HIGHER

C6H Rate and Extent of Chemical Change: Higher Tier Practice

Total Marks

AQA 8462 · Calculator allowed · about 100 minutes

Name: _____ Date: ____ / ____ / _____

Answer ALL questions. Show all your working.

1 Collision theory explains how chemical reactions occur.

(a) State one requirement for a collision between reactant particles to lead to a reaction according to collision theory. **(1)**

(Total for Question 1 is 1 mark)

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2 A student adds excess magnesium ribbon to 50.0 cm3 of dilute hydrochloric acid and measures the volume of hydrogen gas produced over time. After 20 s, a total of 24.0 cm3 of gas had been collected.

(a) Calculate the mean rate of reaction over the first 20 s, in cm3 per second. **(2)**

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(Total for Question 2 is 2 marks)

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3 In an experiment, excess calcium carbonate reacts with dilute hydrochloric acid in a flask standing on a balance. The total loss in mass (as carbon dioxide gas escapes) is recorded every 10 seconds. After 10 s the flask had lost 0.32 g in mass; after 40 s it had lost 0.88 g in total.

(a) Calculate the mean rate of the reaction, in g per second, between 10 s and 40 s. **(3)**

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(Total for Question 3 is 3 marks)

4 A student investigates the effect of temperature on the rate constant k for a reaction. At 300 K k = 0.020 s-1 and at 320 K k = 0.060 s-1.

(a) Explain, using collision theory and activation energy concepts, why k increases with temperature. **(3)**

(Total for Question 4 is 3 marks)

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5 Hydrogen peroxide decomposes in the presence of iodide ions as a catalyst: 2H2O2(aq) -> 2H2O(l) + O2(g). A student measures volume of O2 produced at regular time intervals. The results for two experiments are given below.

Experiment 1 (no catalyst): time / s: 0, 30, 60, 90 ; volume O2 / cm3: 0, 12, 20, 24
Experiment 2 (with iodide catalyst): time / s: 0, 10, 20, 30 ; volume O2 / cm3: 0, 20, 32, 36

(a) Compare the rate of O2 production in the two experiments, and explain the role of the iodide ions. **(4)**

(Total for Question 5 is 4 marks)

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6 In a reversible reaction at equilibrium, the forward reaction is exothermic. Predict and explain how the equilibrium position changes if the temperature is increased.

(a) Predict the shift in equilibrium and explain using Le Chatelier's principle. **(3)**

(Total for Question 6 is 3 marks)

7 A student mixes 25.0 cm3 of 0.100 mol dm-3 solution of Na2S2O3 with 25.0 cm3 of 0.100 mol dm-3 HCl in a flask to produce SO2 or other components in a clock reaction. For a rate calculation simplified here assume total reacting volume is 50.0 cm3.

(a) Calculate the initial concentration of Na2S2O3 in the reaction mixture after mixing. **(2)**

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(b) If the initial rate of appearance of a gaseous product is measured as 1.00 x 10-4 mol dm-3 s-1, calculate the volume of gas formed in the first 120 s, in cm3, in the 50.0 cm3 mixture. Assume 1 mol of gas occupies 24.0 dm3 at room temperature and pressure. Express your answer to three significant figures. **(2)**

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(Total for Question 7 is 4 marks)

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8 Consider the equilibrium: N2(g) + 3H2(g) <-> 2NH3(g) delta H = -92 kJ mol-1. A chemist compresses the system by decreasing the volume while keeping temperature constant.

(a) Predict the direction of the equilibrium shift on compression and explain why, including an effect on yield of ammonia. **(4)**

(Total for Question 8 is 4 marks)

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9 In an experiment to find initial rates, a student measures the gradient at t = 0 from a concentration-time graph. The concentration-time data near t = 0 are: 0.000, 5.0, 9.0 mol dm-3 at times 0, 10 and 20 s respectively. Suggest a method to estimate the initial rate using these data and calculate the estimate.

(a) Suggest how to estimate the initial rate from the data and calculate the value in mol dm-3 s-1 using the first two points. **(3)**

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(Total for Question 9 is 3 marks)

10 A hydrated salt contains water of crystallisation. 1.50 g of hydrated salt is heated and loses 0.27 g of water. The remaining anhydrous salt has Mr = 120. The molar mass of water is 18.0.

(a) Calculate the number of moles of water lost and the number of moles of anhydrous salt present after heating. Show your working and then calculate the value of x in the formula salt.xH2O (number of water molecules per formula unit), to the nearest whole number. **(4)**

(Total for Question 10 is 4 marks)

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11 A reversible esterification equilibrium is: ethanol + ethanoic acid <-> ethyl ethanoate + water. A chemist wants to increase the equilibrium yield of ethyl ethanoate for an industrial production process.

(a) Suggest two practical changes to the reaction conditions that would increase yield of ethyl ethanoate and explain briefly why each helps. **(4)**

(Total for Question 11 is 4 marks)

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12 A graph of volume of gas produced against time for a reaction is a curve. A tangent is drawn to the curve at t = 20 s. The tangent passes through the points (10 s, 8.0 cm3) and (30 s, 32.0 cm3).

(a) Use the tangent to calculate the rate of reaction at t = 20 s, in cm3 per second. **(2)**

(b) Explain why the gradient of a tangent gives the rate of reaction at a specific point in time, rather than a mean rate. **(1)**

(Total for Question 12 is 3 marks)

13 Extended response: A chamber operates an industrial reversible reaction A(g) + B(g) <-> C(g) with delta H = -45 kJ mol-1. The plant manager considers three options to increase production of C: (1) raising pressure, (2) increasing temperature, (3) adding a catalyst. Discuss how each option affects yield, rate and energy costs. In your answer evaluate the best single change to maximise profitable production of C, justifying your conclusion.

(Total for Question 13 is 6 marks)

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14 A reaction profile shows that a catalyst lowers the activation energy of a reaction from 85 kJ per mole to 35 kJ per mole.

(a) Explain, in terms of collision theory, why lowering the activation energy increases the rate of reaction. **(2)**

(b) Explain how a catalyst is able to lower the activation energy, and why a catalyst is not used up in the reaction. **(3)**

(Total for Question 14 is 5 marks)

15 A heterogeneous catalytic reaction on a solid surface converts gas D to gas E. The rate is limited by the surface area of the catalyst. A student compares two catalyst pellets: Pellet P1 has surface area 0.50 m2 and Pellet P2 has surface area 2.00 m2 under otherwise identical conditions. The initial rate with P1 is 0.120 mol s-1.

(a) Assuming rate scales directly with catalyst surface area, calculate the expected initial rate with P2. **(2)**

(b) Explain two practical reasons why the real rate increase might be less than predicted by simple surface area scaling. **(4)**

(Total for Question 15 is 6 marks)

16 The equilibrium constant Kc for the reaction CO(g) + Cl2(g) <-> COCl2(g) is being investigated at a fixed temperature. At equilibrium, in a 1.00 dm3 vessel, the amounts present are 0.025 mol CO, 0.025 mol Cl2 and 0.075 mol COCl2.

(a) Write the expression for Kc for this equilibrium, and state the equilibrium concentrations of CO, Cl2 and COCl2 in mol dm-3. **(2)**

(b) Calculate the value of Kc, including its units. **(3)**

(Total for Question 16 is 5 marks)

Mark scheme · C6H Rate and Extent of Chemical Change: Higher Tier Practice

Question 1

- (a) **B1** particles must collide with sufficient energy (at or above the activation energy), oe
- **(a) Answer: Particles must collide with sufficient energy (at or above the activation energy).**

Question 2

- (a) **M1** substitutes: mean rate = 24.0 / 20
- (a) **A1** 1.20 cm3 per second cao
- **(a) Answer: 1.20 cm3 per second**

Question 3

- (a) **M1** finds the change in mass between 10 s and 40 s: 0.88 - 0.32 = 0.56 g
- (a) **M1** finds the change in time: 40 - 10 = 30 s
- (a) **A1** rate = 0.56 / 30 = 0.0187 g per second (allow 0.019 g/s) cao
- **(a) Answer: 0.0187 g per second (0.019 g/s to 2 s.f.)**

Question 4

- (a) **B1** states that increasing temperature increases particle kinetic energy and fraction of collisions with sufficient energy
- (a) **B1** links increased successful collisions to an increased rate or increased k
- (a) **B1** may refer to activation energy being a threshold that more particles overcome at higher temperature, oe
- **(a) Answer: Raising temperature increases particle kinetic energy so a greater fraction of collisions have energy at or above the activation energy, so more successful collisions occur and k increases.**

Question 5

- (a) **B1** states that Experiment 2 produces oxygen faster (greater volume earlier) cao
- (a) **B1** gives an example from the data, e.g. at 30 s Exp2 gives 36 cm3 but Exp1 gives 12 cm3
- (a) **B1** states that iodide ions act as a catalyst, increasing reaction rate without being consumed
- (a) **B1** explains catalyst provides an alternative pathway with lower activation energy so more successful collisions, oe
- **(a) Answer: Experiment 2 produces oxygen faster; for example at 30 s Exp2 gives 36 cm3 but Exp1 gives 12 cm3. Iodide ions act as a catalyst, providing an alternative route with lower activation energy so more collisions are successful.**

Question 6

- (a) **B1** states the equilibrium shifts in the endothermic direction (to oppose the increase in temperature)
- (a) **B1** explains that for an exothermic forward reaction increasing temperature favours the reverse reaction which is endothermic
- (a) **B1** states consequence e.g. concentration of products decreases, or yield of products falls, oe
- **(a) Answer: Equilibrium shifts in the endothermic direction (reverse reaction favoured). For an exothermic forward reaction increasing temperature favours the reverse reaction, so product concentration falls and yield of products decreases.**

Question 7

- (a) **M1** uses dilution relation: c1v1 = c2v2 or concentration = (moles total)/(total volume)
- (a) **A1** gives 0.0500 mol dm-3 cao
- **(a) Answer: 0.0500 mol dm-3**
- (b) **M1** uses amount = rate x time to find change in concentration: 1.00e-4 x 120 = 1.20e-2 mol dm-3
- (b) **A1** finds moles = concentration x volume = 1.20e-2 mol dm-3 x 0.0500 dm3 = 6.00e-4 mol, then volume of gas = 6.00e-4 x 24.0 dm3 mol-1 = 0.0144 dm3 = 14.4 cm3 cao
- **(b) Answer: 14.4 cm3**

Question 8

- (a) **B1** states equilibrium shifts to side with fewer gas molecules
- (a) **B1** identifies fewer gas molecules are on the product side (2) compared with reactants (4)
- (a) **B1** concludes shift to right (towards NH_3) when volume decreases
- (a) **B1** states yield of ammonia increases as a result, oe
- **(a) Answer: Compression shifts equilibrium to the right because the product side has fewer gas molecules (2) than the reactant side (4), so ammonia yield increases.**

Question 9

- (a) **M1** uses gradient method: rate approx change in concentration / change in time using early points
- (a) **M1** calculates using first two points: (5.0 - 0.0) / (10 - 0) = 0.50
- (a) **A1** gives 0.50 mol dm-3 s-1 cao
- **(a) Answer: 0.50 mol dm-3 s-1**

Question 10

- (a) **M1** calculates moles H_2O = 0.27 / 18.0 = 0.0150 mol
- (a) **M1** calculates mass anhydrous = 1.50 - 0.27 = 1.23 g then moles anhydrous = 1.23 / 120 = 0.01025 mol (or 1.025e-2)
- (a) **M1** calculates ratio x = moles H_2O / moles anhydrous = 0.0150 / 0.01025 = 1.463 approx
- (a) **A1** gives x = 1 (nearest whole number) cao
- **(a) Answer: 1**

Question 11

- (a) **B1** suggests using excess ethanol (or remove ethanoic acid) and explains equilibrium shifts to right
- (a) **B1** suggests removing product water as it forms and explains this shifts equilibrium to right
- (a) **B1** suggests using a dehydrating agent or molecular sieves to remove water, with brief explanation
- (a) **B1** alternative acceptable suggestion: using a catalyst to speed equilibrium attainment (not changing yield), with explanation that catalyst helps reach equilibrium faster
- **(a) Answer: Any two: use excess ethanol to shift equilibrium to products; remove water as it forms (e.g. using a dehydrating agent) to shift equilibrium to products. Both increase yield by Le Chatelier principle. A catalyst can be used to reach equilibrium faster.**

Question 12

- (a) **M1** calculates the gradient of the tangent: (32.0 - 8.0) / (30 - 10)
- (a) **A1** 1.2 cm3 per second cao
- **(a) Answer: 1.2 cm3 per second**
- (b) **B1** the tangent touches the curve at only that one point, so its gradient matches the slope of the curve (and so the rate) at that exact instant, rather than averaging over a time interval, oe
- **(b) Answer: A tangent touches the curve at just one point, so its gradient matches the steepness of the curve at that instant, giving the rate at that specific time rather than an average over an interval.**

Question 13

- **Level 3** (5-6): Detailed evaluation: clear, balanced discussion of how pressure, temperature and catalyst affect yield, rate and energy costs; justified conclusion selecting the best single change with reasoning considering both chemical equilibrium and economic factors.
- **Level 2** (3-4): Some evaluation: describes effects on yield and rate for at least two changes with some consideration of energy or cost; offers a conclusion with limited justification.
- **Level 1** (1-2): Basic statements: limited description of how one or two changes affect yield or rate; little or no evaluation or justification.
- **Indicative content:**
  - Pressure: increasing pressure shifts equilibrium to side with fewer gas molecules. Here reactants 2 mol -> product 1 mol so high pressure increases yield; energy cost of compression is high; rate may increase due to higher collision frequency; equipment costs and safety issues.
  - Temperature: forward reaction exothermic so increasing temperature shifts equilibrium to left reducing yield; increasing temperature does increase rate but lowers product yield; energy costs for heating and potential material limits.
  - Catalyst: does not change equilibrium position so yield unchanged, but increases rate so equilibrium reached faster allowing higher throughput; catalysts often reduce energy costs per unit product by allowing lower temperatures or faster cycles; catalyst cost and lifetime are factors.
  - Evaluation: weigh increased yield from higher pressure versus high operational cost; catalyst may be best single change if yield is already acceptable because it increases throughput with lower energy penalty; if yield must increase substantially pressure may be justified despite cost; final recommendation should justify trade-offs.

Question 14

- (a) **M1** states that, at a given temperature, a greater proportion of colliding particles will now have energy greater than or equal to the (lower) activation energy
- (a) **A1** so more collisions are successful (result in a reaction) in a given time, increasing the rate of reaction
- **(a) Answer: With a lower activation energy, a greater proportion of colliding particles have enough energy to react, so more collisions are successful and the rate of reaction increases.**
- (b) **B1** a catalyst provides an alternative reaction pathway (mechanism) for the reaction
- (b) **B1** this alternative pathway has a lower activation energy than the uncatalysed reaction
- (b) **B1** the catalyst is not chemically changed or used up by the reaction, so it can be reused, oe
- **(b) Answer: A catalyst provides an alternative reaction pathway with a lower activation energy. The catalyst itself is not chemically changed or used up, so it can go on to catalyse further reactions.**

Question 15

- (a) **M1** uses proportional scaling: rate2 = rate1 x (area2/area1)
- (a) **A1** gives rate = 0.480 mol s-1 cao
- **(a) Answer: 0.480 mol s-1**
- (b) **B1** mentions diffusion or mass transport limits to bring reactants to surface, reducing effectiveness of extra area
- (b) **B1** mentions active site availability or site blockage by impurities, meaning not all surface area is catalytic
- (b) **B1** mentions agglomeration or pore structure limiting accessible surface area, oe
- (b) **B1** mentions heat or local concentration gradients that reduce reaction rate efficiency, oe
- **(b) Answer: Real increase may be less because diffusion/mass transport can limit access of reactants to additional surface, and not all surface area may be active due to pore structure or site blockage by impurities. Heat or concentration gradients can also limit effective rate.**

Question 16

- (a) **M1** Kc = [COCl2] / ([CO][Cl2]) cao
- (a) **A1** since the vessel volume is 1.00 dm3, [CO] = [Cl2] = 0.025 mol dm-3 and [COCl2] = 0.075 mol dm-3 cao
- **(a) Answer: Kc = [COCl2] / ([CO][Cl2]); [CO] = [Cl2] = 0.025 mol dm-3, [COCl2] = 0.075 mol dm-3.**
- (b) **M1** substitutes: Kc = 0.075 / (0.025 x 0.025)
- (b) **A1** Kc = 120 cao
- (b) **A1** units: (mol dm-3) / (mol dm-3)^2 = dm3 mol-1 cao
- **(b) Answer: Kc = 120 dm3 mol-1**