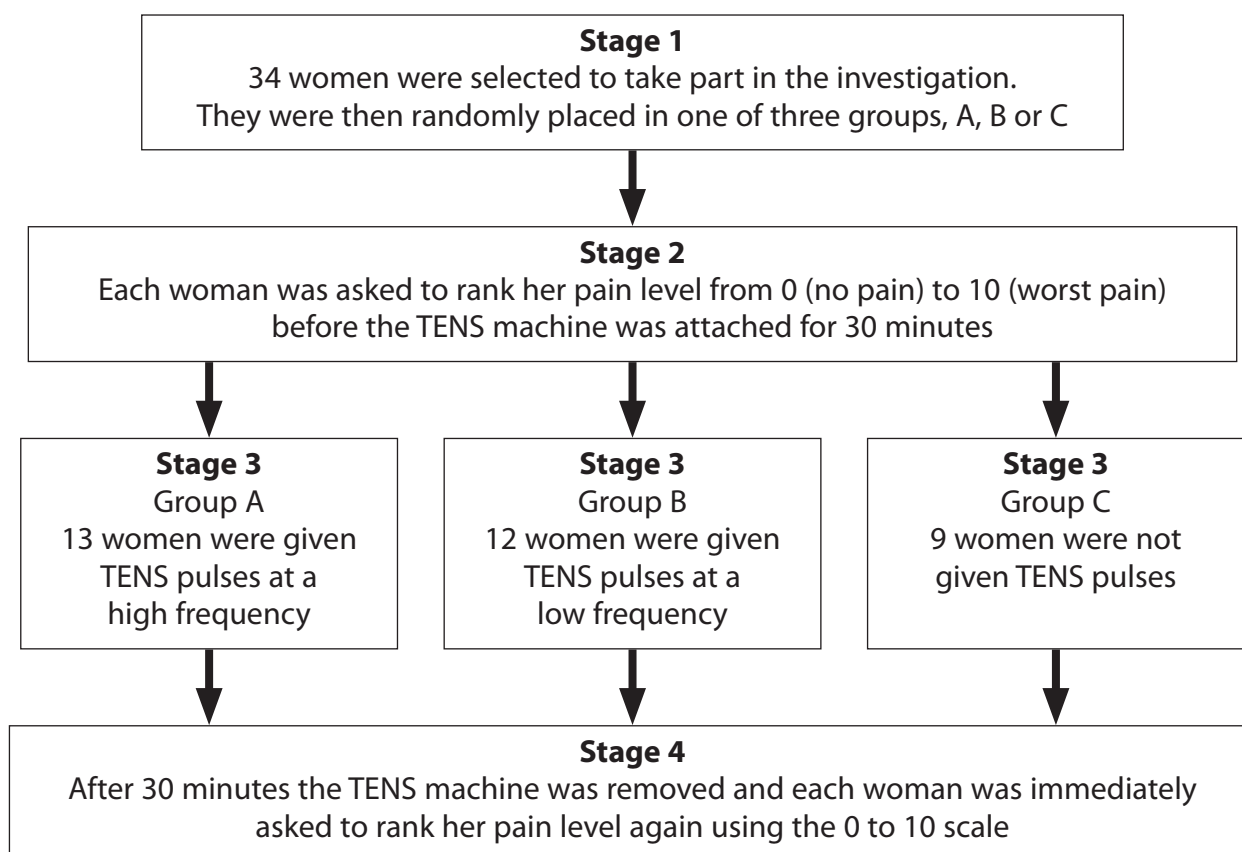


- 2 Some women need to have surgery to aid childbirth. This can lead to pain after surgery.

A TENS (transcutaneous electrical nerve stimulation) machine releases regular pulses of electricity onto the skin surface and can be used in pain relief.

An investigation was carried out to study whether the frequency of the pulses from a TENS machine could help these women with their pain relief.

The diagram shows how the investigation was carried out.



- (a) Describe how the 34 women were selected in stage 1 to ensure that this investigation was valid.

(2)

All the women selected must have required surgical intervention when they gave birth and need pain relief after surgery.

The condition of the mothers must be similar, e.g. same age range, same number of previous babies, same gestation period and no pre-existing pain medication.



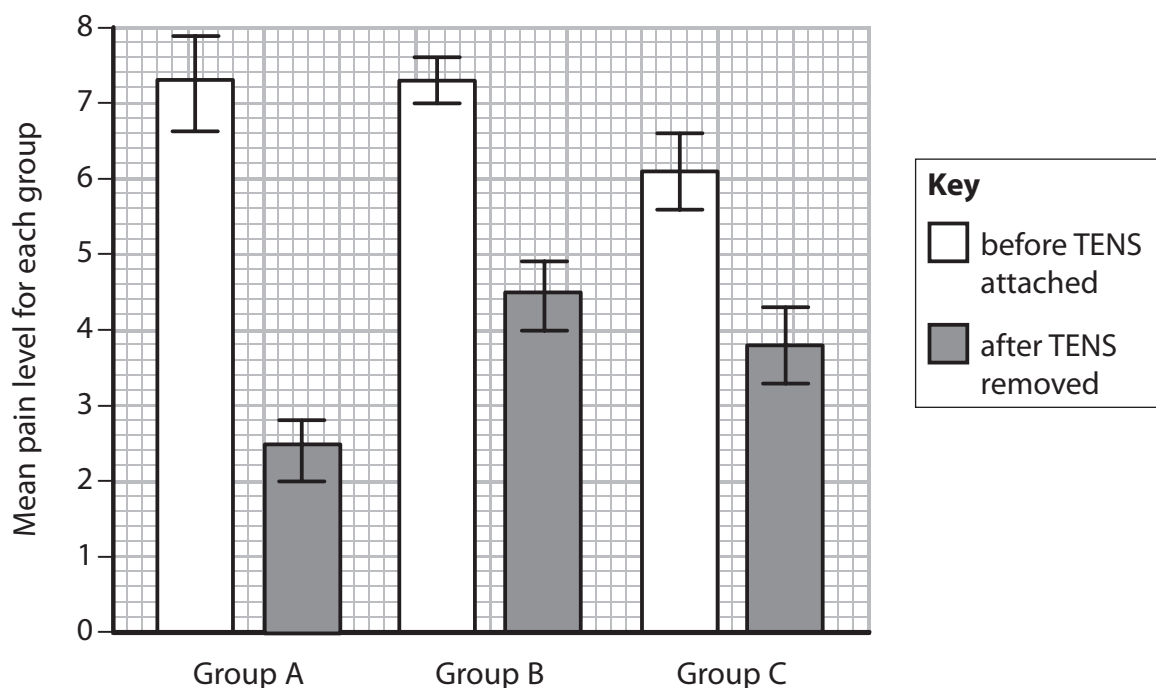
(b) Explain why group C was included in this investigation.

(2)

Group C is a control (placebo): the TENS machine is attached but no pulses are given.

This allows a comparison with groups A and B, to show that any reduction in pain is due to the TENS pulses and not just to the machine being attached or time passing.

(c) The results and range of data for the investigation are shown in the graph.



Determine the effectiveness of the use of a TENS machine in relieving pain following surgery.

(4)

TENS does provide pain relief, as the mean pain level fell after TENS in groups A and B.

High frequency TENS is the most effective, more effective than low frequency.

Group A had the largest reduction, from 7.3 to 2.5, a fall of 4.8 (65.8%), compared with only 2.8 (38.4%) for group B and 2.3 (37.7%) for group C.

However the range bars for low frequency TENS (B) overlap with those of the control with no pulses (C), so low frequency TENS may be no better than a placebo.

- (d) This investigation used only one 30-minute session of TENS pulses. This was done to reduce the risk of habituation.

Describe the process that occurs at a synapse that leads to habituation.

(4)

With a repeated stimulus the presynaptic membrane becomes less sensitive (less permeable): calcium channels become less responsive and do not open.

So fewer Ca^{2+} ions move into the presynaptic neurone.

So fewer vesicles move towards and fuse with the presynaptic membrane.

So less neurotransmitter is released to diffuse across the gap and bind to receptors on the postsynaptic membrane.

So depolarisation is less likely and an action potential is less likely to occur in the postsynaptic neurone.

(Total for Question 2 = 12 marks)



3 Studies have provided evidence for a link between heart rate when a person is at rest and various medical conditions.

- (a) In one study, the relationships between resting heart rate and the percentage incidence of coronary heart disease and cancer were investigated.

The results are shown in the table.

Range of resting heart rate / beats per min	Number of individuals in each range	Percentage incidence of condition (%)	
		Coronary heart disease	Cancer
< 59	961	4.2	1.0
60–69	2277	6.0	1.5
70–79	2120	7.5	2.0
80–89	1202	8.0	2.5
90–99	576	8.2	4.0
> 99	379	7.9	3.8

- (i) Comment on the evidence for a link between resting heart rate and the percentage incidence of coronary heart disease and cancer.

(5)

As resting heart rate increases, the percentage incidence of both coronary heart disease (CHD) and cancer increases: a positive correlation.

CHD incidence rises from 4.2% below 59 bpm to 8.2% at 90 to 99 bpm, a 1.95 times increase.

Cancer incidence rises from 1.0% to 4.0% at 90 to 99 bpm, a 4.0 times increase, so there is a greater increase in incidence of cancer than CHD with increased heart rate.

Above 99 bpm the incidence of both conditions falls slightly (7.9% and 3.8%), so they plateau with little difference.

This only shows a correlation, not causation; other factors such as age, smoking or BMI could affect both, and no statistical test shows the differences are significant.



- (ii) Give two reasons why there were different numbers of people in each resting heart rate group.

(2)

Heart rate is normally distributed in the population, so mid heart rates (60 to 79 bpm) are more common and high and low heart rates are less common.

Fewer people are available at very low and very high heart rates because of other health risks.

- (iii) Give two reasons why the number of people in each resting heart rate group did not affect the validity of this investigation.

(2)

Each group was still a large sample size (at least 379 people), so the results are statistically reliable.

Percentage incidence was used rather than the number of cases, so groups of different sizes can be compared; a wide range of heart rates was also considered.

- (b) Cancer can be due to body cells continuing to undergo mitosis and cell division. Prophase is one stage of mitosis.

Describe the events that occur during prophase in an animal cell.

(3)

The chromosomes (chromatids) condense, becoming shorter and thicker so they become visible.

The centrioles migrate to opposite poles of the cell and spindle fibres are formed.

The nucleolus and the nuclear envelope break down.

(Total for Question 3 = 12 marks)



- 4 A student investigated the effect of salt concentration on the growth of one species of brine shrimp.

The student placed 100 shrimp eggs in a beaker containing 1dm³ of 3% salt solution. Three days after the eggs hatched, 10 shrimps were collected and their lengths measured. Seven days after hatching, another 10 shrimps were collected and their lengths measured.

The procedure was repeated using a 5% salt solution. All other variables were kept constant.

The results are shown in the table.

Specimen number	Length of specimen in 3% salt solution / mm		Length of specimen in 5% salt solution / mm	
	3 days after hatching	7 days after hatching	3 days after hatching	7 days after hatching
1	0.75	1.00	0.75	0.98
2	0.78	1.25	0.73	0.95
3	0.66	1.10	0.61	0.93
4	0.73	1.03	0.63	0.83
5	0.85	1.15	0.53	0.98
6	0.78	1.08	0.60	1.08
7	0.90	1.13	0.52	0.95
8	0.90	1.05	0.81	1.03
9	0.80	1.18	0.58	0.88
10	0.85	1.05	0.68	0.88
Mean	0.800	1.102	0.644	0.949

- (a) (i) Calculate the mean length of shrimp three days after hatching in the 5% salt solution. Give your answer to an appropriate number of significant figures.

(1)

$$0.75 + 0.73 + 0.61 + 0.63 + 0.53 + 0.60 + 0.52 + 0.81 + 0.58 + 0.68 = 6.44$$

$$6.44 \div 10 = 0.644$$

Answer 0.644 mm



- (ii) Explain how these data can be used to show the effect of salt concentration on the rate of growth of brine shrimps.

(2)

Calculate the rate of growth by dividing the change in mean length between day 3 and day 7 by the time, 4 days (rate = change in mean length ÷ time).

Compare the rates for 3% and 5%: 3%: $(1.102 - 0.800) \div 4 = 0.0755$ mm per day;

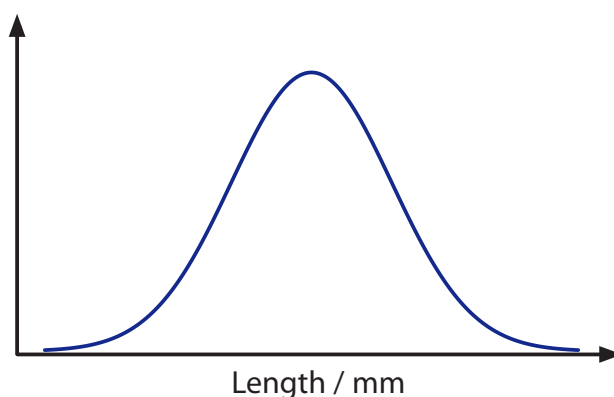
5%: $(0.949 - 0.644) \div 4 = 0.0763$ mm per day, so the shrimps grow slightly faster in 5% salt solution.

- (b) The student carried out a statistical test to see if there was a significant difference between the mean lengths of brine shrimps in these two salt solutions. The student used the 7 days after hatching data.

The student selected the *t*-test because the data are normally distributed.

- (i) Draw a line on the graph to show a normal distribution for a population of brine shrimp.

(1)



- (ii) Complete the table by filling in the missing value for specimen 7 and then calculate the value for Σx_1^2 .

(1)

Specimen number (n)	3% salt solution		5% salt solution	
	Length of specimen (x_1)	Square of length of specimen (x_1^2)	Length of specimen (x_2)	Square of length of specimen (x_2^2)
1	1.00	1.000	0.98	0.960
2	1.25	1.563	0.95	0.903
3	1.10	1.210	0.93	0.865
4	1.03	1.061	0.83	0.689
5	1.15	1.323	0.98	0.960
6	1.08	1.166	1.08	1.166
7	1.13	1.277	0.95	0.903
8	1.05	1.103	1.03	1.061
9	1.18	1.392	0.88	0.774
10	1.05	1.103	0.88	0.774
Sum (Σ)	$\Sigma x_1 = 11.020$	$\Sigma x_1^2 = 12.198$	$\Sigma x_2 = 9.490$	$\Sigma x_2^2 = 9.055$
Mean	$\bar{x}_1 = 1.102$		$\bar{x}_2 = 0.949$	

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(iii) The variances are used in the calculation of a t -value.

The variance for the 3% salt solution $S_1^2 = 0.0059$.

Calculate the variance for the 5% salt solution (S_2^2) using the formula

$$S_2^2 = \frac{\sum x_2^2 - \frac{(\sum x_2)^2}{n}}{n - 1}$$

n = the number of specimens

(2)

$$S_2^2 = (9.055 - 9.490^2 \div 10) \div (10 - 1)$$

$$= (9.055 - 9.006) \div 9$$

$$= 0.049 \div 9 = 0.00544$$

$$S_2^2 = 0.0054$$

(iv) Calculate the t -value using the formula.

Give your answer to an appropriate number of significant figures.

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

(3)

$$t = (1.102 - 0.949) \div \sqrt{(0.0059 \div 10 + 0.0054 \div 10)}$$

$$= 0.153 \div \sqrt{0.00113}$$

$$= 0.153 \div 0.0336$$

$$= 4.55$$

$$t = 4.55$$



- (v) The calculated t -value is greater than the critical value at $p = 0.05$.

Describe what this result indicates about the effect of salt concentration on the length of brine shrimp.

(2)

There is a significant difference between the mean lengths of the shrimps in the 3% and the 5% salt solution, so salt concentration does affect length (shrimps are longer in 3%).

This is at the 5% significance level: there is less than a 5% probability that the difference is due to chance, so the null hypothesis is rejected.

(Total for Question 4 = 12 marks)



- 5 The pigment content of mountain plants can be affected by various environmental factors. These factors include altitude (height up a mountain), exposure to ultraviolet radiation (UV-B) and temperature.

These pigments include chlorophyll, found in chloroplasts, and flavonoids that are found in sap vacuoles.

Flavonoids can protect plants from ultraviolet radiation (UV-B) that can damage DNA.

- (a) State the location of chlorophyll in a chloroplast.

(1)

In the thylakoid membranes (grana) of the chloroplast.

- (b) The altitude at which a plant grows on a mountain affects its flavonoid content.

Devise a procedure to show that an increase in altitude increases the flavonoid content of one species of plant found growing on a mountain.

(5)

Choose a range of different altitudes (heights) on the mountain, e.g. every 100 m from the base to the top, measured with an altimeter.

At each altitude collect several plants of the one species for each sample, e.g. 5 plants chosen at random using random coordinates.

Standardise the plant material analysed: the same part of the plant (e.g. youngest fully grown leaves) and the same mass, e.g. 1.0 g.

Take other abiotic factors into account: sample on the same day and record humidity, wind speed, soil moisture and soil pH.

Extract the pigment by grinding the leaves with sand and a solvent (e.g. ethanol), then filter.

Measure the flavonoid content with a colorimeter (absorbance) using a calibration curve, calculate a mean at each altitude and use Spearman's rank to test for a significant positive correlation.



- (c) Scientists have investigated the effect of UV-B on both chlorophyll and flavonoid content.

A group of plants was exposed to UV-B for 20 minutes per day for one month. The chlorophyll and flavonoid content of each plant were then determined and the means calculated.

This was repeated for three more groups of plants. Each group was exposed to UV-B for different lengths of time. All other variables were kept constant.

The results are shown in the table.

Length of time exposed to UV-B / minutes	Mean chlorophyll content / arbitrary units	Mean flavonoid content / arbitrary units
0	32	25
20	30	24
40	27	39
60	24	40

- (i) Compare and contrast the effect of length of exposure to UV-B on the chlorophyll and flavonoid content of these plants.

(3)

Similarity: exposure to UV-B for 20 minutes decreases both the mean chlorophyll content (32 to 30) and the mean flavonoid content (25 to 24).

Difference: exposure for longer than 20 minutes causes chlorophyll content to keep decreasing (to 24) but flavonoid content to increase (to 40).

There is a greater change in flavonoid content (an increase of 15 a.u., 60%) than in chlorophyll content (a decrease of 8 a.u., 25%).



- (ii) As altitude increases on a mountain, the temperature decreases and the UV-B radiation increases.

Scientists have found that a rise in temperature decreases flavonoid gene expression in plants.

Analyse the data to discuss why altitude can affect plant growth.

(5)

At higher altitude there is more UV-B and a lower temperature, so there is greater expression of the flavonoid gene and more flavonoids are synthesised (flavonoid rises from 25 to 40 a.u. with more UV-B).

Flavonoids absorb UV-B, so DNA is protected from UV-B.

This reduces the risk of mutations, so cells divide normally and there is more growth.

However more UV-B also gives reduced chlorophyll (32 to 24 a.u.), so less light is absorbed, so there is reduced photosynthesis and less growth.

The lower temperature at high altitude also causes reduced enzyme activity (e.g. rubisco), so less glucose is made and there is less growth.

So growth at altitude depends on the balance between protection by flavonoids and reduced photosynthesis.

(Total for Question 5 = 14 marks)



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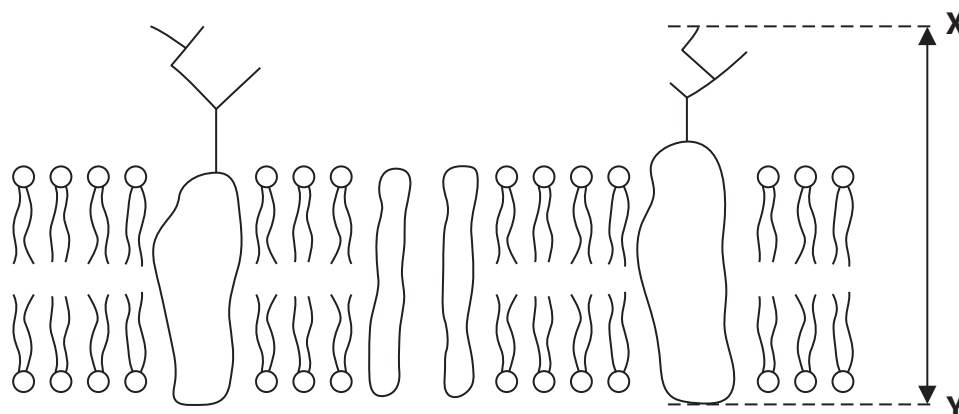
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- 6 The structure of the cell surface membrane can be explained using the fluid mosaic model.

This model suggests that there are a variety of different proteins and glycoproteins present in a phospholipid bilayer.

- (a) The drawing shows the cell surface membrane of a liver cell. The drawing has a magnification of 5×10^6 .



Calculate the actual length of the glycoprotein between points **X** and **Y**.
Give your answer with an appropriate unit.

(2)

length X to Y on drawing = 50 mm

actual length = 50 mm $\div$ 5 000 000

= 0.00001 mm = 10 nm

Answer *10 nm*.....



*(b) The ratio of lipid to protein in a cell surface membrane is approximately 1:1.

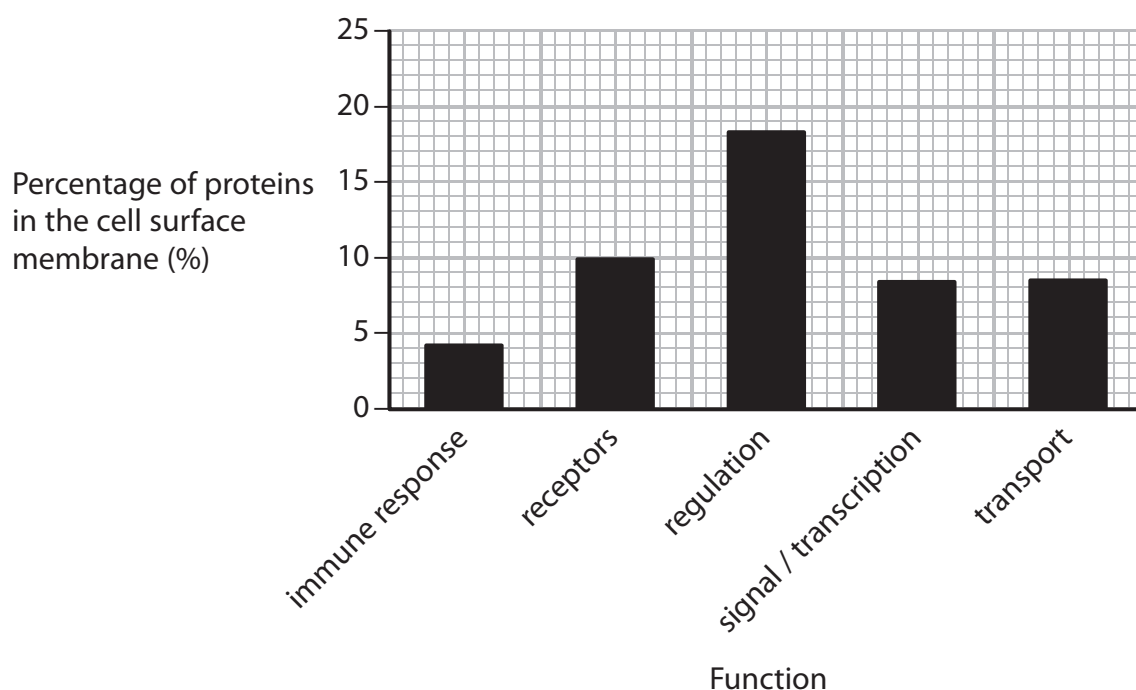
Scientists have studied the proteins present within human cells. Proteins in a cell are found in several locations.

The table shows the percentage of protein found in some locations in a cell.

Location within a cell	Percentage of total protein present (%)
cell surface membrane	68.2
cytoplasm	1.4
endoplasmic reticulum / Golgi apparatus	1.4
nucleus	14.5
other	14.5

The proteins within the cell surface membrane were further analysed for their function.

The graph shows some of the results of this analysis.



Analyse the data to evaluate the following statement.

'The variety of different proteins present in the cell surface membrane makes them more important than the phospholipid bilayer to the functioning of that cell.'

(9)

Most protein in the cell (68.2%) is in the cell surface membrane, far more than in the nucleus (14.5%) or cytoplasm (1.4%). With a lipid to protein ratio of 1:1 the quantities are the same, but the proteins have far more functions: regulation about 18%, receptors 10%, signal/transcription and transport about 8% each, immune response 4%.

Transport proteins include channel proteins for facilitated diffusion, voltage-gated Na^+ and K^+ channels for the nerve impulse, and carriers for active transport such as the Na^+/K^+ pump that maintains the resting potential. Receptors bind neurotransmitters or hormones such as insulin to regulate glucose uptake; sperm receptors trigger the acrosome reaction. Signal proteins activate second messengers and transcription factors. Antigens and MHC proteins allow body defence.

However the phospholipid bilayer is essential too: its hydrophobic core stops polar substances crossing and separates the aqueous cytoplasm from the aqueous surroundings, yet gases such as O_2 diffuse directly across. It gives the membrane fluidity and structure that holds the proteins, and forms the myelin sheath for nerve impulses.

The graph shows only about half the proteins, so not all functions are known.

Judgement: the variety of proteins gives the membrane its specific functions, but they could not work without the bilayer, so both are important and the statement is only partly true.

(Total for Question 6 = 11 marks)



7 The scientific article you have studied is adapted from an article from 'The Scientist'.

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

- (a) Explain why the 'anaerobic oxidation of methane' could be a 'key climate regulator' (paragraph 2).

(3)

Methane is a greenhouse gas: greenhouse gases absorb and trap infrared (heat) energy radiated from the Earth.

The anaerobic oxidation of methane by microbes breaks down methane, so less methane reaches the atmosphere.

This could reduce the greenhouse effect, so less heat is trapped and global warming is reduced.

- (b) Give reasons why 'humble microbes', such as bacteria, are considered less complex than eukaryotes (paragraph 4).

(2)

Bacteria are only one cell, as opposed to the many cells of most eukaryotes.

They have no nucleus (DNA not associated with histones) and no membrane-bound organelles such as mitochondria.



(c) State what is meant by the phrase 'fix carbon into biomass' (paragraph 4).

(2)

To transfer carbon from an inorganic source (CO_2) into organic compounds such as glucose, cellulose or protein.

These organic compounds then become part of the mass (biomass) of that organism.

(d) Humans have a 'requirement for oxygen' (paragraph 5).

Explain the role of oxygen in human respiration.

(4)

Oxygen is the final acceptor of electrons (and H^+) at the end of the electron transport chain, forming water.

This keeps electrons flowing along the chain so that oxidative phosphorylation can take place.

Energy from the electrons is used to pump H^+ , so ATP is synthesised by ATP synthase.

The presence of oxygen allows oxidation of reduced NAD (and reduced FAD), so NAD is regenerated for the link reaction and Krebs cycle to continue.



- (e) Explain how the unfolding of the enzymes in *E. coli* makes them 'become ineffective at 60 °C' (paragraph 12).

(3)

At 60 °C the hydrogen bonds and ionic bonds holding the enzyme in shape vibrate and break, so the enzyme unfolds.

This changes the tertiary structure (3D shape), so the enzyme is denatured and the shape of the active site changes.

The substrate is no longer complementary and cannot bind to the active site, so no enzyme-substrate complexes form.

- (f) State what is meant by the genome of a thermophile (paragraph 14).

(1)

All the DNA (exons and introns) of the thermophile organism.



(g) Explain how cyanobacteria evolved to 'handle high temperatures' (paragraphs 14 and 15).
(5)

As a result of a random mutation, a new advantageous allele arose.

Cyanobacteria with this allele produce proteins containing the amino acid cysteine in strategic positions, which form disulfide bridges.

These cysteine-rich proteins are heat-stable enzymes that are resistant to unfolding.

Other adaptations include enzymes with larger hydrophobic cores, simpler protein folds and fewer amino acids that bond to metal ions.

High temperatures act as a selection pressure: bacteria with these alleles survive and replicate, passing the advantageous allele to the next generation, so its frequency increases over many generations.



- (h) Describe the structure of the 'protein-synthesis machinery' in bacteria (paragraph 20).
(2)

The 70S ribosome, made of a larger and a smaller subunit.

Each subunit contains rRNA and protein.

- (i) Explain how the production of antibiotics by *Streptomyces* species can reduce interspecific competition (paragraph 20).
(3)

The antibiotics reduce the number of other species of bacteria in the soil.

Antibiotics that attack cell walls cause lysis, so are bactericidal; antibiotics that attack protein synthesis machinery (ribosomes) prevent growth, so are bacteriostatic.

This reduces interspecific competition from other bacteria for limited resources such as organic molecules.

- (j) Pyruvate is one of the products of glycolysis (paragraph 20).

State one difference between the structure of pyruvate and the structure of the acetyl group in acetyl CoA.

(1)

Pyruvate has 3 carbons, whereas the acetyl group has 2 carbons.



(k) *Bacillus subtilis* 'initiate a hibernation protocol' (paragraph 25).

Mycobacterium tuberculosis can also become dormant for long periods of time.

Compare and contrast the dormancy of these two species of bacteria.

(4)

Similarities: both enter dormancy to avoid adverse environmental conditions, both reduce metabolic activity and both form a resistant outer coating (capsule).

Differences: B. subtilis carries out sporulation whereas M. tuberculosis has no sporulation.

They have different reasons for entering dormancy: M. tuberculosis to avoid the host immune response, B. subtilis to survive a lack of resources (nutrients).

In B. subtilis only the genetic material is in a protective capsule (the spore).

(Total for Question 7 = 30 marks)

TOTAL FOR PAPER = 100 MARKS



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