S4 Biology Practice Paper: Digestion and Absorption, Circulation and the Heart, Gas Exchange and Breathing, Plant Water and Mineral Transport, Ecosystem Energy and Matter Cycling, Disease Transmission and Immunity (100 marks)

S4 Biology | 100 marks | 75 minutes

1. Digestion and absorption (17 marks)

Give energies and masses to 1 d.p. and percentages to 2 d.p.

(a) A person takes 100 g of protein, 60 g of fat and 300 g of carbohydrate each day. The energy values are 17 kJ/g for protein, 38 kJ/g for fat and 17 kJ/g for carbohydrate. Find the energy supplied by each nutrient, the total energy intake and the percentage of the total supplied by each nutrient. *(5 marks)*

Answer: Protein = 100 x 17 = 1700 kJ; fat = 60 x 38 = 2280 kJ; carbohydrate = 300 x 17 = 5100 kJ. Total = 9080 kJ. Percentages: protein 18.72%, fat 25.11%, carbohydrate 56.17%, which add up to 100%.

(b) Salivary amylase has a relative activity of 100%% at 37 C, 5%% at 60 C and 8%% at 0 C. Find the fall in percentage points at 60 C compared with 37 C, and explain why the low activity at the two temperatures has different causes. *(4 marks)*

Answer: The fall is 100 - 5 = 95 percentage points. At 60 C the enzyme is above its optimum, so the protein is denatured and the active site is permanently changed: the loss is irreversible. At 0 C the molecules simply have low kinetic energy and collide less often, so the structure is intact and activity returns on warming.

(c) Bile emulsifies fat globules from a mean diameter of 0.8 mm to 0.02 mm. Assuming the total volume of fat is unchanged, find the factor by which the diameter is reduced and the factor by which the total surface area increases. *(4 marks)*

Answer: Diameter factor = 0.8 / 0.02 = 40. For a fixed total volume the total surface area is inversely proportional to the diameter, so the area increases 40 times, giving lipase far more surface to act on and a faster rate of digestion.

(d) Compare the routes by which glucose and long-chain fatty acids enter the blood after absorption in the small intestine. *(4 marks)*

Answer: Glucose is absorbed by active transport (co-transport with sodium) into the capillaries of the villus and travels in the hepatic portal vein to the liver first. Long-chain fatty acids and glycerol are re-formed into triglycerides inside the epithelial cells, packaged into chylomicrons and enter the lacteal (lymph), reaching the blood through the thoracic duct and the subclavian vein, thus bypassing the liver at first.

2. Circulation and the heart (17 marks)

Use mL and L; show the working for every rate.

(a) A person at rest has a heart rate of 75 beats per minute and a stroke volume of 70 mL. Find the cardiac output in mL/min and in L/min. *(4 marks)*

Answer: Cardiac output = 75 x 70 = 5250 mL/min = 5.25 L/min.

(b) The person has a blood volume of 5.0 L. Using the cardiac output in (a), how many seconds does one complete circulation of the blood take? *(4 marks)*

Answer: Time = 5000 mL / 5250 mL per min = 0.952 min = 57.1 s.

(c) The total cross-sectional area of the aorta is 3.0 cm2 with a blood velocity of 30 cm/s; the total cross-sectional area of the capillaries is 3,000 cm2. Find the blood flow rate in cm3/s and the mean velocity in the capillaries. *(5 marks)*

Answer: Flow rate = 3.0 x 30 = 90 cm3/s. Capillary velocity = 90 / 3000 = 0.03 cm/s. The much larger total area slows the flow, which favours exchange.

(d) Explain why the wall of the left ventricle is thicker than that of the right ventricle, and state how blood is returned to the heart in the veins. *(4 marks)*

Answer: The left ventricle pumps blood around the whole body (systemic circuit), so it must overcome high resistance and generate high pressure; the right ventricle only serves the lungs, a shorter route with low resistance, hence a thinner wall. Veins rely on contraction of skeletal muscle, valves that prevent backflow and the fall in thoracic pressure during inhalation.

3. Gas exchange and breathing (17 marks)

Give gas volumes in mL and percentages to 1 d.p.

(a) A person has a tidal volume of 500 mL, a breathing rate of 12 per minute and an anatomical dead space of 150 mL. Find the pulmonary ventilation and the alveolar ventilation per minute. *(5 marks)*

Answer: Pulmonary ventilation = 500 x 12 = 6000 mL/min. Alveolar ventilation = (500 - 150) x 12 = 4200 mL/min. Gas in the dead space takes no part in exchange, so alveolar ventilation is clearly lower.

(b) The total alveolar surface area is normally about 70 m2. If emphysema reduces it by 40%, and other factors are unchanged, find the remaining area and the diffusion rate of oxygen as a percentage of normal. *(4 marks)*

Answer: Remaining area = 70 x 60% = 42.0 m2. Diffusion rate is proportional to surface area, so it is 60% of normal, a fall of 40 percentage points.

(c) Each gram of haemoglobin can combine with 1.34 mL of oxygen. A person has a haemoglobin concentration of 150 g/L and a blood volume of 5 L. Find the total volume of oxygen the blood can carry. *(4 marks)*

Answer: Oxygen carried = 1.34 x 150 x 5 = 1005 mL, about 1.0 L.

(d) Explain why a smoker with carbon monoxide poisoning can still be short of oxygen even when inhaling plenty of oxygen. *(4 marks)*

Answer: Carbon monoxide binds haemoglobin far more strongly than oxygen, occupying the binding sites and shifting the oxygen dissociation curve to the left, so oxygen is released to tissues less readily. The oxygen-carrying capacity of the blood falls and tissues are under-supplied.

4. Plant water and mineral transport (16 marks)

Work in g m-2 h-1; time in hours.

(a) A plant with a leaf area of 0.5 m2 loses 250 g of water in 5 hours. Find the mean transpiration rate in g m-2 h-1. *(4 marks)*

Answer: Transpiration rate = 250 / (0.5 x 5) = 100 g m-2 h-1.

(b) The same plant absorbs 1.8 L of water a day, 95% of which is lost by transpiration. Find the daily transpiration loss and the water retained in the plant. *(4 marks)*

Answer: Transpiration loss = 1.8 x 95% = 1.71 L; retained = 1.8 - 1.71 = 0.09 L, used in photosynthesis, turgor and growth.

(c) Compare xylem and phloem in the substances carried, the direction of transport and the driving force. *(4 marks)*

Answer: Xylem carries water and mineral ions one way, upward from the root, driven mainly by transpiration pull (with root pressure and capillarity). Phloem carries sucrose and amino acids in either direction from source to sink, driven by pressure flow set up by active loading.

(d) One plant is placed in distilled water and another in a solution containing potassium ions, both aerated. Predict and explain the difference in potassium uptake by the roots. *(4 marks)*

Answer: The plant in distilled water takes up almost no potassium because none is available; the plant in solution absorbs potassium, and the aerated condition supplies oxygen for respiration to make ATP for active transport against the concentration gradient into the root hair cells. Without oxygen the uptake falls sharply, showing the process needs energy.

5. Ecosystem energy and matter cycling (17 marks)

Work in kJ m-2 yr-1; give efficiency to 1 d.p.

(a) Net production by the producers of an ecosystem is 40,000 kJ m-2 yr-1 and the efficiency of energy transfer between trophic levels is 10%. Find the energy available to the primary, secondary and tertiary consumers and the total energy of the three consumer levels. *(5 marks)*

Answer: Primary consumers = 40,000 x 10% = 4000; secondary = 400; tertiary = 40. The three levels total 4440 kJ m-2 yr-1, which is 11.1% of the producers energy.

(b) A field absorbs 1,200,000 kJ m-2 yr-1 of light energy and its net primary production is 48,000 kJ m-2 yr-1. Find the ecological efficiency. *(4 marks)*

Answer: Efficiency = 48,000 / 1,200,000 x 100% = 4.0%, the rest being lost by reflection, transpiration and respiration.

(c) Describe how carbon passes from the atmosphere into living organisms and how it returns to the atmosphere. *(4 marks)*

Answer: Into organisms: producers fix carbon dioxide by photosynthesis into organic compounds, which pass along food chains to consumers. Back to the atmosphere: respiration by producers, consumers and decomposers releases carbon dioxide; decomposers break down dead matter and faeces; burning fossil fuels returns stored carbon.

(d) A mark-recapture estimate is made: 80 animals are caught and marked, then 100 are recaptured of which 16 are marked. Estimate the population size and state two assumptions of the method. *(4 marks)*

Answer: Population = 80 x 100 / 16 = 500. Assumptions: marked individuals mix at random with the population, marking does not affect survival or the chance of being caught, and there is no birth, death, immigration or emigration between the two samples.

6. Disease transmission and immunity (16 marks)

Give counts as whole numbers and percentages as whole numbers.

(a) A disease has a basic reproduction number R0 of 4. Find the minimum vaccination coverage needed for herd immunity, and the coverage if R0 falls to 2. *(4 marks)*

Answer: Coverage = 1 - 1/R0. For R0 = 4: 1 - 0.25 = 75%; for R0 = 2: 1 - 0.5 = 50%. The lower the R0, the lower the coverage needed.

(b) A bacterium divides every 20 minutes. Starting with 500 cells, how many are present after 2 hours under ideal conditions? *(4 marks)*

Answer: 2 hours = 120 min, so there are 120 / 20 = 6 divisions; number = 500 x 2^6 = 32000 cells.

(c) Explain why stopping a course of antibiotics early encourages the appearance of resistant bacteria. *(4 marks)*

Answer: The antibiotic kills most susceptible bacteria but a few carrying resistance genes survive. Stopping early lets these survivors multiply without competition, and they can pass resistance genes to other bacteria on plasmids, so the population as a whole becomes more resistant.

(d) State three measures that reduce the spread of respiratory infections in a school and explain the principle behind each. *(4 marks)*

Answer: First, wearing a mask physically blocks droplets and reduces inhalation of pathogen-laden droplets. Second, good ventilation and spacing dilute pathogens in the air and reduce close contact. Third, frequent hand washing and disinfecting shared objects interrupts contact transmission by removing pathogens from hands.