C5bD Bond Energies, Cells and Fuel Cells: Exam Drill

AQA 8464 · Calculator allowed · about 90 minutes

Total Marks

Name: ______________________________ Date: ____ / ____ / ______

Answer ALL questions. Show all your working.

1 Give the definition of the term 'average bond enthalpy' used in bond energy calculations.

(a) Give the definition of 'average bond enthalpy'. **(1)**

(Total for Question 1 is 1 mark)

2 A molecule of hydrogen chloride, HCl, has an H-Cl bond enthalpy of 431 kJ per mole. Calculate the energy needed to break all the H-Cl bonds in 0.250 mol of HCl gas.

(a) Calculate the energy needed to break all H-Cl bonds in 0.250 mol HCl gas. **(2)**

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(Total for Question 2 is 2 marks)

3 Use bond enthalpies to estimate the enthalpy change for the reaction: H2(g) + Cl2(g) -> 2HCl(g). Use the bond enthalpies: H-H = 436 kJ mol^{-1}, Cl-Cl = 243 kJ mol^{-1}, H-Cl = 431 kJ mol^{-1}.

(a) Estimate the enthalpy change for the reaction using the bond enthalpy data given. Show substitution. **(2)**

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(Total for Question 3 is 2 marks)

4 Ammonia is manufactured by the reaction $N2(g) + 3H2(g) -> 2NH3(g)$. Use the following average bond enthalpies to estimate the enthalpy change for this reaction: nitrogen-nitrogen triple bond (in N2) = 945 kJ per mole; H-H = 436 kJ per mole; N-H = 391 kJ per mole.

(a) Calculate the enthalpy change for this reaction. Show your working and state the sign and unit. **(3)**

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(Total for Question 4 is 3 marks)

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5 A student makes a simple cell by connecting a magnesium electrode and a copper electrode, each dipped in electrolyte solution and joined by a wire and voltmeter. Magnesium is a much more reactive metal than copper.

a) State which electrode is the negative electrode and explain why.
b) The student then makes a magnesium-iron cell (iron is less reactive than magnesium, but more reactive than copper). State, with a reason, which of the two cells (magnesium-copper or magnesium-iron) would produce the larger potential difference.

(a) State which electrode is the negative electrode and give a brief explanation. **(1)**

(b) State, with a reason, which of the two cells (magnesium-copper or magnesium-iron) would produce the larger potential difference. **(3)**

(Total for Question 5 is 4 marks)

6 The hydrogen-oxygen fuel cell has the overall reaction: 2H2(g) + O2(g) -> 2H2O(l).

Write the two half-equations that occur at the anode and the cathode in a hydrogen-oxygen fuel cell operating with acid electrolyte. Indicate which half-equation goes at the anode.

(a) Write the half-equation at the anode and state it is the anode. **(2)**

(b) Write the cathode half-equation. **(1)**

(Total for Question 6 is 3 marks)

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7 A student measures the bond enthalpy of the C-H bond using different organic molecules and obtains a range of values. Explain why bond enthalpies are quoted as averages and why values for a given bond may differ between molecules.

(a) Explain why bond enthalpies are quoted as averages and why they vary between molecules. **(3)**

(Total for Question 7 is 3 marks)

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8 A class investigates simple cells made from different pairs of metal electrodes in electrolyte solution. Several groups each build an iron-copper cell and record its potential difference with a voltmeter. One group records a noticeably higher voltmeter reading than every other group, even though they used the same metals, electrolyte and method.

(a) Suggest three possible experimental reasons why this group's reading might be unexpectedly higher than the other groups', giving a brief explanation for each. **(4)**

(Total for Question 8 is 4 marks)

9 Calculate the mass of water produced when 0.500 mol of hydrogen reacts completely with oxygen in a fuel cell according to $2H_2 + O_2 \rightarrow 2H_2O$. Relative formula mass H_2O = 18.0.

(a) Calculate the mass of water produced from 0.500 mol H_2. **(2)**

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(Total for Question 9 is 2 marks)

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10 A candidate uses average bond enthalpies to estimate the enthalpy change for the reaction: $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$.
Use bond enthalpies: C-H = 413 kJ mol^{-1}, O=O (double bond) = 498 kJ mol^{-1}, C=O (in CO_2) = 799 kJ mol^{-1}, O-H = 463 kJ mol^{-1}.
Calculate the approximate DeltaH for the reaction. Show working and state the sign and unit.

(a) Calculate DeltaH using bond enthalpies with substitution and arithmetic. **(3)**

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(Total for Question 10 is 3 marks)

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11 Ethane burns completely in oxygen: $2C_2H_6(g) + 7O_2(g) \rightarrow 4CO_2(g) + 6H_2O(l)$. Use average bond enthalpies: C-C = 347 kJ per mole, C-H = 413 kJ per mole, O=O = 498 kJ per mole, C=O (in CO_2) = 799 kJ per mole, O-H = 463 kJ per mole. Calculate the enthalpy change for the reaction as written (for 2 mol of ethane). Show each step and give the final answer with its unit.

(a) Calculate DeltaH for the reaction as written, showing each step. **(4)**

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(Total for Question 11 is 4 marks)

12 In a required practical to investigate the reactivity series, a student measures the emf of cells made with different metal electrodes in a solution of their own ions. Explain one control variable and one improvement the student could make to reduce random error in emf measurements.

(a) State one control variable and explain why it should be controlled. **(1)**

(b) Give one improvement to reduce random error and explain how it helps. **(1)**

(Total for Question 12 is 2 marks)

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13 Explain how hydrogen fuel cells produce electrical energy from hydrogen and oxygen and evaluate two advantages and two disadvantages of using hydrogen fuel cells compared with petrol engines for cars. In your answer include the half-equations and mention sources of energy losses.

(Total for Question 13 is 6 marks)

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14 A student makes a simple cell using a zinc electrode and a silver electrode, both dipped in electrolyte solution and connected by a wire and voltmeter. Zinc is a much more reactive metal than silver.

(a) Explain which electrode is the negative electrode in this cell, and explain what happens to atoms at this electrode in terms of electron transfer. **(3)**

(b) Identify which electrode is the positive electrode. **(1)**

(Total for Question 14 is 4 marks)

15 A hydrogen-oxygen fuel cell releases 286 kJ of energy for every mole of water it produces, according to the overall reaction $2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$. 2.50 mol of hydrogen reacts completely in the fuel cell.

(a) Calculate the moles of water produced from 2.50 mol of hydrogen. **(2)**

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(b) Calculate the total energy released when 2.50 mol of hydrogen reacts completely. **(2)**

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(Total for Question 15 is 4 marks)

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16 A student is asked to compare using hydrogen in fuel cells with using hydrogen in internal combustion engines. Give two scientific advantages of fuel cells over internal combustion using hydrogen and one practical challenge that reduces the widespread use of fuel cells. Each point should be justified.

(a) Give two scientific advantages with justification and one practical challenge with justification. **(3)**

(Total for Question 16 is 3 marks)

Mark scheme · C5bD Bond Energies, Cells and Fuel Cells: Exam Drill

Question 1

- (a) **B1** the average energy required to break one mole of a particular bond in gaseous molecules, measured under standard conditions, oe
- **(a) Answer: The average energy required to break one mole of a particular bond in gaseous molecules under standard conditions.**

Question 2

- (a) **M1** substitutes: energy = 431 kJ mol^{-1} x 0.250 mol
- (a) **A1** 107.75 kJ (allow 108.0 kJ) cao
- **(a) Answer: 108 kJ**

Question 3

- (a) **M1** method: DeltaH approx = sum(bond enthalpies broken) - sum(bond enthalpies formed) and substitution: (436 + 243) - (2 x 431)
- (a) **A1** -183 kJ mol^{-1} (allow -182 to -184) cao
- **(a) Answer: -183 kJ mol^{-1}**

Question 4

- (a) **M1** substitutes bonds broken: (1 x 945) + (3 x 436)
- (a) **M1** substitutes bonds formed: 2NH3 has 6 N-H bonds, so 6 x 391
- (a) **A1** DeltaH = 2253 - 2346 = -93 kJ per mole cao
- **(a) Answer: -93 kJ per mole**

Question 5

- (a) **B1** magnesium electrode is the negative electrode because magnesium is the more reactive metal and loses electrons more readily (is oxidised)
- **(a) Answer: Magnesium electrode is the negative electrode because magnesium is more reactive than copper and loses electrons more readily.**
- (b) **M1** identifies the magnesium-copper cell as producing the larger potential difference cao
- (b) **M1** states that the size of the potential difference produced by a simple cell depends on the difference in reactivity between the two metals used
- (b) **A1** explains that magnesium and copper are further apart in reactivity than magnesium and iron, so the magnesium-copper cell has the bigger reactivity difference and produces the bigger potential difference, oe
- **(b) Answer: The magnesium-copper cell would produce the larger potential difference, because the size of the potential difference depends on the difference in reactivity between the two metals, and magnesium and copper are further apart in reactivity than magnesium and iron.**

Question 6

- (a) **M1** anode half-equation: H2 -> 2H+ + 2e-
- (a) **A1** states this occurs at the anode
- **(a) Answer: Anode: H2 -> 2H+ + 2e- (this is at the anode)**
- (b) **B1** cathode half-equation: O2 + 4H+ + 4e- -> 2H2O
- **(b) Answer: Cathode: O2 + 4H+ + 4e- -> 2H2O**

Question 7

- (a) **M1** states that bond enthalpies depend on the chemical environment so energy to break a C-H bond is not identical in all molecules
- (a) **M1** explains that different neighbouring atoms, bond order and hybridisation change bond strength and so measured values differ
- (a) **A1** concludes that tables give average values to provide useful estimates for calculations, oe
- **(a) Answer: Because the energy to break a C-H bond depends on the molecule and its environment (neighbouring atoms, bond order, hybridisation), measured values differ. Therefore tables quote average bond enthalpies so chemists have useful approximate values for calculations.**

Question 8

- (a) **M1** the electrodes were not cleaned properly (or one electrode was coated in oxide or another metal), changing the reading, explained
- (a) **M1** the electrolyte used was a different (eg more concentrated) solution from the other groups', which can affect the size of the potential difference, explained
- (a) **M1** a faulty or badly zeroed voltmeter, or poor electrical connections, gave an inaccurate reading, explained
- (a) **A1** any other valid experimental reason with explanation, such as accidentally using a different or impure metal sample, or a different temperature
- **(a) Answer: Possible reasons: electrodes not cleaned properly, or coated in oxide/another metal, changing the reading; electrolyte concentration different from the other groups', affecting the potential difference; a faulty or badly zeroed voltmeter, or poor connections, giving an inaccurate reading; or an impure metal sample being used by mistake.**

Question 9

- (a) **M1** uses mole ratio: 2 mol H2 produce 2 mol H2O so moles H2O = moles H2 = 0.500
- (a) **A1** mass = 0.500 x 18.0 = 9.00 g cao
- **(a) Answer: 9.00 g**

Question 10

- (a) **M1** method: DeltaH = sum bonds broken - sum bonds formed with substitution: broken = (4 x C-H) + (2 x O=O) = (4 x 413) + (2 x 498)
- (a) **M1** forms: (2 x C=O) + (4 x O-H) = (2 x 799) + (4 x 463) and correct arithmetic
- (a) **A1** final value = -802 kJ mol^{-1} (allow -792 to -812) cao
- **(a) Answer: -802 kJ mol^{-1}**

Question 11

- (a) **M1** counts and substitutes bonds broken: (2 x C-C) + (12 x C-H) + (7 x O=O) = (2 x 347) + (12 x 413) + (7 x 498)
- (a) **M1** evaluates bonds broken: 694 + 4956 + 3486 = 9136
- (a) **M1** counts and substitutes bonds formed: (8 x C=O) + (12 x O-H) = (8 x 799) + (12 x 463) = 6392 + 5556 = 11948
- (a) **A1** DeltaH = 9136 - 11948 = -2812 kJ cao
- **(a) Answer: -2812 kJ (for the reaction as written, i.e. per 2 mol of ethane burned)**

Question 12

- (a) **B1** control variable: concentration of the metal ion solutions and explanation that emf depends on concentration so must be kept constant
- **(a) Answer: Control variable: concentration of metal ion solutions, because emf depends on ion concentration and must be constant to compare cells.**
- (b) **B1** repeat measurements and take the mean, explanation that this reduces random variation and gives a more reliable emf value
- **(b) Answer: Repeat each emf measurement several times and use the mean, which reduces random variation and gives a more reliable value.**

Question 13

- **Level 3** (5-6): Detailed explanation of how fuel cells produce electricity including correct half-equations, clear evaluation of two advantages and two disadvantages, and mention of energy losses such as heat and overpotential. Links between points are clear and well explained.
- **Level 2** (3-4): Some explanation of fuel cell operation including at least one correct half-equation, and at least one advantage and one disadvantage with some explanation. Some mention of energy losses.
- **Level 1** (1-2): Limited statement about fuel cells, eg saying they produce electricity from hydrogen and oxygen with minimal detail. Advantages or disadvantages may be listed without explanation.
- **Indicative content:**
  - Anode half-equation: $H_2 \rightarrow 2H^+ + 2e^-$ (hydrogen oxidised)
  - Cathode half-equation: $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$ (oxygen reduced)
  - Overall reaction: $2H_2 + O_2 \rightarrow 2H_2O$ producing electrical energy
  - Advantages: produces only water so low local emissions; higher efficiency so less fuel used per km
  - Advantages: can be refuelled faster than battery electric vehicles
  - Disadvantages: hydrogen production often from fossil fuels unless renewable methods used, giving CO_2 emissions
  - Disadvantages: hydrogen storage and transport are difficult and costly
  - Energy losses: heat losses, overpotential at electrodes, internal resistance in the cell reduce the useful electrical energy
  - Practical issues: catalyst cost, durability and infrastructure

Question 14

- (a) **B1** the zinc electrode is the negative electrode cao
- (a) **M1** because zinc is the more reactive metal, so it loses electrons more readily than silver
- (a) **A1** zinc atoms lose electrons (are oxidised) to form Zn^{2+} ions, releasing electrons into the external circuit, oe
- **(a) Answer: The zinc electrode is negative, because zinc is more reactive than silver and loses electrons more readily: zinc atoms are oxidised to Zn^{2+} ions, releasing electrons into the circuit.**
- (b) **B1** silver electrode cao
- **(b) Answer: The silver electrode.**

Question 15

- (a) **M1** uses the 1:1 mole ratio between H_2 and H_2O in the equation
- (a) **A1** 2.50 mol H_2O cao
- **(a) Answer: 2.50 mol**
- (b) **M1** substitutes: energy = 2.50 x 286
- (b) **A1** 715 kJ cao
- **(b) Answer: 715 kJ**

Question 16

- (a) **M1** advantage 1: fuel cells produce water and no NO_x, SO_x or particulates when hydrogen is pure, reducing local pollution, with brief justification
- (a) **M1** advantage 2: fuel cells can be more efficient than combustion engines because chemical energy converts directly to electrical energy, with justification
- (a) **M1** challenge: hydrogen storage and distribution is difficult and energy intensive, explained as a practical barrier
- **(a) Answer: Advantages: (1) Fuel cells produce only water at the point of use, so they do not emit NO_x, SO_x or particulates, improving air quality. (2) Fuel cells can have higher overall efficiency as they convert chemical energy directly into electrical energy rather than via heat. Challenge: storing and transporting hydrogen safely and economically is difficult and energy intensive, limiting infrastructure and increasing costs.**