S4 Biology Practice Paper: cell structure and microscope magnification, enzyme rates and Q10, competitive inhibition, diffusion, osmosis and water potential, photosynthesis and limiting factors, respiration and RQ, DNA base pairing, mitosis and meiosis, Mendelian genetics, energy flow and population estimates (100 marks)

Level: S4 | Subject: Biology | 75 minutes | 100 marks | 24 questions | answer key

Section A: Cells, Microscopes and Magnification (18 marks)

Answer all questions and show your working, units and significant figures.

#	Question	Answer	Marks
1	An eyepiece of x10 and an objective of x40 are used. A cell measures 8.0 mm on the photograph. (a) Find the total magnification. (b) Find the actual length of the cell in mm and in um. (c) If the field of view is 1.8 mm across, how many such cells fit across it?	(a) Total magnification = 10 x 40 = 400 times. (b) Actual length = 8.0 mm / 400 = 0.020 mm = 20.0 um. (c) Number of cells = 1.8 mm / 0.020 mm = 90 cells.	5
2	State one main function of each of the following cell structures: (a) chloroplast (b) mitochondrion (c) ribosome (d) cell wall.	(a) The chloroplast carries out photosynthesis, converting light energy into chemical energy in glucose. (b) The mitochondrion carries out aerobic respiration and releases energy to make ATP. (c) The ribosome is the site of protein synthesis. (d) The cell wall gives support, keeps the cell shape and prevents bursting by excess water uptake (cellulose in plant cells).	4
3	A light microscope has a resolution of 200 nm and an electron microscope 0.2 nm. (a) How many times better is the resolution of the electron microscope? (b) Can a ribosome 20 nm across be clearly resolved with a light microscope? Explain. (c) Why must specimens for the electron microscope be dead?	(a) Ratio = 200 nm / 0.2 nm = 1000 times. (b) No. 20 nm is smaller than the 200 nm resolution limit of a light microscope, so two nearby points cannot be separated and only a blurred image is seen. (c) The electron beam must travel in a high vacuum, so the water in a living specimen would evaporate and the cells would die; the specimen must be fixed, dehydrated and often stained with heavy metals.	5
4	Two cube-shaped cells have sides of 10 um and 30 um. (a) Find the surface area to volume ratio of each in per um. (b) Find the ratio of the two values. (c) Why is exchange of substances more efficient in the smaller cell?	(a) For a cube of side a, SA/V = 6a2 / a3 = 6/a, so the 10 um cell gives 0.6 per um and the 30 um cell gives 0.2 per um. (b) Ratio = 0.6 / 0.2 = 3.0. (c) The small cell has more surface area per unit volume and shorter diffusion distances, so substances enter and leave fast enough for its metabolic needs.	4

Section B: Enzymes and Metabolism (17 marks)

Answer all questions and show your working, units and significant figures.

#	Question	Answer	Marks

5	An experiment measures the gas released by an enzyme reaction: 0 min 0 cm3, 1 min 5.0 cm3, 2 min 14.0 cm3, 4 min 25.0 cm3. (a) Find the mean rate over the first 2 minutes. (b) Find the mean rate from 2 to 4 minutes and explain why it is lower. (c) How would you determine the maximum rate Vmax?	(a) Rate = 14.0 cm3 / 2.0 min = 7.0 cm3/min. (b) Rate = (25.0 - 14.0) / 2.0 = 5.5 cm3/min; the substrate is being used up so its concentration falls and fewer active sites are occupied, so the rate drops. (c) Increase the substrate concentration step by step until the rate stops rising (a plateau); that plateau rate is Vmax.	4
6	The rate of an enzyme reaction is 2.4 at 20 C, 4.8 at 30 C, 5.8 at 40 C and 0.2 cm3/min at 60 C. (a) Find Q10 from 20 C to 30 C. (b) Find Q10 from 30 C to 40 C. (c) Explain why the rate is almost zero at 60 C.	(a) Q10 = 4.8 / 2.4 = 2.0. (b) Q10 = 5.8 / 4.8 = 1.21, below 2 because heat is already damaging the enzyme. (c) 60 C is above the optimum, so the peptide chains and the three-dimensional shape are destroyed (denaturation); the active site changes shape, substrate cannot bind, the reaction nearly stops and denaturation is irreversible.	5
7	Pepsin has an optimum pH of about 2 and trypsin about 8. (a) Which one acts in the stomach? (b) Which one acts in the small intestine? (c) What happens to both at pH 4? (d) Why does extreme pH destroy an enzyme permanently?	(a) Pepsin, whose optimum pH of 2 matches the strongly acidic stomach. (b) Trypsin, because the small intestine is near neutral to slightly alkaline. (c) At pH 4 pepsin activity has already fallen a lot and trypsin activity is also low, since both are away from their optimum. (d) Excess acid or alkali breaks hydrogen and ionic bonds, changing the three-dimensional shape; the active site is permanently distorted and the denaturation is irreversible.	4
8	A control reaction runs at 6.0 cm3/min and falls to 3.0 cm3/min after an inhibitor is added. (a) Find the percentage inhibition. (b) The rate returns to 5.8 cm3/min when much more substrate is added; which type of inhibition is this? Explain. (c) If the rate stayed at 3.0 cm3/min after adding substrate, which type would it be?	(a) Inhibition = (6.0 - 3.0) / 6.0 x 100% = 50.0%. (b) Competitive inhibition: the inhibitor competes with the substrate for the active site, so raising the substrate concentration displaces it and the rate recovers (reversible). (c) Non-competitive inhibition: the inhibitor binds away from the active site and changes its shape, so extra substrate cannot restore the rate.	4

Section C: Diffusion, Osmosis and Water Potential (17 marks)

Answer all questions and show your working, units and significant figures.

#	Question	Answer	Marks
9	A plant cell has a solute potential of -800 kPa and a pressure potential of +300 kPa. (a) Find its water potential. (b) If the cell is placed in a solution of water potential -500 kPa, is there any net movement of water? (c) If it is placed in a solution of -300 kPa, in which direction does water move net? Explain.	(a) Water potential = -800 + 300 = -500 kPa. (b) No net movement, because both the cell and the solution are at -500 kPa, so they are in equilibrium. (c) The solution at -300 kPa has a higher water potential than the cell at -500 kPa, so water moves from the solution into the cell and the pressure potential rises.	4
10	Potato strips of initial mass 4.00 g are kept in sucrose solutions for 30 minutes: 0.0 M gives 4.36 g, 0.2 M gives 4.08 g and 0.4 M gives 3.60 g. (a) Find the percentage change in mass for each. (b) By interpolation between the 0.2 M and 0.4 M results, estimate the isotonic concentration at which there is no change in mass.	(a) 0.0 M: +9.0%; 0.2 M: +2.0%; 0.4 M: -10.0%. (b) Between +2.0% and -10.0%, the zero point is 0.2 + 0.2 x [2.0 / (2.0 + 10.0)] = 0.23 M, about 0.23 M.	5

11	A dye diffuses 2.0 mm through agar in 30 minutes. Assuming the time taken is proportional to the square of the distance, find the time needed to diffuse 4.0 cm, in hours, and explain why diffusion alone cannot support large organisms.	Time is proportional to distance squared, so t = 30 min x (40 mm / 2.0 mm)^2 = 12000 min = 200 hours. In a large organism, diffusion alone would take far too long (here 200 hours for just 4 cm), much slower than metabolic needs, so a circulatory and respiratory system is needed.	4
12	(a) What happens to red blood cells placed in distilled water? Explain. (b) What happens in 0.9% sodium chloride solution? (c) Why is 0.9% sodium chloride, rather than pure water, used for intravenous infusion?	(a) Distilled water has the highest water potential (about 0), so water floods into the cells, which swell and burst (haemolysis). (b) 0.9% sodium chloride is isotonic with plasma, so there is no net water movement and the cells keep their normal shape. (c) Pure water would cause haemolysis, dilute the plasma and upset electrolyte balance, which is life threatening; the 0.9%% solution is isotonic and keeps cell volume and osmotic balance.	4

Section D: Photosynthesis and Respiration (16 marks)

Answer all questions and show your working, units and significant figures.

#	Question	Answer	Marks
13	Photosynthesis: 6CO2 + 6H2O -> C6H12O6 + 6O2 (Mr: CO2 = 44.0, O2 = 32.0, C6H12O6 = 180.0). (a) How many moles of CO2 are needed to make 1.8 g of glucose? (b) What mass of CO2 is that? (c) What mass of oxygen is released at the same time?	(a) n(glucose) = 1.8 / 180.0 = 0.010 mol and the ratio is 6 : 1, so n(CO2) = 0.060 mol. (b) m(CO2) = 0.060 x 44.0 = 2.64 g. (c) n(O2) = 0.060 mol, so m(O2) = 0.060 x 32.0 = 1.92 g.	4
14	An aquatic plant releases oxygen bubbles per minute of 0 (dark), 3.0, 6.0, 6.0 and 6.2 at light intensities 0, 10, 20, 30 and 40 units. (a) At which light intensity is light saturation reached? (b) Which factor becomes limiting after saturation? (c) How would you show experimentally that this factor is carbon dioxide?	(a) At 20 units, since the rate then stays near 6.0 and no longer rises with light. (b) Carbon dioxide concentration (or temperature) becomes limiting. (c) Keep the light intensity fixed and add sodium hydrogencarbonate to raise CO2; if the bubble rate rises, CO2 was limiting. A control with the same volume of distilled water is used.	4
15	Yeast ferments glucose anaerobically: C6H12O6 -> 2C2H5OH + 2CO2 (Mr: glucose 180.0, ethanol 46.0; molar volume at room temperature 24.0 dm3/mol). (a) How many moles of CO2 come from 5.4 g of glucose? (b) What volume of CO2 is that at room temperature? (c) What mass of ethanol is formed?	(a) n(glucose) = 5.4 / 180.0 = 0.030 mol and the ratio is 1 : 2, so n(CO2) = 0.060 mol. (b) V = 0.060 x 24.0 = 1.44 dm3. (c) n(ethanol) = 0.060 mol, so m = 0.060 x 46.0 = 2.76 g.	4
16	An animal uses 200 cm3 of oxygen and releases 160 cm3 of carbon dioxide in one hour. (a) Find its respiratory quotient. (b) What does the RQ suggest about its diet? (c) Why is the RQ of fat lower than that of carbohydrate?	(a) RQ = CO2 released / O2 used = 160 / 200 = %s. (b) Carbohydrate has RQ 1.0 and fat about 0.7; 0.8 lies between them, so the diet is a mixture of carbohydrate and fat. (c) Fat is rich in hydrogen and poor in oxygen, so it needs more oxygen per gram for complete oxidation; the ratio of CO2 released to O2 used is therefore lower.	4

Section E: DNA, Genetics and Cell Division (16 marks)

Answer all questions and show your working, units and significant figures.

#	Question	Answer	Marks
17	A DNA molecule has 1000 bases in total, of which 300 are adenine. (a) Find the numbers of thymine, guanine and cytosine. (b) Find the percentage of adenine.	(a) A pairs with T, so T = 300; then G + C = 1000 - 600 = 400 and G = C = 200 bases. (b) Percentage of A = 300 / 1000 x 100% = 30%.	4
18	A human body cell has 46 chromosomes. (a) How many are in each daughter cell after mitosis? (b) How many are in a gamete after meiosis? (c) How many are in a zygote? (d) When is DNA replicated during mitosis?	(a) 46, because mitosis keeps the diploid number the same. (b) 23, since meiosis halves the chromosome number to the haploid number. (c) The zygote has 23 + 23 = 46 chromosomes, restoring the diploid number. (d) DNA is replicated during interphase (S phase); the chromosome number is still 46 but each chromosome now has two DNA molecules (two sister chromatids).	4
19	Two pea plants of genotype Tt are crossed (T tall dominant, t dwarf recessive). (a) Give the genotype ratio of the offspring. (b) Give the phenotype ratio. (c) If there are 200 offspring, how many tall and how many dwarf plants are expected?	(a) Using a Punnett square: TT : Tt : tt = 1 : 2 : 1. (b) Tall : dwarf = 3 : 1. (c) Tall = 200 x 3/4 = 150 plants; dwarf = 200 x 1/4 = 50 plants.	4
20	A recessive condition is caused by allele a. Two carriers (Aa x Aa) marry. (a) What is the probability that a child is affected? (b) What is the probability that two children are both affected? (c) Why does a carrier (Aa) not show the condition?	(a) Aa x Aa gives 1 AA : 2 Aa : 1 aa, so the chance of an aa child is 1/4, that is 25%. (b) Both children affected = 1/4 x 1/4 = 1/16 = 6.25%. (c) Allele a is recessive; with only one copy the dominant allele A still makes enough normal protein, so the carrier looks normal but can pass a to the next generation.	4

Section F: Ecosystems, Energy Flow and Populations (16 marks)

Answer all questions and show your working, units and significant figures.

#	Question	Answer	Marks
21	Producers in an ecosystem fix 50 000 kJ and only 10% of energy passes to each trophic level. (a) Find the energy available to primary, secondary and tertiary consumers. (b) What percentage of the producers energy reaches the top predator? (c) Why does energy decrease at each level?	(a) Primary consumers = 50 000 x 0.1 = 5000 kJ; secondary = 500 kJ; tertiary = 50 kJ. (b) The top predator (fourth level) gets 5 kJ, which is 5 / 50 000 x 100% = 0.01%. (c) Each level loses most energy through respiration as heat, and some remains in faeces and uneaten parts, so only about 10% passes on.	4
22	In a 400 m2 meadow, 25 quadrats of 1 m2 are placed at random and 75 plants of a species are counted. (a) Find the density in plants per m2. (b) Estimate the total number of plants in the meadow. (c) Why must the quadrats be placed at random?	(a) Density = 75 / 25 = 3.0 plants per m2. (b) Estimated total = 3.0 x 400 = 1200 plants. (c) Random placement avoids bias such as choosing only dense patches, so the sample is representative and the estimate is neither too high nor too low.	4

23	A capture-mark-recapture study of snails marks 40 individuals; a second catch of 50 contains 8 marked ones. (a) Estimate the population using the Lincoln index. (b) Give two factors that would make the estimate too high. (c) Why must marking not affect survival or the chance of being recaught?	(a) N = (M x C) / R = (40 x 50) / 8 = 250 snails. (b) For example marks fall off, so R is too small and N is overestimated; the population is not closed (births, deaths, immigration, emigration); marked animals are not evenly mixed with the rest. (c) If marking changed survival or the chance of being recaught, the proportion of marked animals in the second sample would not reflect the true proportion and the estimate would be wrong; the method assumes a closed population with equal catchability.	4
24	(a) State the role of decomposers in the carbon cycle. (b) Why does the carbon dioxide level in the atmosphere stay roughly stable over long periods? (c) What effect does large-scale burning of fossil fuels have on the carbon cycle?	(a) Decomposers such as bacteria and fungi break down the organic carbon in dead bodies and waste into carbon dioxide, returning it to the atmosphere and releasing mineral nutrients to the soil. (b) Photosynthesis and respiration (including decomposition) are roughly balanced: the CO2 fixed by photosynthesis is about equal to that released by respiration and decay, and the oceans dissolve and store large amounts of CO2. (c) Burning fossil fuels releases carbon that was locked away, upsetting the balance and raising atmospheric CO2, which strengthens the greenhouse effect.	4