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VCE Chemistry ¾

AOS 2 Revision (Rates & Equilibrium) [2.0]

SAC 1 Solutions

50 Marks. 12 Minute Reading. 75 Minutes Writing.

Section A: Multiple Choice Questions (5 Marks)

The following information applies to the two questions that follow.

The equation for the reaction between ethyne and hydrogen is:

$$C_2H_2(g) + 2H_2(g) \rightleftarrows C_2H_6(g) \qquad \Delta H = -355\ kJ\ mol^{-1}$$

At 150°C, the value of K is 248 M^{-2}.

Question 1 (1 mark) **[2.7.5]** Apply RICE tables to find K_c

A sample of C_2H_6 is added to an empty reactor.

Select the correct alternative for the concentrations when the mixture comes to equilibrium at 150°C.

A. $[H_2] > [C_2H_6]$

B. $[H_2] = 2[C_2H_6]$

C. $[H_2] = [C_2H_2]$

D. $[H_2] < [C_2H_6]$

The key to this question is the high value of *K*. This requires the amount of product to be much higher than the amount of reactant as in option D.

Question 2 (1 mark) **[2.7.5]** Apply RICE tables to find K_c

The temperature of an equilibrium mixture of the three gases is increased. As a consequence, the:

A. Amount of C_2H_6 will increase.

The reaction is exothermic so a rise in temperature will favour the back reaction. The stoichiometry of the reaction provides the 2:1 ratio.

B. Amount of H_2 will increase by twice the amount of C_2H_2.

C. Amount of H_2 will increase by the same amount as the C_2H_2.

D. Amount of H_2 will increase by the amount that the C_2H_6drops by.

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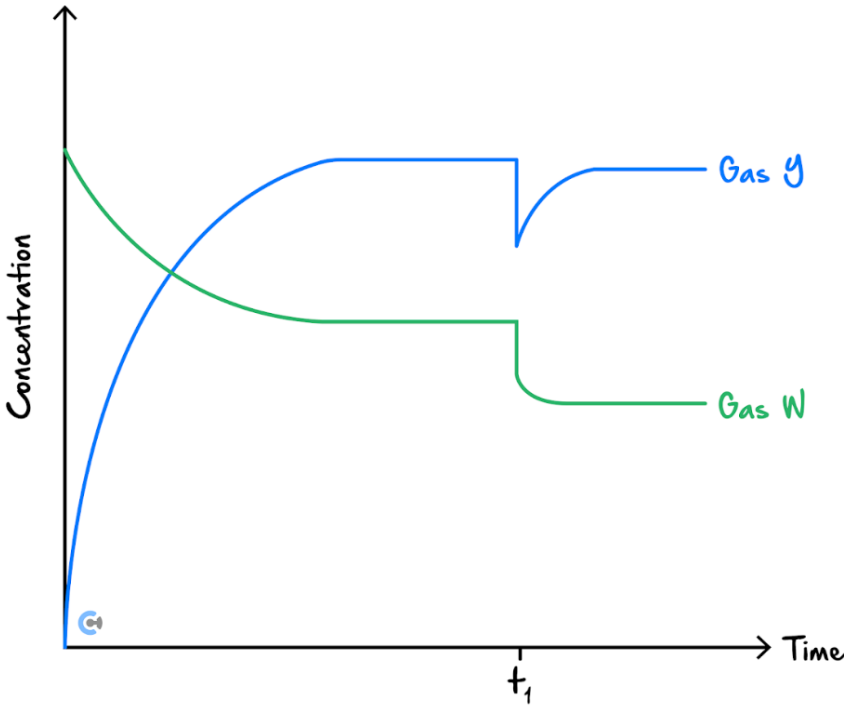
Question 3 (1 mark) **[2.9.3]** Find the change made to system from equilibrium graph

The gases W and X were placed in a sealed container and allowed to reach equilibrium in an exothermic reaction by the equation $W(g) + X(g) \rightleftharpoons 3Y(g) + Z(g)$. The graph below shows the concentration of gases W and Y throughout the reaction.



Which one of the following most likely occurred at t_1?

A. Samples of gas W and gas Y were added to the container.

B. The gases in the container were heated to a higher temperature.

C. The volume of the container was increased at a constant temperature.

D. An inert gas was added to the mixture at a constant temperature.

Question 4 (1 mark) **[2.7.4]** Apply Q_c to find direction of equilibrium shift.

If the reaction quotient Q has a larger value than the related equilibrium constant K then:

A. The reaction is at equilibrium.

B. The reaction is not at equilibrium and will make more products at the expense of the reactants.

C. The reaction is not at equilibrium and will make more reactants at the expense of the products.

D. The value of K will increase until it reaches the Q value.

Question 5 (1 mark)

[2.7.1] Write equilibrium constant expression & find its value (including units)

Write an expression for the equilibrium constant for this reaction.

$$Ti(s) + 2Cl_2(g) \rightleftharpoons TiCl_4(l)$$

A. $\frac{1}{[Cl_2]}$

B. $\frac{[TiCl_4]}{[Ti][Cl_2]^2}$

C. $\frac{1}{[Cl_2]^2}$

D. $\frac{[TiCl_4]}{[Ti][Cl_2]}$

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Section B: Short Answer Questions (45 Marks)

Question 6 (9 marks)

The reaction between hydrochloric acid and oxygen is a reversible, exothermic reaction:

$$4HCl(g) + O_2(g) \rightleftarrows 2H_2O\,(g) + 2Cl_2(g) \qquad \Delta H = -29\ kJ\ mol^{-1}$$

Consider the impact of the following changes on an equilibrium mixture of the above gases.

a. The volume of an equilibrium mixture is doubled. Explain the impact on

i. The value of K. (1 mark)

[2.8.1] Explain effects of addition/removal of substances or pressure/volume changes on equilibrium system

no change to K as temperature has not changed

ii. The concentration of oxygen. (1

[2.8.3] Apply partial opposition during equilibrium to the effects on amount, concentration & colour of substance

the concentration of oxygen will drop as the doubling of the volume halved the concentration. The system will oppose this change but the concentration will still be lower.

b. Oxygen is added to an equilibrium mixture. Explain the impact this has on the final concentration of oxygen. (2 marks)

1 mark for [2.8.1] Explain effects of addition/removal of substances or pressure/volume changes on equilibrium system,
1 mark for [2.8.3] Apply partial opposition during equilibrium to the effects on amount, concentration & colour of substance

Final concentration of oxygen will be higher. The concentration of oxygen was increased, the system moves forward to partially oppose this change but the final concentration is higher than the original.

c. The temperature of an equilibrium mixture is decreased. Explain the impact on the value of K_c, and the concentration of HCl. (3 marks)

2 marks for [2.9.1] Explain effects of temperature, inert gas or catalyst on equilibrium system,
1 mark for [2.9.4] Find equilibrium constant changes due to temperature

As temperature is decreased, Le Chatelier's Principle states the system partially opposes the change by increasing temperature back up, favouring the forwards exothermic reaction. (1 M – Explanation)
This uses HCl, decreasing concentration of HCl. (1 M)
As it shifts forwards, the amount of products present at equilibrium increases, increasing the value of the equilibrium constant. (1 M)

d. A catalyst is added to a sample of HCl and oxygen. Explain how the system will respond compared to the original. (1 mark)

[2.9.1] Explain effects of temperature, inert gas or catalyst on equilibrium system

it will reach the same point of equilibrium but it will reach it faster due to the catalyst.

e. Argon gas is added to the system. State the effect this has on the concentration of hydrogen gas present in the same volume container. (1 mark)

[2.9.1] Explain effects of temperature, inert gas or catalyst on equilibrium system

No effect (explanation - inert gas does not shift position of equilibrium. It increases overall concentration, but partial concentration of hydrogen gas doesn't change.)

Question 7 (9 marks)

Chlorine and fluorine gases react to form the compound, ClF_3. The reaction is:

$$Cl_2(g) + 3F_2(g) \rightleftarrows 2ClF_3(g)$$

a. Write the expression for the equilibrium constant. (1 mark)

[2.7.1] Write equilibrium constant expression & find its value (including units)

$$K_c = \frac{[ClF_3]^2}{[Cl_2][F_2]^3}$$

b.

i. At a particular temperature, an equilibrium mixture in a 5.00 L reactor contains the following.

1.4 mol Cl_2 1.2 mol F_2 2.2 mol ClF_3

Calculate the equilibrium constant value for this reaction. (1 mark)

[2.7.1] Write equilibrium constant expression & find its value (including units)

i. $[Cl_2] = \frac{1.4}{5} = 0.28$ M $[F_2] = \frac{1.2}{5} = 0.24$ $ClF_3 = \frac{2.2}{5} = 0.44$ M

$$K = \frac{0.44^2}{0.28 \times 0.24^3} = 50 \text{ M}^{-2}$$

ii. State whether the extent of the reaction is small, medium or large. Explain your answer. (1 mark)

[2.7.2] Identify the extent of reaction

medium - K_c lies between 10^{-4} and 10^4.

iii. At the same temperature, a different equilibrium mixture is found to have a concentration of Cl_2 of 0.42 M and a ClF_3 concentration of 0.71 M. Find the concentration of F_2 gas. (1 mark)

[2.7.1] Write equilibrium constant expression & find its value (including units)

$$K = \frac{0.71^2}{0.42 \times x^3} = 50 \quad \Rightarrow \quad x^3 = 0.024 \Rightarrow x = 0.29 \text{ M}$$

c. At a new temperature, 0.54 mol of ClF_3 is added to an empty 1.0 L reactor. When equilibrium is reached, the amount of ClF_3 is found to be 0.40 mol. Calculate the equilibrium constant value at this new temperature. (3 marks)

[2.7.5] Apply RICE tables to find K_c

$Cl_2(g)$	+ $3F_2(g)$	⇄ $2ClF_3(g)$	
0	0	0.54	start
		0.40	equil

=> change is 0.14 mole

$n(Cl_2) = 0.07$ mol $n(F_2) = 0.21$ mol

$$K = \frac{0.40^2}{0.07 \times 0.21^3} = 247 \text{ M}^{-2}$$

d. A mixture of the above gases is at equilibrium. If the volume of the reactor is now halved, explain how this affects the amount of fluorine gas present. (2 marks)

[2.8.1] Explain effects of addition/removal of substances or pressure/volume changes on equilibrium system

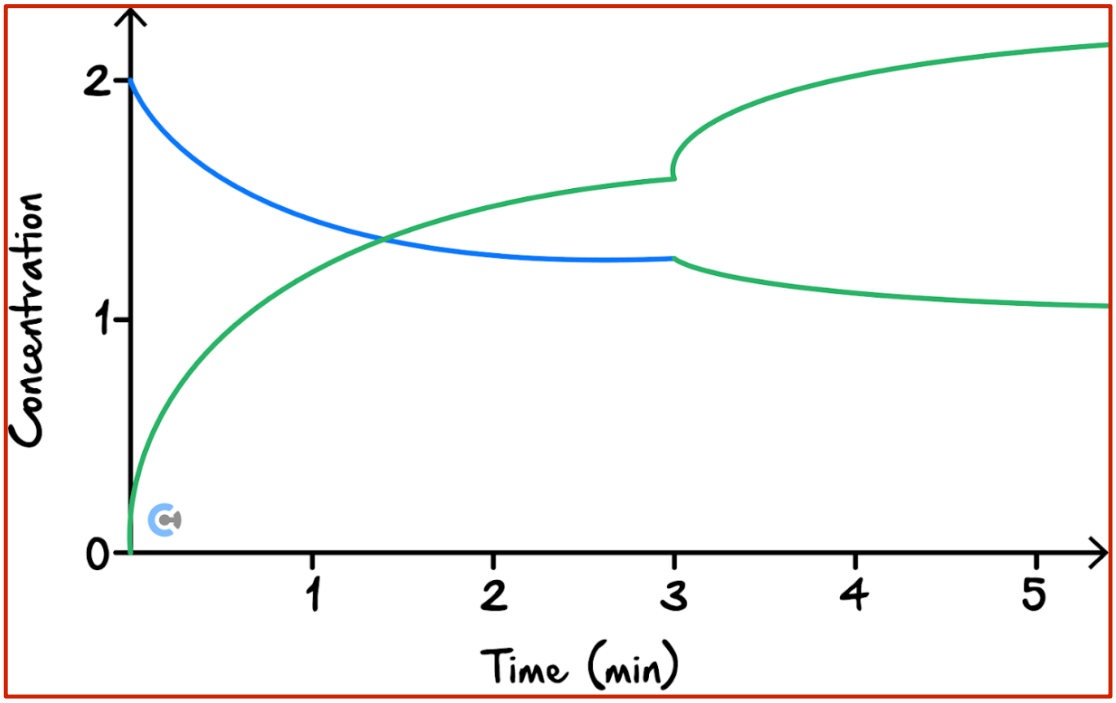
As volume is halved, amount of fluorine gas doesn't change. Overall concentration increases, and the system shifts forwards to partially oppose the change. This decreases the amount of fluorine gas present. (1 M)

Overall, amount of fluorine gas decreases. (1 M)

Question 8 (8 marks)

The graph below is related to the formation of nitrogen dioxide from dinitrogen tetroxide.

$$N_2O_4(g) \rightleftarrows 2NO_2(g) \qquad \Delta H = +173\ kJ\ mol^{-1}$$



a. N_2O_4 is added to an empty reactor. Its concentration is shown on the graph. Draw on the same graph, the graph for the NO_2 concentration. (1 mark)

[2.8.2] Graph effects of addition/removal of substances or pressure/volume changes on equilibrium system

b. Calculate the K_c value at 3 minutes. (2 marks)

[2.7.1] Write equilibrium constant expression & find its value (including units)

$$K = \frac{[NO_2]^2}{[N_2O_4]} = \frac{1.5}{1.25} = 1.8\ M$$

c. At the 3-minute mark, the temp[illegible] concentrations of the two chemi[illegible]s re-established at 5 minutes. (2 mar[illegible])

[2.8.2] Graph effects of addition/removal of substances or pressure/volume changes on equilibrium system

d. NO_2 is brown in colour. The volume of an equilibrium mixture is halved and the system is allowed to establish a new equilibrium.

Explain how the brown colour of the mixture changes during this reaction. (3 marks)

[2.8.3] Apply partial opposition during equilibrium to the effects on amount, concentration & colour of substance.

As volume is halved, concentration overall doubles, including NO_2, making the system more brown initially. (1 M)
According to Le Chatelier's Principle, system partially opposes the change by decreasing overall concentration, favouring the side with less particles and shifting reverse. As it shifts reverse, concentration of NO_2 decreases, making the system less brown. (1 M)
Overall, as the system only partially opposes the change, the system is more brown overall. (1 M)

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Question 9 (7 marks)

The reaction between bromine gas and methanoic acid is:

$$Br_2(aq) + HCOOH(aq) \rightarrow 2Br^-(aq) + 2H^+(aq) + CO_2(g)$$

Br_2 gas has a brown colour but Br^- ions are colourless.

a. A 1.0-mole sample of bromine is reacted with a 0.8-mole sample of methanoic acid.

i. The brown intensity of colour is seen to decrease over time but varies in the rate at which it decreases. Describe how the intensity of brown colour decreases over time, and state the final colour at the end of the reaction. (2 marks)

[2.6.1] Explain how factors increase frequency of collisions

The brown colour should fade quickly at first, then slow down. Some brown will remain at the end as Br_2 is the excess reagent.

ii. The reaction is repeated with the same amount of chemicals but this time with an added catalyst. Compare the change in brown intensity of this reaction with the first reaction. (1 mark)

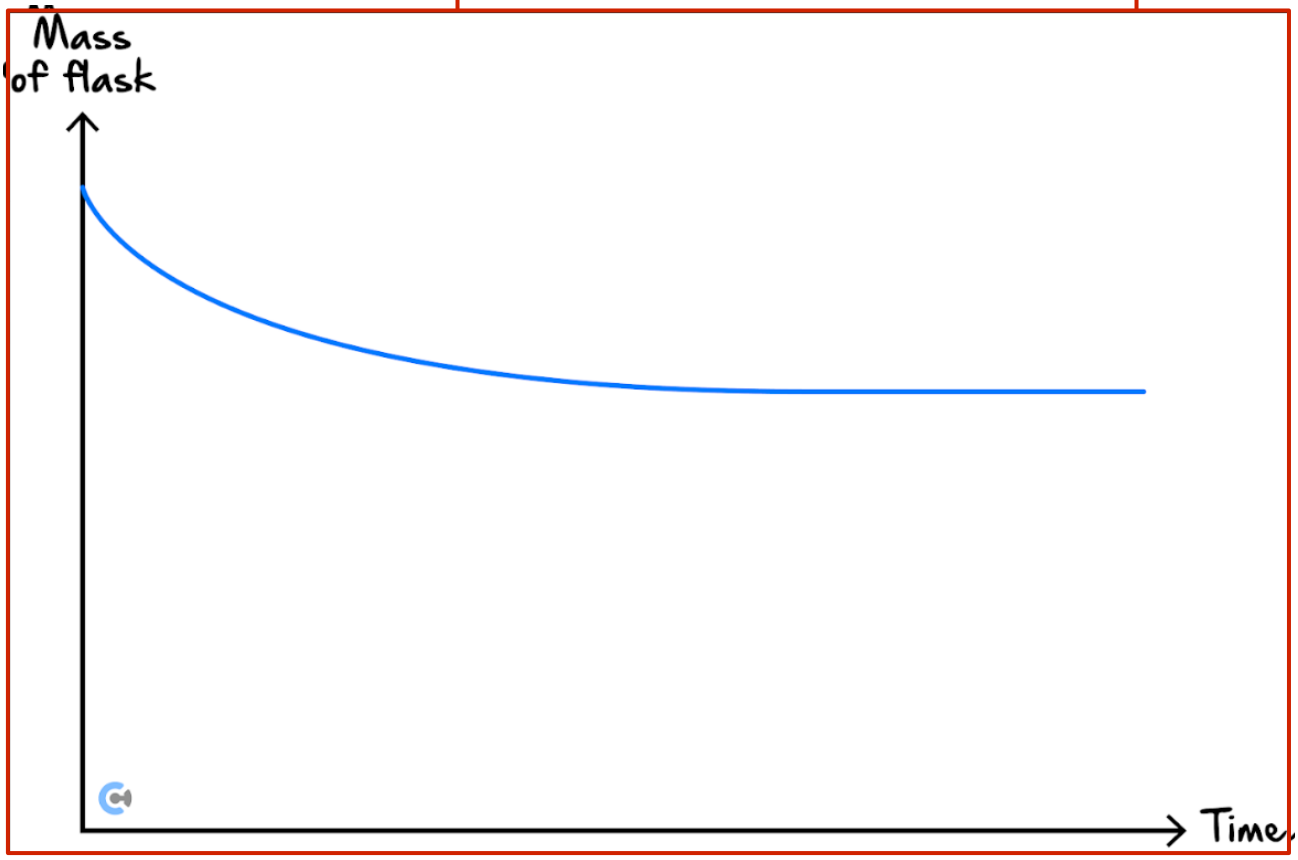
[2.6.2] Explain how temperature & catalyst affect the proportion of successful collisions

The brown intensity will end up the same as the first as the reactant amounts are unchanged. The brown intensity should fade more quickly however.

b.

i. The reaction is repeated in a flask that is sitting on a balance. Draw in the shape of the graph for the mass change of the flask. (1 mark)

[2.6.3] Graph differences in rate & yield



ii. Calculate the final mass loss of the flask. (1 mark)

[2.6.1] Explain how factors increase frequency of collisions

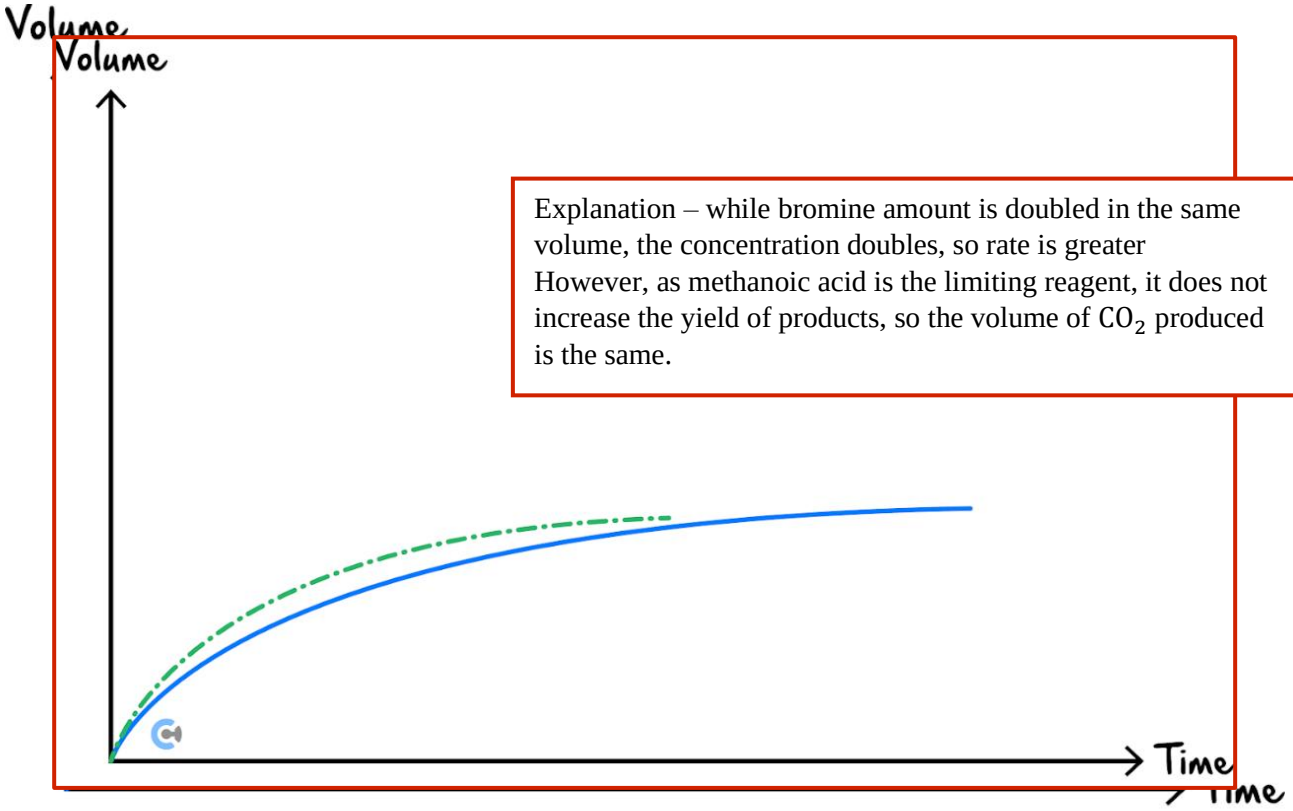
0.8 mole of CO_2 is formed. $Mass = 0.8 \times 44 = 35.2\ g$

iii. Describe how the pH of the reaction mixture changed with time. (1 mark)

[2.6.3] Graph differences in rate & yield

pH will decrease. As the reaction proceeds, acid is produced so the pH drops.

c. The graph below shows the volume of CO_2 produced in the reaction between 1.0 mol of Br_2 and 1.0 mol of methanoic acid in 1.00 L of water.



Explanation – while bromine amount is doubled in the same volume, the concentration doubles, so rate is greater
However, as methanoic acid is the limiting reagent, it does not increase the yield of products, so the volume of CO_2 produced is the same.

The reaction is now repeated but the amount of Br_2 is doubled in the 1.00 L sample of water. Draw on the graph above the graph of the CO_2 produced from this reaction. (1 mark)

[2.6.3] Graph differences in rate & yield

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Question 10 (6 marks)

Consider a solution in which the following equilibrium is established:

$$Br_2(aq) + 2OH^-(aq) \rightleftharpoons OBr^-(aq) + Br^-(aq) + H_2O(l);\ \Delta H = +15\ kJ\ mol^{-1}$$

The molecular bromine (Br_2) gives the aqueous solution a reddish-brown colour. All the other species present are colourless.

The following tests are carried out on separate samples of the solution.

Test 1 A few mL of a concentrated solution of sodiu

Test 2 A few mL of a concentrated HCl solution is m

Test 3 The solution is heated from room temperature to 40°C.

3 marks 2.8.3 Apply partial opposition during equilibrium to the effects on amount, concentration & colour of substance
2 marks 2.8.1 Explain effects of addition/removal of substances or pressure/volume changes on equilibrium system
1 mark 2.9.1 Explain effects of temperature, inert gas or catalyst on equilibrium

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	Test Result		Explanation of test result
	Darker	Lighter	
Test 1	✓		Adding NaBr increases the concentration of Br^-. According to LCP, the system will partially oppose this change by favouring the backwards reaction, thereby increasing the concentration of Br_2, making the solution become browner._____
Test 2	✓		By adding an acid HCl, it will react with the base OH^- in a neutralisation reaction, thereby decreasing the concentration of OH^-. According to LCP, the system partially opposes this change by increasing the $[OH^-]$ back up, favouring the backwards reaction which increases $[Br_2]$, resulting in a darker colour.
Test 3		✓	By increasing the temperature of the system, according to LCP, the system partially opposes this change by favouring the forwards endothermic reaction, thereby decreasing $[Br_2]$ which results in a lighter brown colour.

Question 11 (6 marks)

Consider the following reaction shows the reaction during the hydration of ethene.

$$C_2H_4(g) + H_2O(g) \rightleftharpoons C_2H_5OH(g) \quad \Delta H = -45.5\ kJ\ mol^{-1}$$

a. Explain the effect of increasing temperature on the rate of production of ethanol. (3 marks)

[2.6.2] Explain how temperature & catalyst affect the proportion of successful collisions

Rate is increased (1 M)
It increases the average kinetic energy of particles, increasing average force upon collision, increasing proportion of collisions with sufficient energy to overcome the activation energy. (1 M)
It also increases frequency of collisions, leading to higher frequency of successful collisions with correct orientation. (1 M)

b. Considering both the rate of production of ethanol and the equilibrium yield of ethanol achieved, state the optimum temperature conditions that should be used to maximise both rate and yield. Justify your answer. (2 marks)

[2.9.5] Find optimum operating conditions in all circumstances such as the rate-yield conflict

moderate temperature (1 M)
low temperature results in an increase in yield of ethanol.
high temperature results in increase in rate of production of ethanol.
This is a rate-yield conflict. (1 M)

c. State the optimum pressure conditions used to maximise both rates of production and equilibrium yield of ethanol. (1 mark)

[2.9.5] Find optimum operating conditions in all circumstances such as the rate-yield conflict

high pressure (as it favours both rate and yield)

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