
# STARTER FOR 10...

## 2.2. Calculations with $K_c$

**1.** During the Contact process, $SO_2$ is converted into $SO_3$ in a reversible reaction;

$$2\ SO_2 + O_2 \rightleftharpoons 2\ SO_3 \qquad \Delta H\ -197\ kJ\ mol^{-1}$$

The equilibrium was established at 1000 K and a small sample of the equilibrium mixture extracted. It was found to contain 1.0 mol $dm^{-3}$ of $SO_2$, 0.2 mol $dm^{-3}$ of $O_2$ and 1.4 mol $dm^{-3}$ of $SO_3$.

(a) Calculate $K_c$ at this temperature.

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(b) In the Contact process the temperature of choice is 700 K. What effect will this have on the value of $K_c$ compared to that calculated above?

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**2.** Catherine is studying the hydrolysis of ethyl butanoate;

$$CH_3CH_2CH_2COOCH_2CH_3 + H_2O \rightleftharpoons CH_3CH_2CH_2COOH + CH_3CH_2OH$$

She places exactly 1 mol of ethyl butanoate and 2 mol of water in a conical flask and allows the mixture to reach equilibrium. After this time the equilibrium mixture was analysed and found to contain 0.3 mol of butanoic acid. Calculate $K_c$ for the equilibrium at this temperature.

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**3.** In a different reaction, Catherine wants to make butyl ethanoate. She reacts butanol with ethanoic acid in 50 $cm^3$ of water in a round bottomed flask.

$$C_4H_9OH + CH_3COOH \rightleftharpoons CH_3COOC_4H_9 + H_2O$$

She wishes to make exactly 0.25 mol of butyl ethanoate. If she starts with 0.5 mol of ethanoic acid, how much butanol should she add? ($K_c$ for the equilibrium at 20 °C is 3.0. The density of water is 1 g $cm^{-3}$)

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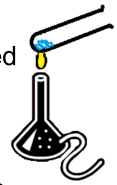
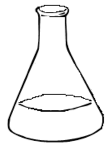
## 2. Equilibria answers

### 2.1. The equilibrium constant, $K_c$

**1.**

Wood burning 

Heating hydrated $CuSO_4.5H_2O$ 

Making an ester; $CH_3COOH(aq) + CH_3OH(aq) \rightleftharpoons CH_3COOCH_3(aq) + H_2O(aq)$ 

A reversible reaction at equilibrium | A reversible reaction | An irreversible reaction

*(2 marks for all three correct, 1 mark for 1 correct)*

The products from burning wood cannot be turned back into wood so it is irreversible. The copper sulphate once dehydrated can be turned back into the hydrated form by the addition of water. Hence it is a reversible reaction *(1 mark for above two points).* The esterification reaction is in a <u>closed system</u> so neither products nor reactants can escape so it is a reaction at equilibrium *(1 mark).*

**2.** (a) $K_c = \dfrac{[CH_3C(OH)(CN)CH_3(aq)]}{[CH_3COCH_3(aq)][HCN(aq)]}$ Units $= \dfrac{\cancel{mol\ dm^{-3}}}{\cancel{mol\ dm^{-3}} \times mol\ dm^{-3}}$ = <u>$mol^{-1}\ dm^3$</u> *(2 marks)*

(b) $K_c = \dfrac{[CH_3CH_2COOCH_3(aq)]\ [H_2O(aq)]}{[CH_3CH_2COOH(aq)]\ [CH_3OH(aq)]}$ Units $= \dfrac{\cancel{mol\ dm^{-3}} \times \cancel{mol\ dm^{-3}}}{\cancel{mol\ dm^{-3}} \times \cancel{mol\ dm^{-3}}}$ = <u>no units</u> *(2 marks)*

(c) $K_c = \dfrac{[NH_3(g)]^2}{[N_2(g)]\ [H_2(g)]^3}$ Units $= \dfrac{(mol\ dm^{-3})^2}{mol\ dm^{-3} \times (mol\ dm^{-3})^3}$ = <u>$mol^{-2}\ dm^6$</u> *(2 marks)*

### 2.2. Calculations with $K_c$

**1.** (a) $K_c = \dfrac{[SO_3]^2}{[SO_2]^2\ [O_2]}$ *(1 mark)* $= \dfrac{(1.4\ mol\ dm^{-3})^2}{(1\ mol\ dm^{-3})^2\ (0.2\ mol\ dm^{-3})}$ = <u>$9.8\ mol^{-1}\ dm^3$</u> *(1 mark for value, 1 mark for units)*

(b) The temperature has been decreased. Therefore the equilibrium will shift in favour of the exothermic reaction (to the right) in order to oppose the temperature decrease. Therefore <u>the value of $K_c$ will increase</u>. *(1 mark)*


# STARTER FOR 10...

## 2. Equilibria answers

**2.**

| | ethyl butanoate | + | water | ⇌ | butanoic acid | + | ethanol | |
|---|---|---|---|---|---|---|---|---|
| **I**nitial | 1 mol | | 2 mol | | 0 mol | | 0 mol | |
| **C**hange | –0.3 mol | | –0.3 mol | | +0.3 mol | | +0.3 mol | |
| **E**quilibrium | 0.7 mol | | 1.7 mol | | 0.3 mol | | 0.3 mol | *(1 mark)* |

$$K_c = \frac{[\text{acid}]\,[\text{alcohol}]}{[\text{ester}]\,[\text{water}]} = \frac{[0.3 \text{ mol / V}]\,[0.3 \text{ mol / V}]}{[0.7 \text{ mol / V}]\,[1.7 \text{ mol / V}]} = \underline{0.076 \text{ no units}}$$

*(1 mark for value, 1 mark for units)*

**3.** No. of moles in 50 $cm^3$ of water;

Mass = 50 $cm^3$ × 1 g $cm^{-3}$ = 50 g

Moles = 50 g / 18 g $mol^{-1}$ = 2.78 mol *(1 mark)*

Substituting into the equilibrium;

| | butanol | + | ethanoic acid | ⇌ | ester | + | water |
|---|---|---|---|---|---|---|---|
| **I**nitial | x mol | | 0.5 mol | | 0 mol | | 2.78 mol |
| **C**hange | –0.25 mol | | –0.25 mol | | +0.25 mol | | +0.25 mol |
| **E**quilibrium | (x – 0.25 ) mol | | 0.25 mol | | 0.25 mol | | 3.03 mol |

$$K_c = \frac{[\text{ester}]\,[\text{water}]}{[\text{butanol}]\,[\text{ethanoic acid}]} = \frac{[0.25 \text{ mol / V}]\,[3.03 \text{ mol / V}]}{[(x - 0.25 \text{ mol}) \text{ / V}]\,[0.25 \text{ mol / V}]}$$

*(1 mark)*

Knowing that $K_c$ = 3.0 under the reaction conditions;

$$3.0 = \frac{[0.25 \text{ mol / V}]\,[3.03 \text{ mol / V}]}{[(x - 0.25 \text{ mol}) \text{ / V}]\,[0.25 \text{ mol / V}]} = \frac{0.7575}{0.25x - 0.0625}$$

3.0 (0.25x – 0.0625) = 0.7575

0.75x – 0.1875 = 0.7575

0.75x = 0.945

<u>x = 1.26 mol</u> *(1 mark)*

### 2.3 Le Châtelier and $K_c$

| | Effect on $K_c$ | Location of Le Châtelier |
|---|---|---|
| **1.** Adding a catalyst to the reaction mixture | no change | 2nd floor |
| **2.** Adding $CO_2$ to the reaction mixture | no change | 2nd floor |