C3bD Concentration, Yield and Atom Economy: Exam Drill

AQA 8464 · Calculator allowed · about 90 minutes

Total Marks

Name: ______________________________ Date: ____ / ____ / ______

Answer ALL questions. Show all your working.

1 Define the term 'concentration' when referring to a solution.

(a) Give a short definition of concentration. **(1)**

(Total for Question 1 is 1 mark)

2 A student dissolves 0.50 mol of sodium chloride (NaCl, Mr 58.5) in enough water to make 250 cm3 of solution. Calculate the concentration in g/dm3 of NaCl in the solution.

(a) Calculate the concentration in g/dm3. **(2)**

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(Total for Question 2 is 2 marks)

3 12.0 g of hydrogen chloride, HCl (Mr 36.5), is dissolved to make 250 cm3 of solution. Calculate the concentration of HCl in mol/dm3. Give your answer to three significant figures.

(a) Calculate the concentration in mol/dm3. **(3)**

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(Total for Question 3 is 3 marks)

4 Calculate the mass of sodium sulfate, Na_2SO_4 (Mr 142.0), required to prepare 500.0 cm3 of a 0.100 mol/dm3 solution.

(a) Calculate the mass in grams. **(2)**

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(Total for Question 4 is 2 marks)

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5 A student repeats a titration and records three titre values (cm3): 25.12, 25.30 and 25.05. Which two results are concordant under the common rule that concordant results differ by no more than 0.10 cm3? Use those concordant results to calculate the mean titre, to two decimal places.

(a) Identify the concordant pair and calculate their mean titre (to two decimal places). **(3)**

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(Total for Question 5 is 3 marks)

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6 In a titration a student uses 25.09 cm3 of 0.100 mol/dm3 hydrochloric acid, HCl, to neutralise 20.0 cm3 of sodium hydroxide solution, NaOH.
Equation: $HCl + NaOH \rightarrow NaCl + H_2O$
Calculate the concentration of the NaOH solution in mol/dm3. Give your answer to three significant figures and include units.

(a) Calculate the concentration of NaOH. **(4)**

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(Total for Question 6 is 4 marks)

7 Consider the reaction used to make methanol from carbon monoxide and hydrogen:
CO + 2H2 -> CH3OH
Calculate the atom economy for producing methanol (CH3OH) from these reactants. Give your answer as a percentage to three significant figures.

(a) Calculate the atom economy for producing methanol. **(2)**

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(Total for Question 7 is 2 marks)

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8 A reaction has a theoretical product mass of 12.0 g but the chemist isolates only 9.00 g. Calculate the percentage yield.

(a) Calculate the percentage yield. **(2)**

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(Total for Question 8 is 2 marks)

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9 Thermite reaction: 2Al + Fe2O3 -> Al2O3 + 2Fe
25.0 g of aluminium (Al, Mr 27.0) reacts with 45.0 g of iron(III) oxide (Fe2O3, Mr 159.7). Ar of Fe = 55.85.
Calculate the mass of iron produced. Give your answer to three significant figures.

(a) Calculate the mass of iron produced. **(4)**

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(Total for Question 9 is 4 marks)

10 Required practical style: To prepare 250.0 cm3 of 0.100 mol/dm3 sodium carbonate solution, what mass of sodium carbonate (Na2CO3, Mr 106.0) should be weighed out? Also state one control the student must keep the same during the preparation and why it should be controlled.

(a) Calculate the mass of Na2CO3 required (give answer to three significant figures). **(2)**

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(b) Give one control variable to keep constant during preparation and explain why. **(1)**

(Total for Question 10 is 3 marks)

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11 A student obtains these titres in a titration (cm3): 12.30, 12.45 and 12.35.
Identify any anomalous result, suggest a plausible cause for the anomaly and give one improvement to reduce this type of error in future titrations.

(a) Identify the anomalous result and suggest a plausible cause. **(2)**

(b) Give one improvement to reduce this error in future titrations. **(2)**

(Total for Question 11 is 4 marks)

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12 You have 250 cm3 of a 0.200 mol/dm3 solution. You need a 0.0500 mol/dm3 solution. Calculate the final volume required (in cm3).

(a) Calculate the final volume in cm3. **(2)**

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(Total for Question 12 is 2 marks)

13 Consider the cracking reaction: $C3H8 \rightarrow C3H6 + H2$.
Calculate the atom economy for producing propene (C3H6) from propane (C3H8). Give your answer to three significant figures.

(a) Calculate the atom economy as a percentage. **(2)**

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(Total for Question 13 is 2 marks)

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14 Evaluate two practical strategies a chemist could use to increase the percentage yield in an organic synthesis (for example: reversible reactions, separation of product, or minimising side reactions). In your answer discuss the scientific reasons why each strategy can increase yield and any limitations or trade-offs.

Evaluate two practical strategies to increase percentage yield in an organic synthesis. Discuss how each method increases yield and any limitations or trade-offs.

(Total for Question 14 is 6 marks)

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15 Higher only: A diprotic acid H2A is titrated. 25.00 cm3 of H2A requires 31.45 cm3 of 0.1000 mol/dm3 NaOH to reach the end point.
Calculate the concentration of H2A in mol/dm3. Show your working.

(a) Calculate the concentration of H2A. **(4)**

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(Total for Question 15 is 4 marks)

16 Ammonia production and yield: 4.00 g of nitrogen gas reacts with 10.0 g of hydrogen gas to form ammonia according to the equation $N2 + 3H2 \rightarrow 2NH3$. If the actual mass of ammonia obtained is 4.20 g, calculate the percentage yield. Give your answer to three significant figures.

(a) Calculate the percentage yield. **(3)**

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(Total for Question 16 is 3 marks)

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17 A water sample contains sodium ions at a concentration of 50.0 mg/dm3. Convert this concentration to mol/dm3 for Na+ (Mr 23.0).

(a) Give the concentration in mol/dm3. **(2)**

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(Total for Question 17 is 2 marks)

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18 A student weighs 0.5000 g (with a balance uncertainty of ±0.0005 g) of a solute (Mr 150.0) and dissolves it to make 100.0 cm3 of solution. Calculate the nominal concentration in mol/dm3 and the maximum and minimum concentrations allowed by the weighing uncertainty. Give answers to five significant figures where applicable.

(a) Calculate the nominal concentration and the range due to weighing uncertainty. **(5)**

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(Total for Question 18 is 5 marks)

19 A solution has a concentration of 250 ppm of a dissolved substance. What mass of that substance (in grams) is present in 2.00 dm3 of the solution? Note: 1 ppm = 1 mg/dm3.

(a) Calculate the mass in grams present in 2.00 dm3. **(3)**

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(Total for Question 19 is 3 marks)

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20 Calcium carbonate reacts with hydrochloric acid: $CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2$. Calculate the atom economy for producing calcium chloride ($CaCl_2$). Use Mr values: Ca 40.08, C 12.01, O 16.00, H 1.008, Cl 35.45. Give your answer to three significant figures.

(a) Calculate the atom economy for $CaCl_2$. **(3)**

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(Total for Question 20 is 3 marks)

Mark scheme · C3bD Concentration, Yield and Atom Economy: Exam Drill

Question 1

- (a) **B1** amount of solute dissolved per unit volume of solution, expressed as mol/dm3 or g/dm3, oe
- **(a) Answer: Amount of solute dissolved per unit volume of solution (for example mol/dm3 or g/dm3).**

Question 2

- (a) **M1** calculate mass of NaCl: mass = moles x Mr = 0.50 x 58.5
- (a) **A1** 117 g/dm3 cao
- **(a) Answer: 117 g/dm3**

Question 3

- (a) **M1** calculate moles: moles = 12.0 / 36.5
- (a) **M1** convert volume to dm3 and divide: concentration = moles / 0.250
- (a) **A1** 1.32 mol/dm3 cao
- **(a) Answer: 1.32 mol/dm3**

Question 4

- (a) **M1** calculate moles required: moles = concentration x volume = 0.100 x 0.500
- (a) **A1** 7.10 g cao
- **(a) Answer: 7.10 g**

Question 5

- (a) **B1** identify 25.12 and 25.05 as concordant (difference 0.07 cm3)
- (a) **M1** calculate mean of concordant pair
- (a) **A1** 25.09 cm3 cao
- **(a) Answer: 25.09 cm3**

Question 6

- (a) **M1** calculate moles HCl: moles = 0.100 x (25.09 / 1000)
- (a) **M1** use 1:1 mole ratio so moles NaOH = moles HCl
- (a) **A1** calculate concentration = moles NaOH / 0.0200
- (a) **A1** 0.125 mol/dm3 cao
- **(a) Answer: 0.125 mol/dm3**

Question 7

- (a) **M1** substitute Mr values: desired product Mr = 32; sum of reactants Mr = 28 + (2 x 2) = 32
- (a) **A1** 100% cao
- **(a) Answer: 100%**

Question 8

- (a) **M1** substitute into percentage yield = (actual / theoretical) x 100
- (a) **A1** 75% cao
- **(a) Answer: 75%**

Question 9

- (a) **M1** calculate moles: Al moles = 25.0 / 27.0 = 0.9259; Fe2O3 moles = 45.0 / 159.7 = 0.2817
- (a) **M1** identify limiting reagent: Fe2O3 limits because required Al for all Fe2O3 = 2 x 0.2817 = 0.5634 mol and available Al is greater
- (a) **M1** calculate moles Fe produced: 2 x moles Fe2O3 = 0.5634 mol
- (a) **A1** 31.5 g cao
- **(a) Answer: 31.5 g**

Question 10

- (a) **M1** calculate moles = 0.100 x 0.250 and mass = moles x Mr
- (a) **A1** 2.65 g cao
- **(a) Answer: 2.65 g**
- (b) **B1** any one reasonable control and brief reason, for example: final volume must be 250.0 cm3 so concentration is correct
- **(b) Answer: Keep the final volume at 250.0 cm3 so the concentration is correct.**

Question 11

- (a) **B1** identify 12.45 cm3 as anomalous (12.30 and 12.35 are concordant, differing by only 0.05 cm3, while 12.45 lies 0.10 cm3 or more above both)
- (a) **M1** plausible cause given, e.g. overshoot end point, parallax when reading burette, air bubble in burette, poor mixing
- **(a) Answer: 12.45 cm3 is anomalous; possible cause: overshot the end point or parallax error when reading the burette.**
- (b) **B1** improvement such as: perform a preliminary titration, add indicator dropwise near end point, ensure burette vertical and read bottom of meniscus at eye level, repeat titrations and use concordant mean
- (b) **B1** explanation of how this reduces error, eg adding dropwise reduces overshoot
- **(b) Answer: Add indicator dropwise near the end point and read the burette at eye level; this reduces the chance of overshooting and minimises parallax error.**

Question 12

- (a) **M1** use C1V1 = C2V2 and calculate V2 = (C1 x V1) / C2
- (a) **A1** 1000 cm3 cao
- **(a) Answer: 1000 cm3**

Question 13

- (a) **M1** substitute Mr: desired product Mr = 42; reactant Mr = 44; perform division
- (a) **A1** 95.5% cao
- **(a) Answer: 95.5%**

Question 14

- **Level 3** (5-6): Detailed evaluation: clearly explains two strategies, gives scientific reasons how each increases yield, and discusses limitations or trade-offs with specific examples.
- **Level 2** (3-4): Clear explanation of two strategies with some reasoning of how they increase yield and at least one limitation or trade-off.
- **Level 1** (1-2): Simple statements of one or two strategies with limited or no reasoning and no discussion of limitations.
- **Indicative content:**
  - Use Le Chatelier approach for reversible reactions: remove product continuously (for example distillation, decanting) to shift equilibrium to products; increases yield but may require extra apparatus, energy and may not be suitable if product and reactant boiling points are similar.
  - Purify product quickly by extraction or filtration to prevent reverse reaction and reduce loss to side reactions; increases isolated yield but may cause losses during transfer and require solvents which introduce cost and waste.
  - Use excess of one reactant to push equilibrium to product side; increases theoretical yield but requires recovery or disposal of excess and lowers atom economy.
  - Improve selectivity and reduce side reactions by optimising temperature, solvent and catalysts; increases yield but may need expensive catalysts and careful control; sometimes increases formation of unwanted by-products if conditions not ideal.
  - Consider trade-offs: higher yield vs purity, cost, energy use, environmental impact and atom economy.

Question 15

- (a) **M1** calculate moles NaOH: 0.1000 x (31.45 / 1000)
- (a) **M1** use mole ratio NaOH:H2A = 2:1 so moles H2A = moles NaOH / 2
- (a) **M1** divide moles H2A by 0.02500 dm3
- (a) **A1** 0.0629 mol/dm3 cao
- **(a) Answer: 0.0629 mol/dm3**

Question 16

- (a) **M1** calculate limiting reagent and theoretical mass: moles N_2 = 4.00 / 28.0 = 0.14286; theoretical moles NH_3 = 2 x 0.14286 = 0.28571; theoretical mass = 0.28571 x 17.0
- (a) **M1** calculate actual/theoretical x100
- (a) **A1** 86.5% cao
- **(a) Answer: 86.5%**

Question 17

- (a) **M1** convert mg to g: 50.0 mg/dm3 = 0.0500 g/dm3 and divide by Mr
- (a) **A1** 2.17×10^{-3} mol/dm3 cao
- **(a) Answer: 2.17×10^{-3} mol/dm3**

Question 18

- (a) **M1** calculate nominal moles and concentration: moles = 0.5000 / 150.0; conc = moles / 0.1000
- (a) **M1** calculate moles and conc for minimum mass 0.4995 g
- (a) **M1** calculate moles and conc for maximum mass 0.5005 g
- (a) **M1** state numeric range
- (a) **A1** gives correct range to stated sig figs, eg 0.033300 to 0.033367 mol/dm3
- **(a) Answer: Nominal 0.033333 mol/dm3; minimum 0.033300 mol/dm3; maximum 0.033367 mol/dm3**

Question 19

- (a) **M1** convert ppm to mg/dm3 and multiply by volume: 250 mg/dm3 x 2.00 dm3
- (a) **M1** convert mg to g
- (a) **A1** 0.500 g cao
- **(a) Answer: 0.500 g**

Question 20

- (a) **M1** calculate Mr $CaCl_2$ = 40.08 + (2 x 35.45) = 110.98 and sum Mr reactants = Mr $CaCO_3$ (100.09) + 2 x Mr HCl (2 x 36.458) = 173.01
- (a) **M1** divide and multiply by 100
- (a) **A1** 64.1% cao
- **(a) Answer: 64.1%**