# Teacher Resource Bank

GCE Chemistry

PSA14: A2 Physical Chemistry

- Determine an equilibrium contstant

# A2 Physical Chemistry

## PSA14 Determine an equilibrium constant

# Technical Sheet

## To determine a value of $K_c$ for the reaction of ethanol with ethanoic acid.

Whenever possible, students should work individually.
If it is essential to work in a pair or in a small group, because of the availability of apparatus, supervisors must be satisfied that they are able to assess the contribution from each student to the practical activity.

## This PSA will require two practical sessions.

Requirements

**Part 1**

- Two 100 $cm^3$ flasks with stoppers
- Communal burettes filled with:
  - glacial ethanoic acid
  - ethanol
  - deionised or distilled water
  - approximately 1 mol $dm^{-3}$ hydrochloric acid

**Part 2**

- burette
- Two 250 $cm^3$ conical flasks
- Standard sodium hydroxide solution (0.100 mol $dm^{-3}$)
- Phenolphthalein indicator
- Accurate 1 $cm^3$ pipette
- Pipette filler
- 100 $cm^3$ measuring cylinder
- Deionised or distilled water
- Wash bottle

## Centres are expected to carry out and be responsible for their own safety risk assessments.

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# Student Sheet

**The aim of this experiment is to determine a value of $K_c$ for the equilibrium which is established when ethanol reacts with ethanoic acid.**

**Introduction**

Ethyl ethanoate is an ester which is manufactured from ethanoic acid and ethanol. The overall reaction can be represented as follows;

$$\underset{\text{ethanoic acid}}{CH_3COOH} + \underset{\text{ethanol}}{CH_3CH_2OH} \rightleftharpoons \underset{\text{ethyl ethanoate}}{CH_3COOCH_2CH_3} + \underset{\text{water}}{H_2O}$$

The reaction requires a strong acid catalyst.

The purpose of this experiment is to find the value of the **equilibrium constant**, $K_c$ , for this reaction at a constant temperature.

The procedure involves setting up a known mixture of ethanoic acid, ethanol, water and dilute hydrochloric acid (the strong acid catalyst) and leaving it for a period of time to allow it to come to equilibrium; one week is sufficient time for this to occur. At the same time, a control is prepared containing only dilute hydrochloric acid.

As soon as equilibrium has been established, the mixture is poured into excess water (this effectively 'freezes' the equilibrium for a short period of time) and then rapidly titrated with standard sodium hydroxide solution. The results of this titration give a measure of the total concentration of acid present in the equilibrium mixture. Titration of the control allows the concentration of dilute hydrochloric acid to be determined and from the two titration results, the equilibrium concentration of ethanoic acid can be determined.

Provided the initial concentrations of ethanoic acid, ethanol, water and dilute hydrochloric acid are known, the equilibrium concentrations of each of these compounds can be calculated and hence a value of $K_c$ can be found for the reaction under the conditions of the experiment.

The first part of the experiment involves the setting up of a mixture of ethanoic acid, ethanol, water and dilute hydrochloric acid and allowing it to come to equilibrium. A control containing only the acid catalyst is also set up.

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The second part of the experiment involves titrating both the equilibrium mixture and the control with standard 0.100 mol $dm^{-3}$ sodium hydroxide solution using phenolphthalein as indicator and using the results from these titrations to calculate $K_c$ for the equilibrium.

**It is the responsibility of the student to carry out and be responsible for their own safety risk assessment before carrying out this experiment. Wear safety glasses at all times. Assume that all of the reagents and liquids are toxic, corrosive and flammable.**

**Experiment**

## Part 1 Preparation of the equilibrium mixture and the control

a) Make up **the control** solution in a 100 $cm^3$ conical flask. Label and stopper this flask.
b) Using the communal burettes provided, make up into a separate 100 $cm^3$ conical flask **the mixture** indicated in the Table below. Label the flask and stopper it securely.
c) Shake the flask well and leave it for approximately one week.
d) Record all results in an appropriate form and to the appropriate precision.

**Table of initial volumes for each reagent to make up the equilibrium mixture and the control**

**All volumes in $cm^3$**

| | | The control | The mixture |
|---|---|---|---|
| **Reagent** | **Density**/g $cm^{-3}$ | | |
| glacial ethanoic acid | 1.05 | 0.0 | 6.0 |
| ethanol | 0.79 | 0.0 | 6.0 |
| water | 1.00 | 18.0 | 6.0 |
| 1 mol $dm^{-3}$ hydrochloric acid | 1.00 | 2.0 | 2.0 |
| | | | |
| Total volume | | 20.0 | 20.0 |

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The ability to calculate the initial moles of each reagent in the two flasks is NOT part of the PSA but this is a useful task to complete.
Your teacher can help you with this part of the work.

e) Using the densities and volumes given for each reagent, calculate the initial amount, **in moles**, for each of ethanoic acid, ethanol and water **in your equilibrium mixture**. You should **assume that 2.0 $cm^3$ of the 1 mol $dm^{-3}$ hydrochloric acid catalyst adds an extra 2.0 $cm^3$ of water to the mixture.**

## Part 2 Titration of the equilibrium mixture and the control against standard sodium hydroxide solution.

**Titration of the control**

You will only have **one opportunity** to carry out this titration, so you must **do it with care**.

a) Fill a burette with the standard sodium hydroxide solution provided.
b) Pour the contents of the control flask into a 250 $cm^3$ conical flask and add approximately 100 $cm^3$ of deionised (or distilled) water.
c) Add two drops of phenolphthalein indicator to the conical flask, swirl the contents and titrate the solution with the standard sodium hydroxide solution from the burette. The indicator will turn pink at the end-point.

**Titration of the equilibrium mixture**

d) Using a pipette filler and an accurate 1 $cm^3$ pipette, transfer **precisely** 1.0 $cm^3$ of your equilibrium mixture to a 250 $cm^3$ conical flask containing approximately 100 $cm^3$ of deionised water.
e) Add two drops of phenolphthalein indicator to the conical flask, swirl the contents and **rapidly** titrate this solution with the standard sodium hydroxide solution provided to the same end-point as before.
f) Repeat this titration with further 1.0 $cm^3$ samples of your equilibrium mixture and aim to achieve concordance. It is important to note that concordance is difficult to achieve and it is recommended that three titrations are carried out and the data recorded. Your teacher will give guidance on how you should analyse your titration results.
g) Record the results of the three titrations in an appropriate form.

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### Analysing the data

The ability to calculate a value for $K_c$ is NOT part of the PSA but this is a useful task to complete.

Your teacher can help you with this part of the work.

**Calculations**

- Calculate the amount of hydrochloric acid, in moles, in the control flask using the titration result for the control.
- Calculate the total amount of acid, in moles, in your equilibrium mixture using the average titre from your titration of the equilibrium mixture. It is difficult in this experiment to achieve concordance, because the equilibrium shifts slightly during the titration. Small errors in determining equilibrium concentrations can lead to larger errors in the value of $K_c$
  It may be necessary to take an average of the three titration results even though they are not concordant.
- Subtract the amount of hydrochloric acid from the total amount of acid in the equilibrium mixture to calculate the amount of ethanoic acid, in moles, remaining in the equilibrium mixture.
- Calculate the amount of ethanoic acid, in moles, that has reacted as the equilibrium is established. This amount of moles is the same as the amount of ethyl ethanoate, in moles, and the amount of water, in moles, which have been formed at equilibrium. It is also the amount of alcohol, in moles, which has reacted as the equilibrium is established.
- Calculate the amount of ethanol, in moles, that remains at equilibrium from the original amount, in moles, that was put in to the flask.
- Calculate the amount of water, in moles, at equilibrium. Do not forget to include the fact that the equivalent of 8.0 $cm^3$ of water were added initially.
- Calculate the concentration in mol $dm^{-3}$ of ethanoic acid at equilibrium.
- Calculate the concentration in mol $dm^{-3}$ of ethanol at equilibrium.
- Calculate the concentration in mol $dm^{-3}$ of ethyl ethanoate at equilibrium.
- Calculate the concentration in mol $dm^{-3}$ of water at equilibrium.
- Use these data to calculate the value of $K_c$ for your equilibrium mixture.

Given that the accepted value for this equilibrium constant is usually quoted as 4.00 at 298 K, comment on your result.


# Teacher Notes and Marking Guidance

**The specific marking guidance in the specification is as follows**

**2 marks: All** areas of the task are carried out competently.
The quantities of reagents are measured precisely.
The titrations are carried out with due care and data recorded precisely.
The value of the equilibrium constant is in the expected range.

**1 mark: One** of the areas of the task is performed poorly.
The quantities of reagents are measured imprecisely **OR**
Titrations are carried out with insufficient care or data recorded imprecisely **OR**
The value of the equilibrium constant is not in the expected range.

**0 marks: At least two** of the areas of the task are performed poorly.
The quantities of reagents are measured imprecisely.
Titrations are carried out with insufficient care or data recorded imprecisely.
The value of the equilibrium constant is not in the expected range.

**Guidance for Teachers**

Teachers are expected to exercise professional judgement in assessing the competence of their candidates in following the instructions.

Candidates should have been given guidance in the correct use of equipment and this guidance **can continue during the practical session** for which this PSA forms a part.

If, however, the guidance required is fundamental or frequent, then the student should **not** be awarded 2 marks.

Most judgements of 2 marks, 1 mark or 0 marks will depend on

- whether the candidate is able to measure the volumes of reagents with appropriate care from the communal burettes and transfer these to the flasks when setting up the equilibrium mixture and the control.
- whether the titration is carried out competently with sensible quantities of indicator and to the expected end-point.

Calculation of the value of $K_c$ is a useful task, but candidates should **not** be judged on their ability to process the data and to calculate the value of $K_c$ from their data. The requirement for 2 marks that the value of $K_c$ is in the expected range, means that their data **could be used** to calculate a value which is of the correct order of magnitude and likely to be in the range 2.0 to 6.0


It must also be understood that students should **not** be judged on whether they have achieved concordance in the titration of the equilibrium mixture, since this is not easy to achieve.

It is important to remember when marking these practical exercises that PSA is about student competence and that for a student to score full marks on this exercise **perfection is neither expected nor required**.