S6 Combined Science Practice Paper (Set 2): Radioactivity and Nuclear Energy, Transformers and Transmission, Immunity and Vaccines, Genetics and Genetic Engineering, Ecology and Diversity, Scientific Investigation and Uncertainty (100 marks)

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

Part 1 Radioactivity and Nuclear Energy (16 marks)

Show all formulae, substitutions and calculation steps.

#	Question	Answer	Marks
1	A radioactive source has an initial activity of 640 Bq and a half-life of 8 days. Find the activity in Bq after 24 days and after 40 days.	24 days = 3 half-lives, so activity = 640 / 2^3 = 80 Bq; 40 days = 5 half-lives, so activity = 640 / 2^5 = 20 Bq.	4
2	After 32 days a sample has decayed to one thirty-second of its original activity. Find its half-life in days.	1/32 = (1/2)^5, so 5 half-lives have passed; half-life = 32 / 5 = 6.4 days.	4
3	One fission event has a mass defect of 3.2 x 10^-28 kg. Taking c = 3.0 x 10^8 m/s, find the energy released in joules (3 significant figures) and in MeV (1 MeV = 1.602 x 10^-13 J).	E = mc^2 = 3.2e-28 x (3.0e8)^2 = 2.88e-11 J; in MeV = 2.88e-11 / 1.602e-13 = 180 MeV.	4
4	1.0 g of uranium-235 undergoes complete fission, releasing 2.88 x 10^-11 J per nucleus (molar mass 235 g/mol, Avogadro constant 6.022 x 10^23). Find the total energy in joules and the equivalent mass of coal in kg and tonnes (coal: 30 MJ per kg).	Nuclei = (1.0 / 235) x 6.022e23 = 2.563e+21; energy = 2.563e+21 x 2.88e-11 = 7.380e+10 J; equivalent coal = 7.380e+10 / 3.0e7 = 2460 kg = 2.46 tonnes.	4

Part 2 Electromagnetic Induction and Transformers (16 marks)

Give units for every numerical answer and use the significant figures requested.

#	Question	Answer	Marks
5	A transformer has 1200 turns on the primary and 60 turns on the secondary, with 220 V across the primary. Find the secondary voltage in V.	V2 / V1 = N2 / N1, so V2 = 220 x 60 / 1200 = 11 V.	4
6	The same transformer delivers 5.0 A at the secondary with an efficiency of 95%. Find the output power in W, the input power in W (3 s.f.) and the primary current in A (3 s.f.).	Output = 11 x 5.0 = 55 W; input = 55 / 0.95 = 57.9 W; primary current = 57.9 / 220 = 0.263 A.	4
7	A transmission cable has a total resistance of 0.5 ohm and carries 20 A. Find the power lost in the cable in W. If the transmitted power is unchanged but the voltage is raised 10 times, find the new current, the new loss in W, and the factor by which the loss falls.	Loss = I^2 R = 20^2 x 0.5 = 200 W; with 10 times the voltage the current is 2 A and the loss is 2^2 x 0.5 = 2 W, i.e. 100 times smaller.	4
8	A 200-turn coil has the flux through it rise uniformly from 0.002 Wb to 0.008 Wb in 0.05 s. Find the induced e.m.f. in V; if the coil resistance is 8 ohm, find the induced current in A (2 s.f.).	EMF = N dPhi/dt = 200 x (0.008 - 0.002) / 0.05 = 24 V; current = 24 / 8 = 3.0 A, i.e. 3.0 A to 2 s.f.	4

Part 3 Immunity and Vaccines (17 marks)

State the formula and assumptions used, and explain what the result means.

#	Question	Answer	Marks
9	A serum sample starts at 1:80 and is then serially diluted 1:2 five times. Find the final dilution factor.	Each step doubles the dilution, 5 steps = 2^5 = 32; final factor = 80 x 32 = 2560.	4
10	For an infection with R0 = 6, find the percentage of the population that must be immune for herd immunity (1 d.p.) and the number of people in a population of 7.5 million. If R0 falls to 3, find the new percentage (1 d.p.).	Threshold = 1 - 1/R0 = 1 - 1/6 = 83.3%; people = 7.5 million x 0.8333 = 6.25 million; for R0 = 3 the figure is 1 - 1/3 = 66.7%.	4
11	In a vaccine trial the attack rate is 4.0% in the unvaccinated group and 0.8% in the vaccinated group. Find the relative risk (decimal) and the vaccine efficacy in %.	Relative risk = 0.8 / 4.0 = 0.2; efficacy = (1 - 0.2) x 100 = 80%, i.e. the risk falls by 80% in the vaccinated group.	4
12	An antibody has a half-life of 21 days in blood. After vaccination its concentration is 1200 units per mL. Find the concentration after 84 days and explain why a booster is needed some months later.	84 / 21 = 4 half-lives; concentration = 1200 / 2^4 = 75 units per mL. Antibody levels keep falling, so once they drop below the protective level a booster re-stimulates memory B cells to restore high antibody output.	5

Part 4 Genetics and Genetic Engineering (17 marks)

Probabilities may be given as fractions, decimals or percentages, but keep one form throughout.

#	Question	Answer	Marks
13	Two carriers of the same recessive allele (Aa x Aa) plan a family. Find the probability that a child is affected; if they have 3 children, find the probability that all 3 are unaffected (%, 1 d.p.).	Aa x Aa gives 1 AA : 2 Aa : 1 aa, so affected (aa) = 1/4 = 25%; all 3 unaffected = (3/4)^3 = 0.4219 = 42.2%.	4
14	For an X-linked recessive disease the mother is a carrier (X^A X^a) and the father is unaffected (X^A Y). Find the probability that a son and a daughter are affected, and explain the daughters.	A son who inherits X^a is affected (the Y carries no allele), so the probability is 1/2; every daughter inherits X^A from the father, so the probability of being affected is 0, though 1/2 of daughters are carriers and remain unaffected.	4
15	PCR starts from 10 DNA copies and doubles every cycle. Find the number of copies after 30 cycles (3 s.f.) and explain why doubling again after 40 cycles matters little in practice.	Copies = 10 x 2^30 = 1.074e+10 (1.07e10 to 3 s.f.). By 40 cycles the theoretical count is 1.100e+13, but primers, dNTPs and polymerase run out and the reaction plateaus, so further doubling is not achieved in practice.	4
16	On a gel a 100 bp fragment migrates 60 mm and a 1000 bp fragment 20 mm (distance is linear in log10 size). Find the migration distance of a 600 bp fragment in mm (3 s.f.) and explain how the method confirms a PCR product.	Gradient = (60 - 20) / (3 - 2) = 40 mm per log unit; log10 600 = 2.778, so distance = 60 - 40 x 0.778 = 28.9 mm. Run the product beside a DNA ladder: a band at the expected size confirms the product, while extra bands indicate non-specific amplification.	5

Part 5 Ecological Succession and Diversity (17 marks)

For ecology questions, write the index formula and compare the two sets of data.

#	Question	Answer	Marks
17	In an ecosystem producers fix 45000 kJ, primary consumers 4500 kJ, secondary consumers 450 kJ and tertiary consumers 45 kJ. Find the transfer efficiency at each level and explain what it means.	Each step gives 4500/45000 = 450/4500 = 45/450 = 10%. About nine tenths of the energy is lost to respiration, excretion and uneaten material, which is why food chains usually have only 4 to 5 levels.	4
18	Lincoln index: 80 animals are marked and released, then 60 are caught of which 12 are marked. Estimate the population and state one factor that makes the estimate too high.	N = (M x n) / m = (80 x 60) / 12 = 400. If marks are lost so that m is too small the estimate is too high; if marking makes animals easier to recapture, m is too large and the estimate is too low.	4
19	Two quadrats of equal area. Quadrat A: species A 50, B 30, C 20. Quadrat B: A 80, B 10, C 10. Using Simpson index D = 1 - sum(n/N)^2, find D for both (2 d.p.) and say which is more diverse.	Quadrat A: sum(n/N)^2 = 0.5^2 + 0.3^2 + 0.2^2 = 0.38, D = 1 - 0.38 = 0.62; quadrat B: 0.8^2 + 0.1^2 + 0.1^2 = 0.66, D = 0.34. Quadrat A is more diverse because its individuals are spread more evenly among species.	4
20	A succession survey records 3 species at year 0, 9 at year 10, 18 at year 50 and 22 at year 100. Find the mean rate of change in species number for each interval (species per year), identify the fastest interval and explain why.	0-10 y = (9 - 3)/10 = 0.60; 10-50 y = (18 - 9)/40 = 0.225; 50-100 y = (22 - 18)/50 = 0.080 species per year. The 0-10 year interval is fastest: pioneer herbs and mosses colonise the disturbed bare ground rapidly, after which competition and shading slow the rate of increase.	5

Part 6 Scientific Investigation and Uncertainty (17 marks)

For uncertainty questions, write the percentage-error or combination formula first.

#	Question	Answer	Marks
21	A length is measured as 12.4 cm with an instrument uncertainty of plus or minus 0.05 cm. Find the percentage error (%, 2 s.f.).	Percentage error = 0.05 / 12.4 x 100 = 0.403%, i.e. about 0.40% (0.40%).	4
22	Mass is 45.2 +/- 0.1 g and volume 18.0 +/- 0.2 cm3. Find the density in g/cm3 (3 s.f.) with its percentage and absolute uncertainty.	Density = 45.2 / 18.0 = 2.511 g/cm3; percentage uncertainty = 0.221% + 1.111% = 1.33%; absolute uncertainty = 2.511 x 1.33% = 0.033, so density = 2.51 +/- 0.03 g/cm3.	4
23	A spring gives 0.98 N at 0.02 m extension, 1.96 N at 0.04 m, 2.94 N at 0.06 m and 3.92 N at 0.08 m. Find the spring constant in N/m and explain how the data support Hooke law.	k = (3.92 - 0.98) / (0.08 - 0.02) = 2.94 / 0.06 = 49 N/m. The four points lie on a straight line with each force/extension ratio equal to 49 N/m, so force is proportional to extension as Hooke law predicts (F = ke).	4
24	The true length is 5.10 cm and four readings are 5.02, 5.04, 5.01 and 5.03 cm. Find the mean, the sample standard deviation in cm (3 s.f.), the percentage difference from the true value, and comment on accuracy and precision.	Mean = 5.025 cm; standard deviation = 0.0129, i.e. 0.013 cm; percentage difference = (5.10 - 5.025) / 5.10 x 100 = 1.47%. The readings are very close together (s.d. only 0.013 cm), so precision is high, but the mean is low by 1.47%, which points to a systematic error such as a zero error; accuracy is poor and the instrument needs calibration.	5