S5 Biology Practice Paper: Cell Cycle and Mitosis, Enzyme Kinetics and Inhibitors, Photosynthesis and Respiration Energetics, Mendelian and Sex-Linked Inheritance, Population Growth and Mark-Recapture, Community Diversity, Vaccines and Herd Immunity (100 marks)

Level: S5 | Subject: Biology | 75 minutes | 100 marks | 24 questions | answer key

Part 1 Cell Cycle, Mitosis and Cell Differentiation (16 marks)

Show all formulae, substitutions and units; give percentages to 1 d.p.

#	Question	Answer	Marks
1	A somatic cell cycle of an animal lasts G1 10 hours, S 8 hours, G2 4 hours and M 2 hours. (a) Find the length of one complete cycle; (b) calculate the percentage of the cycle spent in M phase (1 d.p.); (c) state the main event that occurs during S phase.	(a) Cycle = 10 + 8 + 4 + 2 = 24 hours. (b) M phase = 2 / 24 x 100 = 8.3%. (c) DNA replication occurs in S phase: each chromosome forms two sister chromatids, so DNA content doubles while chromosome number stays the same.	4
2	Of 200 dividing cells observed under a microscope, 16 are in M phase, which is estimated to last 2 hours. (a) Find the proportion of cells in M phase; (b) hence estimate the length of the whole cell cycle; (c) explain why this method may over- or under-estimate the cycle length.	(a) Proportion = 16 / 200 = 0.08 (8.0%). (b) Cycle = 2 / 0.08 = 25.0 hours. (c) Dividing cells are rounder and easier to recognise, so they tend to be over-counted; this raises the proportion and under-estimates the cycle. Poor sampling adds further bias.	4
3	A human somatic cell has 46 chromosomes and has just completed S phase. (a) How many chromosomes does it now contain? (b) How many sister chromatids? (c) After centromeres split in anaphase, how many chromosomes are temporarily in the cell? (d) How many chromosomes does each daughter cell receive?	(a) Still 46, because the centromeres have not yet divided. (b) Two chromatids per chromosome, i.e. 46 x 2 = 92. (c) Once centromeres split, sister chromatids become separate chromosomes, so 92 chromosomes are present temporarily. (d) After cytokinesis each daughter cell receives 46, the same as the parent cell.	4
4	(a) Compare mitosis and meiosis in terms of the number of daughter cells and their chromosome number; (b) explain why skin stem cells can keep replacing epidermal cells while most neurons cannot; (c) state one consequence of uncontrolled mitosis.	(a) Mitosis gives 2 daughter cells with the same chromosome number as the parent (2n to 2n); meiosis gives 4 cells with half the number (2n to n). (b) Stem cells retain the ability to divide, self-renew and differentiate into epidermal cells, whereas neurons are terminally differentiated and normally leave the cycle into G0. (c) A tumour or cancer may form, invading nearby tissue or spreading through the blood.	4

Part 2 Enzyme Kinetics, Michaelis-Menten Equation and Inhibitors (18 marks)

Express rates in μmol min^{-1} or μmol min^{-1} mg^{-1} and always state the unit.

#	Question	Answer	Marks

5	An enzyme reaction produces 45 µmol of product in 30 minutes. (a) Calculate the mean rate in µmol min^{-1}; (b) in another run 90 µmol is produced in 60 minutes — is the rate the same? Explain.	(a) Rate = 45 / 30 = 1.5 µmol min^{-1}. (b) 90 / 60 = 1.5 µmol min^{-1}, the same as (a), because with excess substrate and a fixed amount of enzyme the initial rate is constant and product rises linearly with time. The rate would fall once substrate runs low or product inhibits the enzyme.	5
6	The activity of an enzyme (relative units) at pH 5, 6, 7 and 8 is 22, 48, 35 and 9 respectively. (a) State the optimum pH; (b) calculate how many times greater the activity at pH 6 is than at pH 8 (1 d.p.); (c) explain why activity falls away from the optimum.	(a) The optimum is pH 6 (highest activity 48 units). (b) 48 / 9 = 5.3 times greater. (c) Excess acid or alkali disrupts the ionic and hydrogen bonds holding the enzyme's tertiary structure, so the active site changes shape or the enzyme denatures and the substrate can no longer bind.	5
7	An enzyme has Vmax = 40 µmol min^{-1} and Km = 2 mM. (a) Use the Michaelis-Menten equation to find the rate when substrate concentration is 6 mM; (b) what is the rate when substrate concentration equals Km? (c) explain the biological meaning of Km.	(a) v = Vmax[S] / (Km + [S]) = 40 x 6 / (2 + 6) = 30.0 µmol min^{-1}. (b) When [S] = Km, v = 40 x 2 / (2 x 2) = 20.0 µmol min^{-1}, i.e. half of Vmax. (c) Km is the substrate concentration giving half of Vmax and measures the affinity of the enzyme for its substrate; a smaller Km means higher affinity.	4
8	Compare competitive and non-competitive inhibition. At the same substrate concentration of 6 mM, Vmax = 40 µmol min^{-1} and Km = 2 mM, a competitive inhibitor raises the apparent Km to 6.0 mM (Vmax unchanged), while a non-competitive inhibitor lowers Vmax to 20.0 µmol min^{-1} (Km unchanged). (a) Calculate the rate in each inhibited case at that substrate concentration; (b) explain why a high substrate concentration overcomes competitive inhibition.	(a) Competitive: v = 40 x 6 / (6.0 + 6) = 20.0 µmol min^{-1}; non-competitive: v = 20.0 x 6 / (2 + 6) = 15.0 µmol min^{-1}. (b) A competitive inhibitor competes for the same active site, so raising the substrate concentration lets substrate out-compete it and the rate approaches Vmax again; a non-competitive inhibitor binds elsewhere (allosteric site) and extra substrate cannot reverse it.	4

Part 3 Photosynthesis, Respiration and Energy Efficiency (16 marks)

Express energy in kJ to 1 d.p.; all equations must be balanced.

#	Question	Answer	Marks
9	The overall equation for photosynthesis is $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$. A leaf synthesises 0.5 mol of glucose. (a) How many moles of CO_2 are needed? (b) What mass is that? (c) How many moles of O_2 are released?	(a) CO_2 = 6 x 0.5 = 3.0 mol. (b) Mass = 3.0 x 44 = 132 g (and 54 g of water is used). (c) O_2 released = 3.0 mol.	4
10	An aquatic plant releases 0, 12, 28, 40 and 41 oxygen bubbles per minute at 0, 2, 4, 6 and 8 klx. (a) Describe how oxygen release changes with light intensity; (b) estimate the light saturation point; (c) explain why a few bubbles may still appear at 0 klx; (d) predict the effect of using 0.1% sodium hydrogencarbonate solution.	(a) Between 0 and 6 klx release rises with light: 12 bubbles at 2 klx, 28 at 4 klx, 40 at 6 klx, with the gain shrinking; from 6 to 8 klx it only rises from 40 to 41. (b) Saturation is about 6-7 klx, beyond which more light does not raise the rate. (c) At 0 klx photosynthesis has stopped but respiration continues, releasing CO_2; a few bubbles may be dissolved gas escaping, and net oxygen release is zero or negative. (d) Hydrogencarbonate supplies extra CO_2, so the whole curve shifts up and saturation moves to a higher light intensity.	4

11	Complete aerobic oxidation of 1 mol glucose releases 2870 kJ and yields 38 ATP; each mole of ATP stores 30.5 kJ. (a) Calculate the energy stored in ATP; (b) find the efficiency of energy transfer (1 d.p.); (c) state where the remaining energy goes.	(a) ATP energy = 38 x 30.5 = 1159 kJ. (b) Efficiency = 1159 / 2870 x 100 = 40.4%. (c) The remaining 1711 kJ is lost mainly as heat, some of it helping to maintain body temperature.	4
12	In oxygen shortage muscle carries out lactic acid fermentation, yielding only 2 ATP per mole of glucose. (a) Calculate its energy efficiency (1 d.p.); (b) how many times more efficient is aerobic respiration (1 d.p.); (c) explain why muscles still ache and breathing stays rapid after vigorous exercise.	(a) Efficiency = 2 x 30.5 / 2870 x 100 = 2.1%. (b) 40.4 / 2.1 = 19.0 times (or 38 / 2 = 19 ATP). (c) Lactic acid accumulates and causes the ache until it is carried to the liver and oxidised; the body also repays the oxygen debt, so breathing and heart rate stay high.	4

Part 4 Mendelian Inheritance, Sex Linkage and Blood Group Probability (18 marks)

Give probabilities as both a fraction and a percentage; use standard genetic symbols.

#	Question	Answer	Marks
13	Two heterozygous black mice (Aa x Aa) are crossed, black being dominant. (a) State the gametes produced; (b) use a Punnett square to find the genotype ratio; (c) give the phenotype ratio; (d) if 200 offspring are produced, about how many are expected to be black?	(a) Each parent gives A and a gametes in equal numbers. (b) Genotypes AA : Aa : aa = 1 : 2 : 1. (c) Phenotypes black : white = 3 : 1. (d) Black = 200 x 3/4 = 150 (about 50 white).	5
14	In peas A/a controls seed shape and B/b seed colour, on different chromosomes. A test cross AaBb x aabb yields 160 seeds. (a) List the four gamete types; (b) give the phenotype ratio; (c) how many seeds of each phenotype are expected? (d) What would happen if the two gene pairs were on the same chromosome?	(a) Gametes from AaBb are AB, Ab, aB and ab, each 1/4. (b) Phenotype ratio 1 : 1 : 1 : 1. (c) 160 x 1/4 = 40 seeds of each phenotype. (d) The genes would be linked, so parental types (AB and ab) would greatly outnumber recombinants and the ratio would depart from 1:1:1:1, with the recombination frequency set by the distance between the loci.	5
15	Colour blindness is X-linked recessive. A carrier mother (X^C X) marries a normal father (X Y). (a) Give the possible offspring genotypes and their ratio; (b) the probability that a son is colour-blind; (c) the probability that a daughter is colour-blind; (d) why are affected males far more common than affected females?	(a) Offspring: X^C X (carrier daughter), X X (normal daughter), X^C Y (colour-blind son), X Y (normal son), ratio 1 : 1 : 1 : 1. (b) Half (50%) of sons are colour-blind. (c) No daughter is affected; half are carriers, so the probability is 0. (d) Males have a single X, so one recessive allele is enough; a female needs both X chromosomes to carry it, which requires an affected father and at least a carrier mother.	4
16	The parents are blood group A (I^A i) and B (I^B i). (a) Give the possible blood groups of the children and their ratio; (b) the probability that both of two children are group O; (c) if they have 4 children, how many are expected to be group AB? (d) explain why group O parents cannot have a group AB child.	(a) Children: I^A I^B (AB), I^A i (A), I^B i (B) and i i (O) in the ratio 1 : 1 : 1 : 1, i.e. 25% each. (b) Each child has a 1/4 chance of group O, so both = 0.25 x 0.25 = 0.0625 (6.25%). (c) AB has probability 1/4, so the expected number among 4 children is 1. (d) Group O parents must be i i and can pass only i, so no child can carry I^A or I^B and all must be group O.	4

Part 5 Population Growth, Mark-Recapture and Community Diversity (16 marks)

State the formula used for each population estimate; round indices to whole numbers.

#	Question	Answer	Marks
17	Producers in a grassland fix 20,000 kJ m-2 yr-1 and only 10% of the energy passes to the next trophic level. (a) Find the energy available to primary, secondary and tertiary consumers; (b) explain where the other 90% goes; (c) why do food chains rarely exceed 4-5 levels?	(a) Primary consumers = 20,000 x 10% = 2,000 kJ; secondary = 200 kJ; tertiary = 20 kJ m-2 yr-1. (b) The other 90% is used in respiration and lost as heat, or leaves as faeces, excreta and uneaten remains that pass to decomposers. (c) With only about a tenth surviving each step, a fourth or fifth level could not support a viable breeding population.	4
18	A population starts the year with 100 individuals; during the year 20 are born, 8 die, 4 immigrate and 2 emigrate. (a) Find the net change; (b) the growth rate (%); (c) the population at year end; (d) what long-term growth pattern is expected if resources are fixed?	(a) Net change = 20 - 8 + 4 - 2 = 14 individuals. (b) Growth rate = 14 / 100 x 100 = 14.0%. (c) Year end = 100 + 14 = 114. (d) With limited food, space and other resources the population follows an S-shaped (logistic) curve, levelling off at the carrying capacity and being regulated by disease, predation and competition.	4
19	Mark-recapture is used to estimate a snail population: 80 snails are caught, marked and released, and after mixing 100 are recaught of which 8 are marked. (a) Estimate the population size; (b) give two factors that make the estimate too high; (c) why must marking not affect survival or movement?	(a) N = (M x C) / R = (80 x 100) / 8 = 1,000 snails. (b) Marked animals may be easier to recatch (slower, conspicuous) and marks may be lost, both lowering R and inflating the estimate. (c) If marking changed movement or survival, marked and unmarked animals would no longer be equally catchable, breaking the assumption of random mixing and equal catchability.	4
20	Community A has species proportions 0.25, 0.25, 0.25 and 0.25; community B has 0.7, 0.1, 0.1 and 0.1. (a) Calculate the Simpson index D = 1 - sum(p squared) for both (2 d.p.); (b) which is more diverse? (c) What happens to diversity if the dominant species disappears from B?	(a) A: sum p squared = 4 x 0.0625 = 0.25, D = 0.75; B: 0.49 + 0.03 = 0.52, D = 0.48. (b) A is more diverse (0.75 > 0.48) because its four species are evenly represented. (c) Without its dominant species B would hold three species at 1/3 each, giving D = 1 - 3 x (1/3)^2 = 0.67, so the index rises even though total abundance and ecological function fall.	4

Part 6 Immunity, Vaccines, Herd Immunity and Disease Surveillance (16 marks)

Express all rates per 100 000 population to 1 d.p.

#	Question	Answer	Marks
21	A disease has a basic reproduction number R0 = 4. (a) Calculate the vaccination coverage needed for herd immunity (%); (b) in a population of {pop:,}, how many people must be vaccinated? (c) explain why the coverage actually required is usually higher than the theoretical value.	(a) Threshold = 1 - 1/R0 = 1 - 1/4 = 0.75, i.e. 75.0%. (b) 700,000 x 75.0% = 525,000 people. (c) Vaccines are not perfectly effective, some people cannot be vaccinated (infants, the immunosuppressed), mixing is uneven and R0 rises in crowded settings, so real coverage must exceed the theoretical figure.	4
22	After two exposures to the same antigen, antibody concentration rises within 3 days of the second exposure to five times the first peak, which took about 14 days. (a) Name the two responses; (b) explain why the second is faster and stronger;	(a) A primary immune response first, then a secondary (memory) response. (b) The first exposure leaves memory B and T cells that proliferate and differentiate into plasma cells on re-exposure, giving more antibody faster and for longer. (c) Vaccines present a harmless antigen (attenuated, killed or subunit) that builds memory cells without causing disease, so a real	4

	(c) how do vaccines exploit this? (d) name one immune mechanism that kills pathogens without antibodies.	infection is met at once. (d) Cytotoxic T cells kill infected cells directly, and phagocytes engulf pathogens; neither needs antibody.	
23	A city of 50,000 people records 150 new cases in one year. (a) Calculate the incidence per 100 000 population (1 d.p.); (b) if the population rises to {int(popn*1.2):,} next year at the same incidence, predict the number of new cases; (c) distinguish incidence from prevalence.	(a) Incidence = 150 / 50,000 x 100 000 = 300.0 per 100 000. (b) 60,000 x 300.0 / 100 000 = 180 new cases. (c) Incidence counts new cases in a period and measures risk and spread; prevalence counts all existing cases at a point in time, measures burden and depends on how long the disease lasts.	4
24	(a) Explain why antibiotics do not work on viruses but do on bacteria; (b) explain how misuse of antibiotics leads to resistance; (c) give two public health measures that limit the spread of resistance; (d) why is it important to finish the whole course?	(a) Antibiotics target structures unique to bacteria (cell wall, bacterial ribosome, DNA gyrase) that human cells and viruses lack; viruses have no metabolism of their own and need antivirals. (b) Unnecessary or sub-lethal use kills susceptible bacteria and leaves those carrying resistance genes, which multiply and can pass genes horizontally on plasmids. (c) Guideline-based prescribing with no self-medication, restricted agricultural use, and infection control with hand hygiene in hospitals. (d) Stopping early leaves the toughest resistant strains, causing relapse and more transmission.	4