S6 Biology Practice Paper: Mendelian Genetics and Probability, DNA Structure and Semi-conservative Replication, Transcription and Translation, Gene Mutation and Genetic Disorders, Hardy-Weinberg Equilibrium, Recombinant DNA and PCR, Ecosystem Energy Flow and Carbon Cycle, Population Dynamics and Biodiversity (100 marks)

Level: S6 | Subject: Biology | 75 minutes | 100 marks | 24 questions | answer key

Section A: Mendelian Genetics and Probability (17 marks)

Each question is worth 4-5 marks; show the gametes and ratios.

#	Question	Answer	Marks
1	In peas, seed shape (R round > r wrinkled) and cotyledon colour (Y yellow > y green) are inherited independently. Two RrYy plants are crossed and produce 240 seeds. Work out the expected number of each of the four phenotypes (round-yellow, round-green, wrinkled-yellow, wrinkled-green).	A dihybrid F2 gives a 9:3:3:1 phenotypic ratio over 16 parts. Round-yellow = 240 x 9/16 = 135; round-green = 45; wrinkled-yellow = 45; wrinkled-green = 15. Total 240 seeds.	4
2	The 240 seeds are classified as round-yellow 140, round-green 42, wrinkled-yellow 44, wrinkled-green 14. Use the chi-square test, chi-square = sum of (O-E)^2/E, and decide whether the 9:3:3:1 ratio is rejected (critical value 7.82 at df = 3, p = 0.05).	chi-square = (5)^2/135 + (-3)^2/45 + (-1)^2/45 + (-1)^2/15 = 0.185 + 0.200 + 0.022 + 0.067 = 0.474. Since 0.474 is below 7.82, the deviation is not significant and the 9:3:3:1 ratio is not rejected.	4
3	An RrYy plant is test-crossed with a homozygous recessive rryy plant, giving 160 offspring. Give the expected number and the ratio of the four phenotypes.	RrYy makes four gamete types (RY, Ry, rY, ry) in equal numbers while rryy makes only ry, so the phenotypes appear in a 1:1:1:1 ratio: 160 x 1/4 = 40 plants each.	4
4	Human ABO blood groups are controlled by three alleles IA, IB and i. The parents are IAi (group A) and IBi (group B). (a) List the possible genotypes, blood groups and probabilities of their children. (b) If they have four children, what is the probability that all four are group O?	(a) Gametes IA or i crossed with IB or i give IAIB (AB) 1/4, IAi (A) 1/4, IBi (B) 1/4 and ii (O) 1/4. (b) Each child has probability 1/4 of being group O, so all four = (1/4)^4 = 1/256, about 0.39%.	5

Section B: DNA Structure, Replication and Protein Synthesis (17 marks)

Each question is worth 4-5 marks; show your working for base and hydrogen-bond numbers.

#	Question	Answer	Marks
5	A double-stranded DNA molecule is 1200 base pairs long and adenine (A) makes up 30% of all bases. Find the numbers of A, T, G and C, and the total number of hydrogen bonds in the molecule (2	Total bases = 1200 x 2 = 2400. A = T = 30% of 2400 = 720; G + C = 2400 - 2 x 720 = 960, so G = C = 480. Hydrogen bonds = 720 x 2 + 480 x 3 = 1440 + 1440 = 2880.	4

	between A and T, 3 between G and C).		
6	A polypeptide contains 250 amino acids. (a) What is the minimum number of bases in the mRNA that codes for it, including the stop codon? (b) What is the minimum number of bases in the template strand of the corresponding DNA?	(a) Each amino acid is coded by 3 bases (one codon): 250 x 3 = 750, plus one stop codon of 3 bases = 753. (b) The mRNA is transcribed from the template strand with the same number of bases, so at least 753 bases.	4
7	DNA replicates semi-conservatively. One DNA molecule replicates 3 times in succession. Find (a) the total number of DNA molecules produced, (b) the number of molecules containing a parental (original) strand, and (c) the total number of newly synthesised strands.	(a) 2^3 = 8 molecules. (b) Two molecules each contain one original strand, so 2 molecules contain parental DNA. (c) The molecules have 16 strands in total; 2 are original, so 16 - 2 = 14 strands are newly synthesised.	4
8	Describe the three main stages of DNA replication, explain why an RNA primer is needed, and state one experiment that demonstrates that replication is semi-conservative.	1. Unwinding: helicase breaks the hydrogen bonds between base pairs and the double helix opens into two template strands. 2. Complementary base pairing: DNA polymerase adds free deoxyribonucleotides against the template (A-T, G-C) but only in the 5-prime to 3-prime direction, so a short RNA primer is needed to supply a 3-prime OH starting point. 3. Joining: DNA ligase seals the Okazaki fragments into a continuous strand. Evidence: the Meselson-Stahl experiment, in which E. coli grown in 15N medium and then transferred to 14N gave one intermediate-density band after the first generation in density-gradient centrifugation - one heavy and one light strand per molecule.	5

Section C: Mutation, Genetic Disorders and Hardy-Weinberg Equilibrium (17 marks)

Each question is worth 4-5 marks; express allele frequencies as q and p.

#	Question	Answer	Marks
9	A recessive disorder affects 1 in 10,000 people in a population at Hardy-Weinberg equilibrium. Find the recessive allele frequency q, the dominant allele frequency p and the carrier (heterozygote) frequency.	q squared = 1/10,000 = 0.0001, so q = 0.01 and p = 1 - q = 0.99. Carrier frequency = 2pq = 2 x 0.99 x 0.01 = 0.0198, about 1.98%% (roughly 1 in 50 people).	4
10	In a population of 1000 people, 40 are affected by a recessive disorder. Assuming Hardy-Weinberg equilibrium, find q, p and the number of carriers.	q squared = 40/1000 = 0.04, so q = 0.2 and p = 0.8. Carrier frequency 2pq = 2 x 0.8 x 0.2 = 0.32, giving 1000 x 0.32 = 320 carriers.	4
11	A disorder is inherited as an X-linked recessive trait. The mother is a carrier (X^A X^a) and the father is normal (X^A Y). Find (a) the probability that a son is affected, (b) the probability that a daughter is	The mother gives X^A or X^a with equal probability. (a) A son takes his X from his mother, so X^a Y is affected: probability 1/2. (b) A daughter always receives X^A from her father, so she is X^A X^A or X^A X^a and never affected: probability 0. (c) Overall = 1/2 (a son) x 1/2 = 1/4.	4

	affected, and (c) the overall probability that a child is affected.		
12	(a) Explain why X-linked recessive disorders are usually more common in males than in females. (b) Using q = 0.01, compare the number of carriers with the number of affected individuals and hence explain why consanguineous marriage increases the risk of recessive disorders.	(a) A male has only one X chromosome, so a single recessive allele is not masked by a normal allele and the disorder is expressed; a female needs two recessive alleles (probability q squared). (b) With q = 0.01 the frequency of affected females is 0.0001 while carriers are 0.0198, i.e. carriers outnumber affected individuals about 198 to 1. Carriers look normal but pass the allele on, and relatives are far more likely than unrelated people to carry the same recessive allele, so two carriers marrying and producing an affected child becomes much more likely.	5

Section D: Recombinant DNA, PCR and Biotechnology (17 marks)

Each question is worth 4-5 marks; name the enzymes and the steps used.

#	Question	Answer	Marks
13	A plasmid is 4000 bp long. A 800 bp human cDNA is inserted to form a recombinant plasmid. Find the size of the recombinant plasmid and explain how gel electrophoresis can distinguish recombinant from non-recombinant plasmids.	Recombinant plasmid = 4000 + 800 = 4800 bp. In gel electrophoresis smaller fragments move faster, so the non-recombinant plasmid bands at 4000 bp while the recombinant one bands at 4800 bp; digesting with the same restriction enzyme should give back 4000 bp and 800 bp fragments.	4
14	The polymerase chain reaction (PCR) starts from a single DNA template molecule and runs for 30 cycles. Find the number of DNA molecules after amplification.	The number doubles each cycle, so the number of molecules = 2^30 = 1073741824 (about 1.07 x 10^9).	4
15	E. coli divides every 0.5 hour at a suitable temperature. Starting from one cell, the culture is grown for 4 hours. Find (a) the number of cells and (b) the total number of insulin molecules if each cell produces 5000 molecules.	(a) Number of divisions = 4/0.5 = 8 generations, so cells = 2^8 = 256. (b) Total = 256 x 5000 = 1280000 molecules.	4
16	Describe the four main steps in producing human insulin using bacteria, and explain why cDNA rather than human genomic DNA must be used.	1. Extract mRNA from pancreatic beta cells and make cDNA with reverse transcriptase. 2. Cut the plasmid and the cDNA with a restriction enzyme and join them with DNA ligase to form a recombinant plasmid. 3. Introduce the plasmid into E. coli (transformation) and select transformed colonies using an antibiotic-resistance marker. 4. Grow the bacteria in large fermenters, then harvest and purify the insulin. cDNA is used because human genomic DNA contains introns, and bacteria cannot splice them out, so the introns would be translated and a wrong polypeptide produced; cDNA is copied from mature mRNA and therefore has no introns.	5

Section E: Ecosystem Energy Flow and the Carbon Cycle (16 marks)

Each question is worth 4 marks; give energy in kJ per square metre per year.

#	Question	Answer	Marks
17	Producers in an ecosystem fix 250000 kJ per square metre per year. If the transfer efficiency between successive trophic levels is 10%, find the energy available per square metre per year to the primary, secondary and tertiary consumers.	Primary consumers = 250000 x 10% = 25000 kJ; secondary = 2500 kJ; tertiary = 250 kJ.	4
18	An ecosystem absorbs 20000 kJ of light energy per year. Gross primary production (GPP) is 2000 kJ and producers respire 1200 kJ. Find (a) the photosynthetic efficiency and (b) the net primary production (NPP).	(a) Efficiency = GPP/light absorbed x 100% = 2000/20000 x 100% = 10.0%. (b) NPP = GPP - respiration = 2000 - 1200 = 800 kJ.	4
19	If a tertiary consumer needs 50 kJ of energy per year and the transfer efficiency is 10%, what is the minimum energy the producers must fix? Explain what happens to the rest of the energy.	The tertiary consumer is at the fourth trophic level, so the efficiency is 0.1^3 = 0.001 and the producers must fix 50/0.001 = 50000 kJ. About 90% of the energy at each level is lost as heat from respiration, in excretory products such as faeces and urine, and in uneaten body parts such as hair and bone; energy is not recycled in the food chain.	4
20	Explain the roles of photosynthesis, respiration, decomposition and the burning of fossil fuels in the carbon cycle, and use energy flow to explain why food chains usually have only 4 to 5 trophic levels.	Photosynthesis: producers fix atmospheric CO2 into organic carbon (carbohydrates) and this is the main route by which carbon enters living organisms. Respiration: all organisms oxidise organic carbon, releasing CO2 back to the atmosphere and obtaining energy. Decomposition: decomposers break down organic carbon in dead bodies and excretory products, releasing CO2 and minerals. Burning fossil fuels: releases carbon that had been locked away for millions of years as CO2 very quickly, and is the main cause of rising atmospheric CO2. Food chains are short because only about 10%% of the energy is passed on at each level; the other 90%% is lost, largely as heat from respiration, so by the fourth or fifth level too little energy remains to support a breeding population.	4

Section F: Population Dynamics and Biodiversity (16 marks)

Each question is worth 4 marks; state the formula and assumptions.

#	Question	Answer	Marks
21	A mark-recapture study is used to estimate population size: 40 snails are caught, marked and released; a week later 36 snails are caught, of which 12 are marked. Estimate the population size using the Lincoln index N = (M x C)/R.	N = (M x C)/R = (40 x 36)/12 = 1440/12 = 120 snails, assuming marking does not affect survival or the chance of recapture and that there is no migration.	4

22	A quadrat survey is made of grassland plants: 50 quadrats of 0.5 square metres each are placed at random and contain on average 4.2 plants of the target species. Find (a) the population density (plants per square metre) and (b) the estimated total in a grassland of 2000 square metres.	(a) Density = 4.2/0.5 = 8.4 plants per square metre. (b) Total = 8.4 x 2000 = 16800 plants (the 50 quadrats cover 25 square metres in total).	4
23	A population grows from 1200 to 1560 individuals in one year with no immigration or emigration. Find (a) the percentage growth rate, (b) the per capita growth rate r, and (c) the doubling time from t = ln2/r (2 decimal places).	(a) Increase = 1560 - 1200 = 360, so the growth rate is 360/1200 x 100% = 30%. (b) r = 360/1200 = 0.3. (c) t = ln2/0.3 = 0.693/0.3, about 2.31 years.	4
24	(a) List the three levels of biodiversity with one example each. (b) Give two reasons why an ecosystem with higher biodiversity is more resistant to environmental change.	(a) 1. Genetic diversity: differences in genes between individuals of one species, e.g. rice varieties differ in disease-resistance genes. 2. Species diversity: the number and relative abundance of species in a community, e.g. the many fish and invertebrates on a coral reef. 3. Ecosystem diversity: the variety of habitat and ecosystem types, e.g. Hong Kong has freshwater wetlands, mangroves and montane forest. (b) 1. Functional redundancy: several species occupy similar niches, so if one is lost its role is still performed by others and the food web does not collapse. 2. A more complex food web gives alternative pathways between predators and prey, so energy and matter flow can continue and cascading extinctions are less likely.	4