Heterogeneous equilibria and Kc

OCR A H432 · Full A-level

Show your working where needed. Check the worked answers when you finish.

Name _____ Date _____

1. Write an equilibrium expression

$CaCO_3(s) \rightleftharpoons CaO(s) + CO_2(g)$. Both solids are present at equilibrium. Write the expression for Kc, explain your choice of terms and give the units.

2. Use two measured concentrations

$NH_4HS(s) \rightleftharpoons NH_3(g) + H_2S(g)$. The vessel initially contains NH_4HS and some NH_3. At equilibrium the concentrations of NH_3 and H_2S are 0.0450 and 0.0280 mol dm^{-3} respectively. Calculate Kc with units.

3. Liquid and vapour

Two sealed vessels contain pure liquid water and water vapour at equilibrium at the same temperature. One contains twice as much liquid water as the other. Compare the equilibrium vapour concentrations and explain your answer.

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4. Work from gas amounts

$C(s) + CO_2(g) \rightleftharpoons 2CO(g)$. A 2.00 dm^3 vessel initially contains excess carbon, 0.500 mol of CO_2 and no CO.

At equilibrium there is 0.300 mol of CO. Calculate Kc and give its units.

5. Write the equilibrium in both directions

$FeO(s) + CO(g) \rightleftharpoons Fe(s) + CO_2(g)$. At equilibrium [CO] = 0.0120 mol dm^{-3} and [CO_2] = 0.0360 mol dm^{-3}. Calculate Kc for the equation shown and for the reverse equation. State whether either has units.

6. Change the volume

$NH_4HS(s) \rightleftharpoons NH_3(g) + H_2S(g)$ is at equilibrium. The vessel volume is halved rapidly at constant temperature. Explain how the gas concentrations change at once and how the equilibrium responds.

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7. Check the amount of solid

$MgCO_3(s) \rightleftharpoons MgO(s) + CO_2(g)$. When both solids are present, Kc is 0.0500 mol dm^{-3} at this temperature.

A 2.00 dm^3 vessel starts with 0.0600 mol of $MgCO_3$ and no other substances. Determine whether both solids can be present at equilibrium. Support your decision with a calculation.

8. A gas already in the vessel

$2NaHCO_3(s) \rightleftharpoons Na_2CO_3(s) + CO_2(g) + H_2O(g)$. A hot 5.00 dm^3 vessel starts with excess $NaHCO_3$, 0.120 mol CO_2 and no steam. At equilibrium it contains 0.0800 mol steam. Calculate Kc with units.

9. Extra challenge · Check whether enough solid is present

$NH_4HS(s) \rightleftharpoons NH_3(g) + H_2S(g)$. In a 2.00 dm^3 vessel, some NH_4HS is added to 0.200 mol NH_3. At equilibrium 0.100 mol H_2S is present and some solid remains.

Find Kc and its units. At the same temperature a second evacuated 2.00 dm^3 vessel contains 0.300 mol NH_4HS. Determine whether any solid remains at equilibrium, and how much.

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Worked answers

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1. Write an equilibrium expression

Kc = $[CO_2]$, with units mol dm^{-3}. CO_2 is the gas whose concentration can vary. Each pure solid has a constant concentration within its phase, so neither solid appears in the expression.

2. Use two measured concentrations

Kc = $[NH_3][H_2S]$ = 0.0450 × 0.0280 = 1.26×10^{-3} mol^2 dm^{-6}. The units come from multiplying two concentrations. The pure solid is omitted.

3. Liquid and vapour

For $H_2O(l) \rightleftharpoons H_2O(g)$, Kc = $[H_2O(g)]$. Both vessels have the same Kc because their temperatures are the same. Both contain liquid at equilibrium, so changing the mass of liquid does not change the equilibrium vapour concentration.

4. Work from gas amounts

Making 0.300 mol CO consumes 0.150 mol CO_2, leaving 0.350 mol CO_2. The equilibrium concentrations are [CO] = 0.300 ÷ 2.00 = 0.150 mol dm^{-3} and $[CO_2]$ = 0.350 ÷ 2.00 = 0.175 mol dm^{-3}.

Kc = $[CO]^2/[CO_2]$ = 0.150^2 ÷ 0.175 = 0.129 mol dm^{-3}.

5. Write the equilibrium in both directions

For the equation shown, Kc = $[CO_2]/[CO]$ = 0.0360 ÷ 0.0120 = 3.00. For the reverse, interchange numerator and denominator to get 0.333. The concentration units cancel in each case.

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Worked answers

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6. Change the volume

The gas amounts have not yet changed, so both gas concentrations initially double. Their product is then four times Kc. Kc stays constant because the temperature stays constant.

The net reaction goes left, using both gases and producing more NH_4HS until the concentration product returns to Kc.

7. Check the amount of solid

For both solids to be present, $[CO_2]$ must equal Kc, so $0.0500 \times 2.00 = 0.100$ mol CO_2 would be needed. Even if all the $MgCO_3$ decomposes, it can make only 0.0600 mol CO_2, giving 0.0300 mol dm^{-3}.

There is too little $MgCO_3$ to reach the CO_2 concentration required for the two solids to coexist.

8. A gas already in the vessel

Every mole of steam formed is accompanied by one mole of CO_2. At equilibrium there is 0.120 + 0.0800 = 0.200 mol CO_2, so $[CO_2] = 0.0400$ mol dm^{-3} and $[H_2O] = 0.0160$ mol dm^{-3}.

$Kc = [CO_2][H_2O] = 6.40 \times 10^{-4}$ mol^2 dm^{-6}.

9. Extra challenge · Check whether enough solid is present

In the first vessel, 0.100 mol NH_3 also forms, so $[NH_3] = 0.300/2.00 = 0.150$ mol dm^{-3} and $[H_2S] = 0.100/2.00 = 0.0500$ mol dm^{-3}. $Kc = [NH_3][H_2S] = 0.00750$ mol^2 dm^{-6}.

In the second vessel the two gas concentrations are equal. If solid remains, each concentration is $\sqrt{0.00750} = 0.0866$ mol dm^{-3}. This requires 0.173 mol solid to decompose, which is less than the amount available. The solid remaining is 0.127 mol.

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