S5 Biology Practice Paper: Genetics and Mutation, Energy Flow in Ecosystems, Gas Exchange and Transport, Osmosis and Water Potential, Enzymes and Metabolism

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

Section A Genetics and Mutation (18 marks)

Show genetic diagrams or working. Use correct genotype symbols and explain your reasoning.

#	Question	Answer	Marks
1	A tall pea plant (genotype Tt) is crossed with a dwarf plant (tt). (a) Use a genetic diagram to show the genotypes of the offspring. (b) Calculate the percentage of tall plants among the offspring.	(a) Tt gives gametes T and t; tt gives only t. The offspring genotypes are Tt : tt = 1 : 1, i.e. 2 Tt and 2 tt. (b) Tall plants (Tt) make up 2 out of 4 = 50%; dwarf plants (tt) are the other 50%. This is a test cross, and the 1 : 1 ratio shows the parent was heterozygous.	4
2	Two gene pairs are on different chromosomes: AaBb x AaBb. (a) State the phenotypic ratio of the offspring. (b) Calculate the percentage of double recessives (aabb). (c) Explain why the two gene pairs assort independently.	(a) Each gene pair gives 3 : 1, so the joint ratio is 9 : 3 : 3 : 1. (b) The chance of aabb is 1/4 x 1/4 = 1/16 = 6.25%. (c) The two pairs lie on non-homologous chromosomes, so they orient independently at metaphase I and give four equally frequent gametes AB, Ab, aB and ab.	5
3	One base in the beta-globin gene changes from A to T, so the sixth amino acid changes from glutamine (codon GAG) to valine (codon GUG). (a) Name this type of mutation. (b) Explain why a single base change can affect protein function. (c) Contrast the effect of inserting two bases instead.	(a) It is a base substitution, a missense point mutation. (b) One changed codon puts a different amino acid in the chain; the hydrophobic valine makes haemoglobin stick together at low oxygen, so red cells sickle and cause sickle-cell anaemia. (c) Inserting two bases (not a multiple of three) causes a frameshift: every codon downstream is regrouped, so the whole amino acid sequence changes and the protein usually loses all function.	4
4	Red-green colour blindness is X-linked recessive, written X^c. A carrier mother (X^c X) marries a normal father (X Y). (a) What is the chance that a son is colour blind? (b) What is the chance that a daughter is a carrier? (c) What is the chance that any child is colour blind?	(a) A son gets X or X^c from his mother, so 50% are X^c Y and colour blind. (b) A daughter must get X from her father, and has a 50% chance of X^c from her mother, giving X^c X: a carrier with normal vision. (c) Only X^c Y out of the four combinations is affected, so 25%. No daughter can be colour blind because the father supplies a normal X.	5

Section B Energy Flow in Ecosystems (17 marks)

Show the formula and units in every calculation. Give answers to three significant figures.

#	Question	Answer	Marks
5	Producers in a grassland fix 50,000 kJ per square metre per year, and the energy transfer efficiency between trophic levels is 10%. (a) Calculate the energy available to primary consumers. (b) Calculate the energy available to tertiary consumers. (c) Calculate the overall transfer efficiency from producers to tertiary consumers.	(a) 50,000 x 0.10 = 5,000 kJ per square metre per year. (b) 50,000 x 0.10 cubed = 50 kJ per square metre per year. (c) 0.10 cubed x 100% = 0.1%, because only one tenth survives each transfer, so top consumers receive very little energy.	5

6	A forest ecosystem has a gross primary productivity of 4,800 kJ per square metre per year, and producers respire 2,300 kJ per square metre per year. (a) Calculate the net primary productivity. (b) Explain what NPP means for the ecosystem. (c) State where the remaining energy goes.	(a) NPP = GPP - R = 4,800 - 2,300 = 2,500 kJ per square metre per year. (b) NPP is the energy locked into new plant growth and reproduction, which is what other trophic levels can eat; it is the entry point of energy flow. (c) The rest is lost as heat from respiration, becomes litter for decomposers, or is eaten and partly egested undigested by herbivores.	4
7	Consider the food chain: grass -> grasshopper -> frog -> snake -> hawk. (a) State the trophic level of the hawk. (b) Give three reasons why so much energy is lost between adjacent trophic levels. (c) Explain why food chains rarely exceed four or five trophic levels.	(a) Grass is the producer, so grasshopper is the primary consumer and the hawk, as the fourth consumer, occupies the fifth trophic level. (b) Energy is lost as heat in respiration; parts such as bone, hair and cellulose are not eaten or not digested and are egested; and wastes and corpses are taken by decomposers. (c) Only about 10% passes on at each step, so by the fifth level too little energy remains to support a viable population.	4
8	A hectare of forest holds 12,000 kg of dry biomass, which is 45% carbon by dry mass. (a) Calculate the mass of carbon stored. (b) If decomposers break it all down completely, calculate the mass of carbon dioxide released. (c) State the role of decomposers in the carbon cycle.	(a) 12,000 kg x 0.45 = 5,400 kg of carbon. (b) Mass of carbon dioxide = 5,400 x 44/12 = 19,800 kg, using molar masses 44 for CO2 and 12 for carbon. (c) Decomposers secrete enzymes that break down litter and corpses, oxidising organic carbon to CO2 that returns to the air, and release mineral ions for producers, so carbon is recycled.	4

Section C Gas Exchange and Transport (17 marks)

Show working with units. In explanation questions name the structures involved.

#	Question	Answer	Marks
9	A student breathes in 500 cm3 of air per breath, 12 times per minute, and uses 250 cm3 of oxygen per minute. (a) Calculate the ventilation rate per minute. (b) Calculate the percentage of oxygen extracted from the inhaled air. (c) Explain why the extraction percentage rises during exercise.	(a) 500 x 12 = 6,000 cm3 per minute, which is 6.0 dm3 per minute. (b) 250 / 6,000 x 100% = 4.17%. (c) Active tissues use more oxygen, so venous oxygen partial pressure falls and the gradient from alveolus to blood steepens; with a larger cardiac output and ventilation, more oxygen is taken from each litre of air.	5
10	Haemoglobin is 98% saturated in lung capillaries and 75% saturated in muscle capillaries during exercise. (a) Calculate the percentage of oxygen released per unit of haemoglobin in the tissue. (b) Explain how the Bohr effect assists this. (c) Explain the advantage of the fetal haemoglobin curve lying to the left.	(a) 98% - 75% = 23%, so about 23% of the bound oxygen is released. (b) Respiring tissue releases CO2, lowering pH and raising temperature; this lowers the affinity of haemoglobin for oxygen and shifts the curve right, unloading more oxygen at the same partial pressure. (c) Fetal haemoglobin is more saturated at any given partial pressure, so it can take oxygen from maternal blood across the placenta where partial pressure is low.	4
11	A leaf has an area of 25 cm2 and a lower-epidermis stomatal density of 200 per square millimetre. (a) Calculate the total number of stomata on the leaf. (b) Explain the mechanism that opens stomata by day and closes them at night. (c) State the effect of stomatal closure on water loss.	(a) 25 cm2 = 2,500 mm2, so 200 x 2,500 = 500,000 stomata. (b) In daylight ATP from photosynthesis drives potassium ions into the guard cells, lowering their water potential; water enters, the cells become turgid and the thinner inner wall stretches more, opening the pore. At night or in drought potassium leaves, the cells go flaccid and the pore closes. (c) Closure almost stops transpiration and so conserves water, but it also restricts CO2 entry and lowers the rate of photosynthesis.	4

12	A person has a stroke volume of 70 cm3 and a resting heart rate of 72 beats per minute. (a) Calculate the resting cardiac output. (b) During exercise the heart rate rises to 150 per minute; assuming stroke volume is unchanged, calculate the cardiac output and the percentage increase. (c) State the benefit of the higher cardiac output to muscles.	(a) 70 x 72 = 5,040 cm3 per minute, about 5.04 dm3 per minute. (b) 70 x 150 = 10,500 cm3 per minute, or 10.5 dm3 per minute; the increase is (10,500 - 5,040) / 5,040 x 100% = 108.3%. (c) More blood reaches the muscle, delivering oxygen and glucose and removing CO2 and lactate faster, so aerobic respiration is maintained and fatigue is delayed.	4

Section D Osmosis and Water Potential (16 marks)

Water potential is measured in kPa. Show the formula and give units in every answer.

#	Question	Answer	Marks
13	A plant cell has a solute potential of -800 kPa and a pressure potential (turgor) of 400 kPa. The surrounding solution has a water potential of -600 kPa. (a) Calculate the water potential of the cell. (b) State and explain the net direction of water movement. (c) Predict how the cell changes after some time.	(a) psi-w = psi-s + psi-p = -800 + 400 = -400 kPa. (b) The cell at -400 kPa has a higher water potential than the solution at -600 kPa, so water moves out of the cell down the gradient. (c) The cell loses water, turgor falls and the protoplast shrinks away from the wall, so the cell becomes plasmolysed and flaccid.	4
14	A 0.10 mol dm-3 sodium chloride solution is prepared at 25 degrees Celsius. R = 8.31 J mol-1 K-1 and NaCl is fully ionised (i = 2). (a) Calculate the solute potential of the solution. (b) Explain why i equals 2 for NaCl. (c) Compare it with a glucose solution of the same concentration.	(a) psi-s = -iCRT = -2 x 0.10 x 8.31 x 298 = -495.3 kPa, about -495 kPa. (b) NaCl dissociates completely into Na+ and Cl-, so the number of particles is twice the number of formula units and i = 2. (c) Glucose does not ionise, so i = 1 and psi-s is about -248 kPa: at the same concentration glucose has only half the solute potential of NaCl and pulls in less water.	5
15	Four potato strips of the same batch each start at 2.40 g. After one hour, strip A weighs 2.70 g and strip B weighs 2.10 g. (a) Calculate the percentage change in mass for each strip. (b) Decide which strip was in pure water and which in concentrated sugar solution, and explain. (c) State how the experiment could be made more reliable.	(a) A: (2.70 - 2.40) / 2.40 x 100% = +12.5%; B: (2.10 - 2.40) / 2.40 x 100% = -12.5%. (b) A was in pure water: outside water potential is higher than in the cells, water enters osmotically and mass rises as cells become turgid. B was in sugar solution: outside water potential is lower, water leaves and the cells plasmolyse. (c) Use several strips per solution and average, blot surface water, weigh on a balance, keep temperature and soaking time constant, and standardise strip size.	4
16	A plant transpires 24 cm3 of water in two hours. (a) Calculate the mean transpiration rate in cm3 per hour and per minute. (b) Explain how the transpiration pull moves water from root to leaf.	(a) 24 / 2 = 12 cm3 per hour, and 12 / 60 = 0.2 cm3 per minute. (b) Transpiration from stomata lowers the water potential of mesophyll cells, so water is drawn from the xylem. Cohesion between water molecules and adhesion to the xylem walls hold a continuous column under tension, and the pull is transmitted down to the roots, which take up more water.	3

Section E Enzymes and Metabolism (16 marks)

Show working. In explanation questions refer to the active site or enzyme-substrate complex.

#	Question	Answer	Marks

17	An enzyme works at 8 units per minute at 20 degrees Celsius and 16 units per minute at 30 degrees Celsius. (a) Calculate the temperature coefficient Q10. (b) Predict the rate at 45 degrees Celsius and explain. (c) Distinguish Q10 from denaturation.	(a) Q10 = rate at 30 / rate at 20 = 16 / 8 = 2.0, so the rate doubles for each 10 degree rise. (b) At 45 degrees the rate collapses towards zero: the enzyme is a protein, and heat breaks the hydrogen and ionic bonds holding its tertiary structure, so the active site loses its shape, substrate can no longer bind and denaturation is irreversible. (c) Q10 measures how sensitive the rate is to temperature (about 2 for most enzymes), while denaturation is permanent loss of the active site shape and catalytic ability.	4
18	An enzyme is studied with two inhibitors. Without inhibitor Vmax = 120 and Km = 4 mmol dm-3; with inhibitor X, Vmax = 120 and Km = 8; with inhibitor Y, Vmax = 60 and Km = 4. (a) Identify the type of inhibition for X and for Y. (b) Explain how X works. (c) State how the inhibition by X can be relieved experimentally.	(a) X is competitive inhibition (Vmax unchanged, Km raised); Y is non-competitive (Vmax halved, Km unchanged). (b) X resembles the substrate and competes for the same active site, so more substrate is needed to reach half maximum rate and Km rises from 4 to 8; at saturating substrate all active sites can still be occupied, so Vmax is unchanged. (c) Raising the substrate concentration outcompetes X, so the inhibition weakens and the rate approaches the original Vmax again.	4
19	Initial rates of an enzyme at different substrate concentrations are: at 2 mmol dm-3 the rate is 40; at 4 it is 60; at 8 it is 80; and at saturation the rate is 120 units. (a) Find Vmax and Km. (b) Explain the biological meaning of Km. (c) Explain why the rate eventually levels off.	(a) Vmax = 120 units; half of Vmax is 60, which occurs at 4 mmol dm-3, so Km = 4 mmol dm-3. (b) Km is the substrate concentration giving half maximum rate and is an inverse measure of affinity: the smaller the Km, the tighter the binding and the more effective the enzyme at physiological concentrations. (c) At high substrate concentration every active site is occupied, so adding more substrate cannot increase the number of enzyme-substrate complexes; the rate is then limited by enzyme concentration and levels off.	5
20	Complete oxidation of 1 mol of glucose releases 2,870 kJ. The cell produces 38 mol ATP, and each mole of ATP stores 30.5 kJ. (a) Calculate the energy stored in ATP. (b) Calculate the efficiency of respiration. (c) State where the remaining energy goes.	(a) 38 x 30.5 = 1,159 kJ. (b) Efficiency = 1,159 / 2,870 x 100% = 40.4%. (c) The remaining 60% is lost as heat, some of which keeps the body warm; the loss arises from proton leakage and inefficiency in the electron transport chain.	3

Section F Integrated Data Analysis (16 marks)

Show the formula, substitute values and interpret. For the statistical test state the degrees of freedom.

#	Question	Answer	Marks
21	Two heterozygous tall pea plants are crossed. Of 400 offspring, 310 are tall and 90 are dwarf. A 3 : 1 ratio predicts 300 and 100. (a) Calculate chi-square. (b) State the degrees of freedom. (c) Decide whether the 3 : 1 hypothesis is supported (critical value 3.84).	(a) chi-square = sum of (O - E) squared over E = (310 - 300) squared / 300 + (90 - 100) squared / 100 = 0.333 + 1.000 = 1.33. (b) There are two phenotype classes, so degrees of freedom = 2 - 1 = 1. (c) Since 1.33 is below 3.84 the deviation is not significant (p > 0.05), so the 3 : 1 hypothesis is not rejected and the data fit a monohybrid Mendelian ratio.	5
22	A grassland food chain is grass -> rabbit -> snake -> hawk, with 10% energy transfer efficiency. The hawk population needs 5 kg of biomass. (a) Calculate the	(a) Snakes need 5 / 0.1 = 50 kg, rabbits 50 / 0.1 = 500 kg, and grass 500 / 0.1 = 5,000 kg. (b) Only about 10% of energy survives each transfer, so the energy reaching the top is tiny and can support	4

	biomass of snakes, rabbits and grass required. (b) Explain why top predators are usually few in number. (c) State the effect on the grass if people hunt snakes heavily.	only a small population. (c) Fewer snakes means less predation on rabbits, so rabbits increase, graze the grass heavily, and the vegetation and the whole web become less stable.	
23	The rate of gas diffusion is proportional to surface area and concentration difference, and inversely proportional to diffusion distance. If a respiratory surface doubles its area and halves its thickness, with the same concentration difference: (a) calculate the factor by which the diffusion rate changes. (b) Apply this to the structure of alveoli. (c) Explain how smoking disrupts this relationship.	(a) The rate scales with area over thickness, so it becomes 2 / 0.5 = 4 times the original rate. (b) There are millions of alveoli giving a total area of about 70 m2, and each alveolar and capillary wall is one cell thick, so the diffusion distance is very short; ventilation and blood flow keep the gradient steep and exchange fast. (c) Smoke destroys alveolar walls so alveoli merge into large sacs and area falls; secretion and inflammation thicken the walls; and poor ventilation lowers the gradient, so all three factors cut the diffusion rate.	4
24	The water potential of a guard cell falls from -300 kPa to -700 kPa. (a) Calculate the increase in turgor pressure available. (b) Explain how this opens the stoma. (c) Explain how a plant protects itself in drought.	(a) The fall in water potential is -300 - (-700) = 400 kPa, giving up to 400 kPa of extra force for water uptake. (b) With lower water potential than the surrounding epidermal cells, the guard cells take in water and swell; the outer wall is thinner and stretches more than the inner wall, so the cells bow apart and the pore opens. (c) In drought the plant releases abscisic acid, potassium leaves the guard cells, water potential rises, the cells go flaccid and stomata close to cut transpiration; leaves may also roll or drop and roots grow deeper.	3