InkChemistry

ANSWER BOOK

Dynamic equilibrium, Le Chatelier's principle and industrial compromise

Chemical equilibria · Unit C06

AQA 3.1.6.1 · OCR A 3.2.3

16 questions · 55 marks

NAVY EDITION

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SECTION A · Short, 1 to 2 marks

A1 DEL-Q1

B1 the forward and reverse reactions are both still taking place, at equal rates. [2]
B1 the concentrations of the reactants and products remain constant; reject 'equal concentrations'.

SECTION B · Standard, 3 to 5 marks

B1 DEL-Q2

B1 if a system at equilibrium is subjected to a change in conditions, the position of equilibrium shifts in the direction that opposes the change. **B1** for SO_3 there are three moles of gas on the left and two on the right, so the position shifts right, to fewer moles of gas, which lowers the pressure; allow 'fewer gas molecules'. **B1** for HI there are two moles of gas on each side of the equation. **B1** a shift in either direction would not change the number of gas molecules, so it could not oppose the change in pressure and the yield of HI is unchanged. [4]

B2 DEL-Q7

B1 the brown colour pales at once, because the same molecules now occupy a larger volume, so the concentration of NO_2 falls. **B1** the pressure has decreased, so the position of equilibrium shifts to the right, the side with more moles of gas. **B1** N_2O_4 molecules dissociate into NO_2, which raises the pressure, so the brown colour then deepens again. **B1** the final colour is still paler than at the start, because the shift only partly opposes the change. [4]

B3 DEL-Q8

B1 the catalyst lowers the activation energy of the forward and the reverse reaction by the same amount. **B1** both rates increase by the same factor and stay equal, so the concentrations do not change; equilibrium is only reached sooner. **B1** the converter could run at a lower temperature, where the exothermic forward reaction gives a higher equilibrium yield on each pass, at the same rate. **B1** less unreacted gas would be recycled and recompressed, or a lower pressure could be used, so less energy is spent on compression. [4]

B4 DEL-Q17

B1 three moles of gas become one, so a higher pressure shifts the position to the right and raises the equilibrium yield. **B1** a higher pressure also increases the concentration of the gases and so the rate. **B1** against this, compression needs much more energy and the plant needs thicker, more expensive vessels and pipes, with a greater hazard from leaks. **B1** a judgement: the proposal is justified only if the value of the extra methanol exceeds the extra energy and plant cost, and with recycling the gain is likely to be small; allow either conclusion if it follows from the points made. [4]

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B5 DEL-Q18 **B1** both run at about 450 °C as a compromise between yield and rate for an exothermic forward reaction. **B1** the Haber process uses about 200 atm, because its equilibrium yield at low pressure is too small. **B1** the Contact process uses only 1 to 2 atm, because the conversion over several catalyst beds is already above 99%, so compression would not pay for itself. **B1** the Haber process uses an iron catalyst and recycles its unreacted gas; the Contact process uses vanadium(V) oxide, excess air and cooling between the beds. [4]

B6 DEL-Q4 **B1** a temperature of about 300 °C; allow 250 to 350 °C. **B1** a pressure of about 60 to 70 atm; allow 6 to 7 MPa. **B1** a catalyst of phosphoric acid on a silica support; accept phosphoric(V) acid or H_3PO_4. [3]

B7 DEL-Q5 **B1** at the start the forward rate is at its highest, because hydrogen and iodine are at their highest concentrations, and the reverse rate is zero. **B1** as hydrogen and iodine are used up the forward rate falls, and as hydrogen iodide builds up the reverse rate rises. **B1** equilibrium is reached when the two rates become equal, after which the concentrations no longer change. [3]

B8 DEL-Q6 **B1** in the sealed container the carbon dioxide cannot escape, so it builds up and the reverse reaction with calcium oxide takes place. **B1** when the reverse rate equals the forward rate a dynamic equilibrium is set up; this needs a closed system. **B1** in the open kiln the carbon dioxide is carried away, so the reverse reaction cannot occur and the forward reaction continues until all the calcium carbonate has decomposed. [3]

B9 DEL-Q11 **B1** raising the pressure has no effect on the yield, because there are two moles of gas on each side. **B1** raising the temperature lowers the yield, because the forward reaction is exothermic and the position shifts in the endothermic direction, to the left. **B1** a catalyst allows a lower temperature, which favours the yield, while keeping the rate high enough. [3]

B10 DEL-Q12 **B1** ΔH is positive: heating shifts the position to the right, which is the endothermic direction. **B1** adding concentrated hydrochloric acid raises the chloride concentration, shifting the position right, so the solution turns blue. **B1** adding water dilutes the solution and lowers the chloride concentration, so the position shifts to the left and the solution turns pink. [3]

B11 DEL-Q15 **M1** ammonia = $0.270 \times 1.00 \times 10^4 = 2700$ mol, so nitrogen and hydrogen together = 7300 mol. **M1** nitrogen is one quarter of this and hydrogen three quarters, from the 1 : 3 ratio. **A1** nitrogen = 1830 mol and hydrogen = 5480 mol, to three significant figures; accept 1825 and 5475 mol. [3]

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B12 DEL-Q16

B1 the gas mixture is cooled, and ammonia condenses to a liquid while nitrogen and hydrogen remain as gases. **B1** the liquid ammonia is run off and the unreacted nitrogen and hydrogen are recycled to the converter. **B1** over many passes about 98% of the reactants are converted, so little is wasted despite the low yield per pass. [3]

B13 DEL-Q19

B1 in hot water the solution turns blue, so the position has shifted to the right. **B1** in iced water the solution turns pink, so the position has shifted to the left. **B1** a rise in temperature shifts the position in the endothermic direction, so the forward reaction, favoured by heating, is endothermic. [3]

B14 DEL-Q20

B1 one tube is placed in hot water at about 80 °C and one in iced water. **B1** the third tube is left at room temperature as a control, against which the colours of the other two are compared. **B1** the hot tube turns blue and the cold tube pink, and both return to purple at room temperature, showing a reversible shift in the position of equilibrium. [3]

SECTION C · Long, 6 marks or more

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C1 [6]
DEL-Q9

Indicative content

B1 the forward reaction is exothermic, so a low temperature would shift the position of equilibrium to the right and give a higher equilibrium yield of ammonia. **B1** at a low temperature too few collisions have energy equal to or greater than the activation energy, even on the catalyst, so the rate and the output per hour would be far too low. **B1** about 450 °C is therefore a compromise between equilibrium yield and rate, accepting a lower yield to make ammonia quickly. **B1** four moles of gas become two, so a high pressure shifts the position to the right, towards fewer moles of gas, and also raises the rate by raising the concentrations. **B1** a very high pressure needs much more energy for compression and thicker, more expensive pipes and vessels, with a greater hazard from leaks, so about 200 atm balances yield against cost and safety. **B1** the iron catalyst raises the forward and reverse rates equally without changing the yield, and recycling the unreacted nitrogen and hydrogen makes about 98% of them into ammonia overall although each pass converts only about 15%.

Levels

Level 3 (5–6 marks) all three conditions are explained, each as a compromise: the temperature between equilibrium yield and rate for the exothermic reaction, the pressure between yield and the cost and hazard of compression, and the catalyst with the recycling that raises the overall conversion.

Level 2 (3–4 marks) temperature and pressure are explained as compromises through Le Chatelier's principle; the catalyst or the recycling is not explained, or one compromise is argued from one side only.

Level 1 (1–2 marks) a low temperature or a high pressure is said to favour ammonia; the catalyst is commonly said to raise the yield, and nothing is weighed against cost or rate.

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