# Determining an equilibrium constant

**Teacher’s Guide**

It is possible to determine experimentally the equilibrium constant for the reaction between methanol, CH­3­.OH, and ethanoic acid, CH­3.COOH, to form the ester methyl ethanoate, CH3.CO.OCH3, and water. The esterification is catalysed by hydrogen ions.

The reaction is reversible and proceeds slowly towards an equilibrium. It is therefore necessary to set up the experiment and leave it for a week before the calculation is to

be completed. After this period of time, the concentration of ethanoic acid in the equilibrium mixture is determined by titration with a standardised 1 mol l-1 sodium hydroxide solution. If the initial concentrations of the methanol and ethanoic acid are known, the equilibrium constant can then be calculated.

**Procedure:**

**Flasks should be left for one week to allow equilibrium to be attained.**

Weigh a 100cm3 flask. From a burette, add 3.7cm3 of methanol and reweigh.

From a burette, add 3.0g of glacial (pure) ethanoic acid and again reweigh the flask.

From a burette, add 6.2cm3 of a standardised 1 mol l-1 hydrochloric acid solution.

Stopper the flask and wrap the neck in parafilm.

Set up a second identical flask and leave both for one week, shaking occasionally.

At the end of one week, add 25cm3 of distilled water to each flask, followed by 2 drops of phenolphthalein indicator. Titrate at once with a 1 mol l-1 standardised sodium hydroxide solution and record the volume of alkali added to each flask.

**Calculation from the reaction of methanol and ethanoic acid**:

1. Calculate the mass of methanol used and hence the number of mol of methanol originally present. (Let this equal ***a***)

2. Calculate the mass of ethanoic used and hence the number of mol of ethanoic acid originally present. (Let this equal ***b***)

1. If M is the concentration of the hydrochloric, calculate the number of mol of acid added. Let this equal***c*** mole where

***c*** = 6.2 x M

 1000

1. Now calculate the number of mol of water originally present. Let this be ***d*** molwhere

***d*** = mass of acid solution (6.2g) – mass of HCl (36.5 x **c** g)

Mass of one mol of water (18g)

1. Therefore the initial concentrations in the reaction are

 ***a*** mol ***b*** mole ***none*** ***d*** mol

1. From the volume of sodium hydroxide titrated, calculate the number of mol of hydrogen ions in the equilibrium mixture. (Let this equal ***e*** mol).

This is the total from the ethanoic and hydrochloric acids.

1. Therefore the number of mol of **ethanoic acid** in the equilibrium mixture

is (***e*** – ***c***) mol.

1. Therefore the number of mol of ethanoic acid which reacted to form the ester is [***b*** - (***e*** – ***c***)] mol. This will be the number of mol of ester. (Let this equal ***f*** mol).

Therefore at equilibrium we have the following quantities present:

 (***a*** – ***f***) mol (***e*** – ***c***) mol ***f*** mol (***d*** + ***f*** ) mol

1. The equilibrium constant can be calculated by inserting these figures in the equilibrium rate expression:

Results: Flask 1 Flask 2 Flask 3

Mass of methanol 3.00g 3.00g 3.97g

Mass of glacial ethanoic acid used 3.00g 3.04g 2.5g

Volume HCl added 6.2 cm3 6.2 cm3 4.0 cm3

Concentration of HCl(aq) 0.9638 mol l-10.9638 mol l-1 0.9638 mol l-1

NaOH(aq) titre 31.1cm3 31.3cm3 17.5mls

Concentration of NaOH(aq) 0.99 mol l-10.99 mol l-1 0.99 mol l-1

**Calculations:**

Number of moles of methanol used (***a***) 9.375x 10-2 9.375 x 10-2 1.241 x 10-1

Number of moles of ethanoic acid used (***b***) 5.000 x 10-2 5.067 x 10-2 4.167 x 10-2

Number of moles of HCl present (***c***) 5.976 x 10-3 5.976 x 10-3 3.855 x 10-3

Number of moles water originally present (***d***) 3.323 x 10-1 3.323 x 10-1 2.144 x 10-1

Titre 31.1mls 31.3mls 17.5mls

Number of moles of H+ in the 3.079 x 10-23.099 x 10-2 1.733 x 10-2

equilibrium mixture (***e***)

Number of moles of ethanoic acid in 2.481 x 10-22.501 x 10-2 1.348 x 10-2

the equilibrium mixture (***e*** – ***c***)

Number of moles of ethanoic acid reacting to 2.519 x 10-22.566 x 10-2 2.819 x 10-2

form the ester [***b*** - (***e*** – ***c***)]

Number of moles of ester in

the equilibrium mixture is (***f***) {= [***b*** - (***e*** – ***c***)]} 2.519 x 10-22.566 x 10-2 2.819 x 10-2

Number of moles of water in 3.575 x 10-13.580 x 10-1 2.426 x 10-1

the equilibrium mixture (***d*** + ***f*** )

Number of moles of alcohol in 6.856 x 10-26.809 x 10-2 9.591 x 10-2

the equilibrium mixture (***a*** - ***f*** )

Inserting these figures into the equilibrium expression gives values for K of 5.294, 5.394 and 5.297 respectively.

As a further exercise, the equilibrium constant can be calculated using differing quantities of reactants. The value of K should of course always be the same, emphasising the same equilibrium mixture is obtained every time.

As an interesting exercise and teaching point, the same equilibrium mixture can be formed by the hydrolysis of methylethanoate.

Once again the equilibrium concentrations of all species can be found and hence the equilibrium constant calculated for the reaction

 The value of K should be equal to that found from the formation of the ester.

**Procedure:**

**Flasks should be left for one week to allow equilibrium to be attained.**

Weigh a 100cm3 flask. From a burette, add 3.2cm3 of methylethanoate and reweigh.

From a burette, add 6.2cm3 of a standardised 1 mol l-1 hydrochloric acid solution.

Stopper the flask and wrap the neck in parafilm.

Set up a second identical flask and leave both for one week, shaking them frequently during the first day and occasionally thereafter.

At the end of one week, add 25cm3 of distilled water to each flask, followed by 2 drops of phenolphthalein indicator. Titrate at once with a 1 mol l-1 standardised sodium hydroxide solution and record the volume of alkali added to each flask.

**Calculation from the reaction of methylethanoate and water**:

1. Calculate the mass of methylethanoate used and hence the number of mol of methylethanoate originally present. (Let this equal ***m***)

1. If M is the concentration of the hydrochloric, calculate the number of mol of acid added. Let this equal***n*** mole where

***n*** = 6.2 x M

 1000

1. Now calculate the number of mol of water originally present. Let this be ***p*** molwhere

***p*** = mass of acid solution (6.2g) – mass of HCl (36.5 x **n** g)

Mass of one mol of water (18g)

1. Therefore the initial concentrations in the reaction are

 ***none*** ***none*** ***m*** mol ***p*** mol

1. From the volume of sodium hydroxide titrated, calculate the number of mol of hydrogen ions in the equilibrium mixture. (Let this equal ***q*** mol).

This is the total from the ethanoic and hydrochloric acids.

1. Therefore the number of mol of **ethanoic acid** in the equilibrium mixture

is (***q*** – ***n***) mol.

1. Therefore the number of mol of ester in the equilibrium mixture is

[***m*** - (***q*** – ***n***)] mol.

1. The number of moles of water in the equilibrium mixture is [***p*** - (***q*** – ***n***)] mol.

9. Therefore at equilibrium we have the following quantities present:

 (***q*** – ***n***) mol (***q*** – ***n***) mol [***m*** - (***q*** – ***n***)] mol [***p*** - (***q*** – ***n***)] mol

1. The equilibrium constant can be calculated by inserting these figures in the equilibrium rate expression:

Results: Flask 1 Flask 2 Flask 3

Mass of methylethanoate 2.98g 3.00g 3.72g

Number of moles of methylethanoate present (***m***) 4.027 x 10-2 4.054 x 10-2 5.027 x 10-2

Volume HCl added 6.2 cm3 6.2 cm3 5.0 cm3

Number of moles of HCl present (***n***) 5.976 x 10-3 5.976 x 10-3 4.819 x 10-1

Number of moles water originally present (***p***) 3.323 x 10-1 3.323 x 10-1 2.680 x 10-1

Titre 33.6mls 33.8mls 35.2mls

Number of moles of H+ in the equilibrium mixture (***q***)3.326 x 10-2 3.346 x 10-2 3.485 x 102

Number of moles of ethanoic acid in

the equilibrium mixture (***q*** – ***n***) 2.728 x 10-2 2.748 x 10-2 3.003x 10-2

Number of moles of methanol in

the equilibrium mixture (***q*** – ***n***) 2.728 x 10-2 2.748 x 10-2 3.003 x 10-2

Number of moles of ester in

the equilibrium mixture [***m*** - (***q*** – ***n***)] 1.299 x 10-2 1.306 x 10-2 2.024 x 10-2

Number of moles of water in

the equilibrium mixture ***p*** - (***q*** – ***n***)] 3.050 x 10-1 3.048 x 10-1 2.380 x 10-1

Inserting these figures into the equilibrium expression gives values for K of 5.324 , 5.271 and 5.342 respectively.