Catalytic oxidation of tartaric acid

Aims of the experiment

- To oxidise tartaric acid with hydrogen peroxide and a cobalt catalyst.
- To bring about a catalytic reaction.
- To show that a catalyst remains unchanged throughout a reaction.
- To estimate the effect of a catalyst on the activation energy.

Principles

In 1836, the Swedish researcher Jöns Jakob Berzelius coined the term “catalysis”. The origin of this word comes from the Greek and means to trigger. Berzelius discovered that there are substances which can accelerate a reaction but remain unaffected by it. These substances are called catalysts.

Catalysts themselves only affect the speed of a reaction, but not the equilibrium condition. Catalysts affect forward and reverse reactions equally. They assist in overcoming energy barriers (activation energy) required for the reaction to occur by lowering the activation energy of a reaction.

Another feature is that they remain unchanged after the reaction. The precise mechanisms that take place are still not always understood. For the most part, however, a kind of transition state occurs.

Catalysts are very important for industry. They are used in the production of a number of basic chemicals, such as ammonia, sulfuric acid or methanol. Their utility is that they accelerate reactions and can be used at lower temperatures. This, in turn, provides cost benefits for industry, which is why about 80% of processes in the chemical industry use catalysts.

The human body also uses catalysts to facilitate certain processes at body temperature. These catalysts are called enzymes and help the human metabolism to function.

In this experiment, we will show that the reaction of tartaric acid with hydrogen peroxide can be accelerated using the catalyst cobalt(II) chloride, which remains unchanged after the reaction. The reaction that takes place is as follows:

$$C_4H_4O_6^{2-} + 5\ H_2O_2 + 2\ H_3O^+ \xrightarrow{Co^{3+}} 4\ CO_2 + 10\ H_2O$$

Fig. 1: Experimental set-up.

MS-2018-07

Risk assessment

When working with hydrogen peroxide and cobalt(II) chloride hexahydrate (never in the hands of the students!), protective clothing absolutely must be worn. Hydrogen peroxide can cause serious eye damage and cobalt(II) chloride must never be inhaled.

Hydrogen peroxide 30 %	
  **Signal word: Hazard**	**Hazard warnings** H302 Harmful if swallowed. H318 Causes serious eye damage. **Safety information** P280 Wear protective gloves/protective clothing/eye protection/face protection. P305+P351+P338 IF IN EYES: Rinse carefully with water for several minutes. Remove contact lenses if present and it is possible to do so. Continue rinsing. P313 Get medical advice/attention.
Cobalt(II) chloride hexahydrate	
   **Signal word: Hazard**	**Hazard warnings** H350i Can cause cancer if inhaled. H341 Suspected of causing genetic defects. H360F Can impair fertility. H302 Harmful if swallowed. H334 Can cause allergies, asthma-like symptoms or respiratory distress if inhaled. H317 Can cause allergic skin reactions. H410 Very toxic to aquatic life with long-lasting effects. **Safety information** P201 Obtain special instructions before use. P281 Use personal protective equipment as required. P273 Avoid release into the environment. P308+P313 If exposed or concerned: Get medical advice/attention. P304+P341 IF INHALED: In case of breathing difficulties, take the person into fresh air and keep at rest in a position comfortable for breathing.

Equipment and chemicals

1 Sensor CASSY 2 .... 524 013
1 CASSY Lab 2 .... 524 220
1 pH adapter S 524 0672
1 pH sensor with plastic shaft, BNC 667 4172
1 NiCr-Ni adapter S, type K 524 0673
1 Temperature probe, NiCr-Ni, 1.5 mm, type K ... 529 676
1 Beaker, Boro 3.3, 250 ml, squat 664 130
1 Electronic balance 440-3N, 200 g : 0.01 g........ 667 7977
1 Graduated pipette, 10 ml 665 997
1 Pipetting ball 666 003
1 Spatula, micro double ended, 185 mm 666 961
1 Magnetic stirrer... 666 8451
1 Stirring magnet, 15 mm x 5 mm diam............... 666 850
1 Stirring bar retriever.. 666 859
1 Bunsen burner stand, 450 mm tall................... 666 502
2 Bosshead S 301 09
2 Universal clamp 0...80 mm 666 555
1 Watch glass dish, 40 mm diam........................ 664 152
1 Potassium sodium tartrate, 250 g 672 6710
1 Hydrogen peroxide, 30 %, 250 ml 675 3500
1 Cobalt(II) chloride-6-hydrate, 25 g 672 8000

Additionally required:
PC with Windows 7 or higher
Water

Set-up and preparation of the experiment

Set-up of the apparatus

1. The apparatus is set up as can be seen in Fig. 1.
2. Fasten two bosshead clamps to the Bunsen burner stand and then fasten the universal clamps to the bosshead clamps.
3. Clamp the pH sensor into a universal clamp and a temperature sensor into the other clamp.
4. Connect the temperature sensor to the Sensor CASSY 2 via the NiCr-Ni S adapter. Connect the pH sensor to the sensor CASSY 2 using the pH adapter S.
5. Place the magnetic stirrer next to the stand. Place a beaker (250 ml) onto the stirrer with a stirring magnet in it.

Performing the experiment

1. For the measurement, weigh 3 g of potassium sodium tartrate into the beaker (250 ml).
2. Weigh 200 mg of cobalt(II) chloride hexahydrate onto a watch glass dish.
3. First dissolve the potassium sodium nitrate in 50 ml of warm water of about 50 °C.
4. During this time, load the CASSY Lab 2 settings.
5. During the experiment, the values for temperature, pH and voltage are recorded.
6. In the same beaker, add 10 ml of 30% hydrogen peroxide solution and start the measurement.
7. After about 1 minute, add the cobalt(II) chloride hexahydrate.

Note: Caution! A large amount of CO_2 is generated and the solution foams significantly. The solution should not be hotter than 40 °C since the reaction would otherwise proceed even more violently and can foam over.

8. Run the experiment for as long as it takes until the solution turns back to a pink colour.

Observation

After addition of cobalt(II) chloride hexahydrate, the solution is initially pink in colour because of the Co^{2+}_{aq} ions.

Very quickly, the colours into a deep, dark green due to the Co^{3+} ions formed. At the same time, the solution begins to foam.

At the end, the deep, dark green colour disappears again and the solution returns to its original colour.

The measured values show (see Fig. 2) that the temperature increases significantly and after a short drop, an increase in the pH also takes place.

Evaluation

In Fig. 2, the diagram for temperature and pH during the experiment is shown.

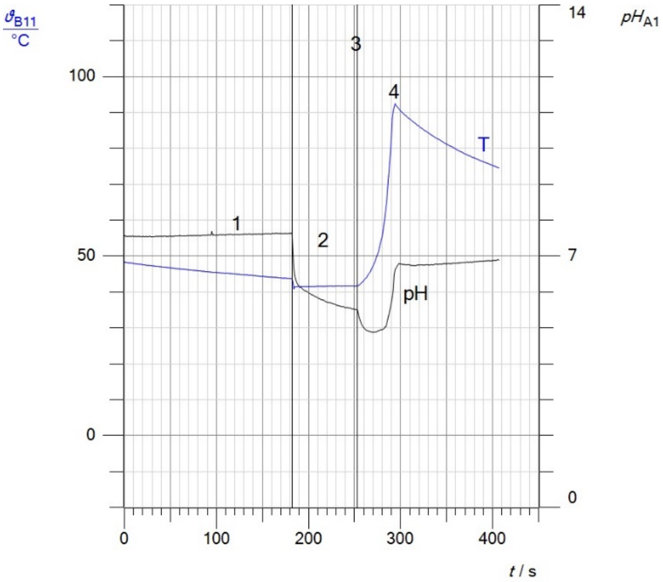

Fig. 2 Diagram for temperature and pH values.

After the potassium sodium tartrate (1) is dissolved and the hydrogen peroxide (2) is added, only a minimum temperature drop and reduction in pH occurs. The reason is that hydrogen peroxide itself is slightly acidic. Otherwise, there is no initial reaction seen. Without a catalyst, the reaction is very slow.

With the addition of cobalt(II) chloride hexahydrate (3), the reaction proceeds instantaneously. Right after the cobalt(II) chloride hexahydrate is added, the solution is pink. This is because of the Co^{2+} ions in solution.

Very quickly thereafter, significant foaming occurs and the solution becomes deep, dark green. Tartaric acid is being oxidised to CO_2 by the hydrogen peroxide, which causes the foaming. The deep green colour comes from the Co^{3+} ions (the hexaaquacobalt(III) complex) now present in the solution. These ions derive from the reaction with hydrogen peroxide. The reaction now occurring is:

$$C_4H_4O_6^{2-} + 5\ H_2O_2 + 2\ H_3O^+ \xrightarrow{Co^{3+}} 4\ CO_2 + 10\ H_2O$$

After the addition of cobalt(II) chloride hexahydrate (3), a rapid temperature increase takes place since the reaction is strongly exothermic. At the same time, the sudden formation of CO_2 causes the pH to drop. Since this gas leaks during the reaction, the pH value increases after a short time (4).

Since the concentration of ions increases, there is also an increase in voltage at the same time. This proceeds in parallel to the pH increase (4).

As soon as the hydrogen peroxide is used, the values slowly return to their initial values since the reaction no longer occurs (4). This is also the time when the pink colour reappears due to the Co^{2+}_{aq} ions.

Results

In this experiment, it is shown that a catalyst accelerates a reaction but is not converted by it. This means that it remains unchanged at the end of the reaction.

During the experiment, the majority of the hydrogen peroxide decomposes and is then no longer available for reaction. When it is consumed, the reaction comes to a halt and the solution returns to its pink colour. This means that Co^{2+} ions are once again present and the catalyst that had started the reaction, is still unchanged.

The potassium sodium tartrate is usually not consumed in an experiment. By adding more hydrogen peroxide, the reaction can be re-started.

Cleaning and disposal

The solution is disposed of in the waste for inorganic salt solutions, containing heavy metals .