S6 Biology Practice Paper

S6 | Biology | Time: 60 minutes | Total: 100 marks | 24 questions

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Part A Genetics and Molecular Biology (18 marks)

Answer all questions. Show your working and units.

1. A double-stranded DNA molecule of a species has 1200 base pairs, and guanine (G) makes up 40% of all bases. Calculate the number of G, C, A and T bases, and state the base-pairing rule you used.

Answer: Total bases = 1200 x 2 = 2400. G + C = 2400 x 40% = 960, so G = C = 480. A + T = 2400 - 960 = 1440, so A = T = 720. Rule: G pairs with C by three hydrogen bonds and A pairs with T by two, therefore G = C and A = T.

2. The coding region of a gene contains 900 base pairs. If the whole region is translated, what is the maximum number of amino acids coded for? How many peptide bonds are formed? Explain why one is deducted.

Answer: Number of codons = 900 / 3 = 300. One of these is a stop codon which does not code for an amino acid, so at most 299 amino acids are produced. Peptide bonds = amino acids - 1 = 299.

3. Two genes assort independently and the parents are AaBb x AaBb. If 1600 offspring are produced, state the expected ratio of the four phenotypes and the number of each.

Answer: The phenotypic ratio of AaBb x AaBb is 9:3:3:1. Numbers: dominant/dominant = 900; dominant/recessive = 300; recessive/dominant = 300; recessive/recessive = 100.

4. The observed numbers in such an experiment rarely match the expected numbers exactly. Give one reason, and name the statistical test used to judge whether the difference is significant, together with its null hypothesis.

Answer: Reason: the number of offspring is finite and fertilisation is random, so sampling error (chance deviation) occurs. Test: the chi-square goodness-of-fit test; here the degrees of freedom = 4 - 1 = 3. Null hypothesis: there is no significant difference between the observed numbers and the expected 9:3:3:1 numbers. Reject the null hypothesis if $p < 0.05$.

Part B Genetic Engineering and Biotechnology (17 marks)

Answer all questions. Show your working; give percentages to one decimal place.

5. The polymerase chain reaction (PCR) starts from a single DNA molecule. Calculate the number of DNA molecules after 20 cycles, and find the minimum number of cycles needed to exceed 1,000,000 molecules.

Answer: Each cycle doubles the number of molecules, so the count is 2^n. After 20 cycles: 2^20 = 1048576 molecules. 2^19 = 524288 is below 1,000,000 while 2^20 = 1048576 is above it, so at least 20 cycles are needed.

6. A plasmid vector is 4000 bp long and a 1200 bp target gene is inserted to form a recombinant plasmid. Find the total length of the recombinant plasmid and the percentage of the recombinant plasmid contributed by the insert.

Answer: Total length = 4000 + 1200 = 5200 bp. Percentage of insert = 1200 / 5200 x 100% = 23.1%.

7. A 100 microlitre sample of a 10^-3 dilution of a bacterial culture is spread on an agar plate and 120 colonies grow. Calculate the concentration of the original culture in CFU per mL and show the calculation.

Answer: CFU/mL = colonies / volume plated x dilution factor = 120 / 0.1 mL x 1000 = 1200000, i.e. 1.2 x 10^6 CFU/mL.

8. A gel electrophoresis standard curve shows that a 1000 bp fragment migrates 2.0 cm and a 100 bp fragment migrates 6.0 cm. Estimate the position of a 300 bp fragment and explain why smaller fragments travel further.

Answer: Migration distance is inversely related to the logarithm of fragment size. By interpolation: d = 2.0 + (6.0 - 2.0) x (log 1000 - log 300) / (log 1000 - log 100) = 4.09 cm, about 4.09 cm. Smaller fragments meet less resistance from the gel mesh, so they move faster and further at the same voltage.

Part C Ecosystems and Energy Flow (17 marks)

Answer all questions; give energy in kJ as whole numbers.

9. The producers of an ecosystem fix 50000 kJ of energy in a year and the energy transfer efficiency between trophic levels is 10%. Calculate the energy available to the primary, secondary and tertiary consumers, and explain where the rest of the energy goes.

Answer: Primary consumers = 50000 x 10% = 5000 kJ; secondary consumers = 5000 x 10% = 500 kJ; tertiary consumers = 500 x 10% = 50 kJ. About 90% of the energy is lost as heat from respiration, and some is not eaten or is egested in faeces and never assimilated.

10. A population grows from 200 to 260 individuals in one year with no immigration or emigration. Calculate its intrinsic growth rate r and its doubling time, and state which growth model this represents.

Answer: r = (N1 - N0) / N0 = (260 - 200) / 200 = 0.30 per year. Doubling time t_d = ln2 / r = 0.693 / 0.30 = 2.31 years. With unlimited resources this is exponential growth; in a real environment limited resources would give logistic growth.

11. A mark-recapture study marks 40 animals and releases them. A second sample of 50 animals contains 16 marked individuals. Estimate the population size and state two assumptions of the method.

Answer: Lincoln index: N = (M x C) / R = (40 x 50) / 16 = 125 individuals. Assumptions: (1) marked individuals mix evenly with the population and the recapture sample is random; (2) no births, deaths, immigration or emigration during the period, and marking does not affect survival or the chance of being caught.

12. A pioneer community contains only 3 plant species while the climax community that develops contains 12. Calculate the increase in species number (absolute and percentage) and give two environmental changes that occur during succession.

Answer: Increase = 12 - 3 = 9 species; percentage = 9 / 3 x 100% = 300%. Environmental changes: (1) soil organic matter and nutrients increase, the soil layer thickens and holds more water; (2) greater shading raises humidity and lowers light at ground level, favouring shade-tolerant species; (3) food webs and habitat complexity increase, niche partitioning raises biodiversity.

Part D Human Physiology and Transport (16 marks)

Answer all questions. State the formula and the units.

13. At rest a person has a heart rate of 72 beats per minute and a stroke volume of 70 mL. Calculate the cardiac output in mL/min and in L/min, and state the formula used.

Answer: Formula: cardiac output = heart rate x stroke volume. 72 x 70 = 5040 mL/min = 5.04 L/min.

14. During exercise the same person reaches a heart rate of 140 beats per minute and a stroke volume of 110 mL. Calculate the cardiac output during exercise and how many times the resting value this is.

Answer: Cardiac output during exercise = 140 x 110 = 15400 mL/min = 15.4 L/min. Ratio = 15400 / 5040 = 3.06 times the resting value.

15. A person has a glomerular filtration rate of 125 mL/min. Calculate the volume of filtrate produced per day in litres, and the daily urine volume if 99% of the filtrate is reabsorbed by the tubules.

Answer: Daily filtrate = 125 mL/min x 60 x 24 / 1000 = 180 L/day. Urine volume = 180 x (1 - 0.99) = 1.8 L/day.

16. A person has a tidal volume of 500 mL, a breathing rate of 12 breaths per minute and an anatomical dead space of about 150 mL. Calculate the minute ventilation and the alveolar ventilation, and explain why the difference matters.

Answer: Minute ventilation = 500 x 12 = 6000 mL/min. Alveolar ventilation = (500 - 150) x 12 = 4200 mL/min. The difference is 1800 mL/min (about 30%). Gas in the dead space does not take part in gas exchange, so only alveolar ventilation determines the actual uptake of oxygen and removal of carbon dioxide.

Part E Plant Physiology and Photosynthesis (16 marks)

Answer all questions. Show your working and units.

17. A leaf fixes a net 18 micromol of CO2 per square metre per second under a light intensity of 600 micromol per square metre per second. Calculate its quantum yield and suggest one reason why the value is low.

Answer: Quantum yield = 18 / 600 = 0.03, about 3%. Reason: some absorbed light is lost as fluorescence or heat, and some photosynthate is consumed by respiration, so net fixation is below gross photosynthesis.

18. A plant loses 45 g of water by transpiration in 5 hours and its total leaf area is 0.03 square metres. Calculate the transpiration rate in g/h and in g per square metre per hour, and state two environmental factors that affect it.

Answer: Transpiration rate = 45 g / 5 h = 9 g/h; per unit leaf area = 9 / 0.03 = 300 g per square metre per hour. Environmental factors: relative humidity (lower means faster), wind speed (higher means faster), temperature (higher means faster) and light (stomata open).

19. At light intensities of 200, 400 and 800 micromol per square metre per second the net photosynthetic rates are 8, 15 and 16 micromol of CO2 per square metre per second. Describe how the rate changes with light intensity and explain the limiting factor at the higher intensities.

Answer: Between 200 and 400 the rate rises from 8 to 15, a clear increase, so light is the limiting factor. Between 400 and 800 it rises only from 15 to 16 (about +7%), approaching light saturation; carbon dioxide concentration, temperature or chlorophyll content is now limiting.

20. If a ring of bark is removed from a tree trunk (ringing), sugars accumulate in the leaves above the ring and the roots below eventually die. Explain this observation and name the transport tissue involved.

Answer: The phloem in the bark transports sucrose from sources (leaves) to sinks (roots, fruits) in either direction. Ringing cuts the phloem, so sucrose cannot move down to the roots and accumulates above the ring. The roots are starved of sugar, respiration fails and they die. The xylem lies inside the bark and carries water and minerals, so it may not be affected at first.

Part F Health, Disease and Immunity (16 marks)

Answer all questions. Show your working; give percentages to one decimal place.

21. An infectious disease has a basic reproduction number R0 = 5. Calculate the herd immunity threshold and explain what it means.

Answer: Threshold = 1 - 1/R0 = 1 - 1/5 = 0.80, that is 80%. Meaning: once more than 80% of the community is immune, each infected person infects fewer than one other on average and the outbreak dies out.

22. A vaccine has been given to 85% of a population and is 90% effective. Calculate the proportion actually protected and decide whether this is enough for herd immunity against a disease with R0 = 5.

Answer: Proportion protected = coverage x efficacy = 0.85 x 0.90 = 0.765, that is 76%. The herd immunity threshold is 80%, and 76% is below it, so it is not enough. The effective reproduction number R_eff = R0 x (1 - 0.765) = 5 x 0.235 = 1.175, which is above 1, so the outbreak will still grow.

23. A patient carries 10^9 bacteria and the natural frequency of a resistance mutation is 10^-6. Calculate the number of resistant bacteria present before treatment and explain why the full course of antibiotics must be completed.

Answer: Resistant bacteria = 10^9 x 10^-6 = 10^3 = 1000. The antibiotic kills most susceptible bacteria but the resistant ones survive and multiply, forming a resistant population. If treatment stops early, the survivors regrow without competition and may pass resistance genes to other bacteria on plasmids. The full course is needed to clear the infection and reduce selection for resistance.

24. Explain how a vaccine produces immunological memory, and compare active immunity with passive immunity produced by injecting antibodies.

Answer: A vaccine contains antigens (attenuated or inactivated pathogens, their proteins or polysaccharides). Antigen-presenting cells present them to helper T cells, which activate B cells and cytotoxic T cells specific to the antigen. B cells differentiate into plasma cells that secrete antibody, and some become memory B cells and memory T cells. On later infection the memory cells multiply rapidly and give a faster, stronger antibody response. Active immunity takes weeks to develop but is long lasting, often for life. Passive immunity from injected antibodies protects immediately, which suits emergencies, but there are no memory cells and protection lasts only weeks to months.