2.23 Bond Energies, Cells and Fuel Cells: 1-hour Pack

AQA 8464 · Calculator allowed · about 60 minutes

Total Marks

Name: _____ Date: ____ / ____ / _____

Answer ALL questions. Show all your working.

1 Use bond enthalpies to estimate the enthalpy change for the reaction: $H_2(g) + Cl_2(g) \rightarrow 2HCl(g)$. 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 1 is 2 marks)

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2 The overall reaction taking place inside a hydrogen fuel cell is between hydrogen and oxygen, producing water.

(a) Write the balanced symbol equation, including state symbols, for the overall reaction in a hydrogen fuel cell. **(2)**

(b) State the energy transfer that takes place inside a hydrogen fuel cell, and identify, in terms of electron transfer, what happens to hydrogen during this reaction. **(2)**

(Total for Question 2 is 4 marks)

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3 Chemical cells and batteries are used to store chemical energy and release it as electrical energy when needed.

(a) State what is meant by a 'chemical cell'. **(1)**

(b) State what is meant by a 'battery'. **(1)**

(c) State what is meant by an 'electrode'. **(1)**

(d) State one similarity between how a battery and a hydrogen fuel cell each produce electricity. **(1)**

(Total for Question 3 is 4 marks)

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4 Fatima investigates how the voltage produced by a simple chemical cell depends on the pair of metal electrodes used. She sets up cells using different pairs of metal electrodes dipped into dilute sulfuric acid, connects a voltmeter, and repeats each measurement three times. Her results are shown in Figure 2.

Figure 2: voltage produced by different pairs of metal electrodes

Metal pair	Repeat 1 / V	Repeat 2 / V	Repeat 3 / V
Iron and copper	0.78	0.79	0.80
Zinc and copper	1.08	1.10	1.65
Magnesium and copper	2.70	2.72	2.71
Magnesium and silver	3.15	3.17	3.16

(a) Identify the independent variable and the dependent variable in this investigation. **(2)**

(b) State two variables Fatima should control to make this a fair test. **(2)**

(c) Identify the anomalous result in the 'zinc and copper' row of the table, and calculate the mean voltage for this pair of metals, excluding the anomalous result. **(3)**

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(d) Describe the pattern shown by Fatima's results, linking it to the reactivity series. **(2)**

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.....

(e) Suggest one improvement Fatima could make to increase confidence in her conclusion. **(1)**

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(f) The bottle of dilute sulfuric acid used is labelled with a hazard symbol showing a black exclamation mark on an orange background. Name the hazard indicated by this symbol, and state one safety precaution Fatima should take. **(2)**

(g) Fatima now wants to investigate how the concentration of the sulfuric acid electrolyte affects the voltage produced by a zinc and copper cell. Describe how she could adapt her method to investigate this, name one variable she would need to keep constant, and state how she should present her results to identify any pattern. **(4)**

(Total for Question 4 is 16 marks)

5 A torch can be powered either by non-rechargeable alkaline batteries or by a rechargeable lithium-ion battery pack. Evaluate the use of a rechargeable lithium-ion battery pack compared with non-rechargeable alkaline batteries, for powering a torch that is used regularly over several years. In your answer, consider how each type of battery works, and their relative cost, convenience and environmental impact.

(Total for Question 5 is 6 marks)

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6 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 6 is 4 marks)

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7 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 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 four 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)

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9 Higher tier only. Hydrogen reacts with oxygen (including inside a hydrogen fuel cell) according to the equation $2H_2 + O_2 \rightarrow 2H_2O$. Bond energies: H-H = 436 kJ/mol, O=O = 498 kJ/mol, O-H = 463 kJ/mol.

(a) Calculate the total energy needed to break all the bonds in the reactants (2 mol of H_2 and 1 mol of O_2). **(2)**

(b) Each mole of H_2O contains two O-H bonds. Calculate the total energy released when the new bonds form in 2 mol of H_2O. **(2)**

(c) Calculate the overall energy change for this reaction (per 2 mol of hydrogen gas), and state whether the reaction is exothermic or endothermic. **(2)**

(d) State one reason why this large exothermic energy change makes hydrogen a useful fuel for a hydrogen fuel cell. **(1)**

(Total for Question 9 is 7 marks)

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Mark scheme · 2.23 Bond Energies, Cells and Fuel Cells: 1-hour Pack

Question 1

(a) method: DeltaH approx = sum(bond enthalpies broken) - sum(bond enthalpies formed) and substitution: (436 + 243) - (2 x 431) **M1**

(a) -183 kJ mol^{-1} (allow -182 to -184) cao **A1**

(a) Answer: -183 kJ mol^{-1}

Question 2

(a) correct formulae shown: H_2, O_2, H_2O oe **M1**

(a) correctly balanced with state symbols: $2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$ cao **A1**

(a) Answer: $2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$

(b) chemical energy (stored in the hydrogen and oxygen) is transferred to electrical energy, with some energy wasted as thermal energy oe **B1**

(b) hydrogen is oxidised (it loses electrons) oe **B1**

(b) Answer: Chemical energy is transferred to electrical energy (with some wasted as thermal energy). Hydrogen is oxidised, losing electrons, during this reaction.

Question 3

(a) a single unit that uses a chemical reaction between two electrodes and an electrolyte to produce a voltage (a source of electrical energy) oe **B1**

(a) Answer: A chemical cell is a single unit that uses a chemical reaction to produce a voltage.

(b) two or more chemical cells connected together (in series) oe **B1**

(b) Answer: A battery is two or more chemical cells connected together.

(c) a conductor (often a metal) that allows electric current to pass into or out of an electrolyte/cell oe **B1**

(c) Answer: An electrode is a conductor, often a metal, that allows electric current to pass into or out of a cell.

(d) both convert chemical energy (from a chemical/redox reaction) into electrical energy oe **B1**

(d) Answer: Both a battery and a hydrogen fuel cell convert chemical energy into electrical energy through a chemical reaction.

Question 4

(a) independent variable = the pair of metals used (the metal combination) oe **B1**

(a) dependent variable = the voltage produced (the voltmeter reading) oe **B1**

(a) Answer: Independent variable: the pair of metals used. Dependent variable: the voltage produced (voltmeter reading).

(b) the concentration of the dilute sulfuric acid (electrolyte) oe **B1**

(b) the volume of electrolyte used and/or the size (surface area) of the electrodes and/or the distance apart of the electrodes (any second valid control) oe **B1**

(b) Answer: For example: the concentration of the dilute sulfuric acid used, and the size (surface area) of the electrodes.

(c) 1.65 V cao **B1**

(c) (1.08 + 1.10) / 2 oe **M1**

(c) 1.09 V cao **A1**

(c) Answer: Anomalous result: 1.65 V. Mean voltage (excluding the anomaly) = (1.08 + 1.10) / 2 = 1.09 V.

(d) the greater the difference in reactivity between the two metals used, the greater the voltage produced oe **M1**

(d) e.g. magnesium and silver, which are furthest apart in the reactivity series, give the highest voltage (about 3.2 V); iron and copper, which are closest together, give the lowest voltage (about 0.8 V) oe **A1**

(d) Answer: The greater the difference in reactivity between the two metals, the greater the voltage produced: magnesium and silver (furthest apart in reactivity) give the highest voltage, while iron and copper (closest together) give the lowest voltage.

(e) repeat each measurement more times (and/or test additional pairs of metals with a range of reactivity differences) oe **B1**

(e) Answer: Repeat each measurement more times, and test additional pairs of metals covering a wider range of reactivity differences.

(f) irritant oe (accept harmful) **B1**

(f) wear eye protection/safety goggles oe (accept gloves) **B1**

(f) Answer: The symbol indicates the acid is an irritant. Fatima should wear eye protection (safety goggles) throughout the investigation.

(g) vary the concentration of the sulfuric acid electrolyte in a series of steps (e.g. by diluting a stock solution), using the same zinc and copper electrodes each time oe **B1**

(g) measure the voltage produced at each concentration, repeating each concentration to check for anomalies oe **B1**

(g) keep constant, e.g. the volume of electrolyte used, the size/surface area of the electrodes, or the distance apart of the electrodes oe **B1**

(g) plot a graph of voltage (y-axis) against concentration (x-axis) to identify the pattern/trend oe **B1**

(g) Answer: Vary the concentration of the sulfuric acid in steps (e.g. by dilution), keeping the same zinc and copper electrodes, and measure (repeating) the voltage at each concentration. Keep the volume of electrolyte and the size/distance apart of the electrodes constant. Plot a graph of voltage against concentration to identify the pattern.

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Question 5

Level 1 Simple, isolated statements are made, such as identifying that one type is rechargeable and one is not, with little or no linked explanation of cost, convenience or environmental impact. **1-2**

Level 2 A logical evaluation is given, covering some relevant factors (e.g. how the two chemistries differ, and one of cost, convenience or environmental impact), with some supporting detail, but coverage is not balanced or complete. **3-4**

Level 3 A balanced, well-linked evaluation is given, correctly explaining the difference between the reversible reaction in a rechargeable cell and the irreversible reaction in a non-rechargeable cell, and comparing cost, convenience and environmental impact, leading to a justified overall conclusion. **5-6**

Indicative content:

- A non-rechargeable alkaline battery uses a chemical reaction that cannot easily be reversed; once a reactant is used up, the battery must be thrown away and replaced.
- A rechargeable lithium-ion battery uses a reversible reaction; connecting it to a charger passes an electrical current through it that reverses the reaction, regenerating the original reactants so it can be reused many times.
- Buying replacement alkaline batteries repeatedly over several years is likely to cost more in total than the higher one-off cost of a rechargeable battery pack and charger.
- Rechargeable batteries are convenient in that new batteries do not need to be bought, but less convenient in that they take time to recharge and the torch may be unusable (or need a charged spare) while charging.
- Single-use alkaline batteries create ongoing waste, since large numbers must be manufactured and disposed of over the torch's lifetime, using up raw materials and energy.
- Lithium-ion batteries reduce the number of batteries thrown away, but contain reactive and potentially hazardous materials, and have a finite number of charge cycles before they must eventually be replaced and recycled.
- Overall, for a torch used regularly over several years, a rechargeable lithium-ion battery pack is likely to be the better financial and environmental choice, though a non-rechargeable battery may be more convenient for occasional or emergency use where recharging is not possible.

Question 6

(a) the zinc electrode is the negative electrode cao **B1**

(a) because zinc is the more reactive metal, so it loses electrons more readily than silver **M1**

(a) zinc atoms lose electrons (are oxidised) to form Zn^{2+} ions, releasing electrons into the external circuit, oe **A1**

(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) silver electrode cao **B1**

(b) Answer: The silver electrode.

Question 7

(a) advantage 1: fuel cells produce water and no NOx, SOx or particulates when hydrogen is pure, reducing local pollution, with brief justification **M1**

(a) advantage 2: fuel cells can be more efficient than combustion engines because chemical energy converts directly to electrical energy, with justification **M1**

(a) challenge: hydrogen storage and distribution is difficult and energy intensive, explained as a practical barrier **M1**

(a) Answer: Advantages: (1) Fuel cells produce only water at the point of use, so they do not emit NOx, SOx 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.

Question 8

(a) the electrodes were not cleaned properly (or one electrode was coated in oxide or another metal), changing the reading, explained **M1**

(a) the electrolyte used was a different (eg more concentrated) solution from the other groups', which can affect the size of the potential difference, explained **M1**

(a) a faulty or badly zeroed voltmeter, or poor electrical connections, gave an inaccurate reading, explained **M1**

(a) any other valid experimental reason with explanation, such as accidentally using a different or impure metal sample, or a different temperature **A1**

(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) 2 x 436 (for 2 mol H-H) + 498 (for 1 mol O=O) oe **M1**

(a) 1370 kJ/mol cao **A1**

(a) Answer: 1370 kJ/mol

(b) 2 mol H_2O contains 4 O-H bonds in total, so 4 x 463 oe **M1**

(b) 1852 kJ/mol cao **A1**

(b) Answer: 1852 kJ/mol

(c) 1370 - 1852, ft from a and b **M1**

(c) -482 kJ/mol; exothermic cao **A1**

(c) Answer: -482 kJ/mol; exothermic

(d) a large amount of energy is released (and transferred electrically) for every mole of hydrogen used, giving the fuel cell a high energy output per mole of fuel oe **B1**

(d) Answer: A large amount of energy is released per mole of hydrogen used, giving the fuel cell a high energy output for the fuel it consumes.

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