Electrolytic water decomposition according to Hoffmann

Aims of the experiment

- Getting to know water as a chemical compound.
- Performing electrolysis.
- Detecting hydrogen and oxygen.
- Determining a molecular formula.
- Learning about practical redox reactions.

Principles

The majority of our Earth's surface is covered by water (71 %), and this is probably where life originated and evolution began. Water is thus one of the most important chemical compounds without which life as we know would not be possible.

In chemical terms, water consists of the elements hydrogen and oxygen, which are combined at a ratio of 2:1. It is transparent as a liquid and at the same time largely colourless, tasteless and odourless.

Furthermore, water is one of the electrolytes. This means that it is subject to electrolytic dissociation and is thus able to conduct electrical current. In the process, water decomposes into its chemical constituents at the cathode and anode. The reactions that take place are as follows:

Cathode: $4\ H_3O^+ + 4\ e^- \rightarrow 2\ H_2 + 4\ H_2O$

Anode: $6\ H_2O \rightarrow 4\ H_3O^+ + O_2 + 4\ e^-$

Whole: $2\ H_2O \rightarrow 2\ H_2 + O_2$

The positively charged oxonium ions (H_3O^+) attracted by the negative charge accumulate at the cathode. Hydrogen gas is formed there through their reduction. Oxidation takes place at the anode, which is positively charged. Electrons are extracted from the water here, which leads to the formation of oxygen gas.

Pure water is not a particularly good charge carrier, since H^+ and OH^- ions are only present at very low concentrations. For this reason, the addition of substances that increase electrolysis current flow, but which do not take part in the reaction, are required for water decomposition experiments. These substances may include sodium sulphate or diluted sulfuric acid, for example.

In this experiment, the water decomposition is carried out in the apparatus according to Hoffmann. In the process, the gases formed accumulate in two glass side arms and the gas volumes can be determined precisely at the end by reading them off. In conclusion, the molecular formula can thus be deduced through the identification of both gases.

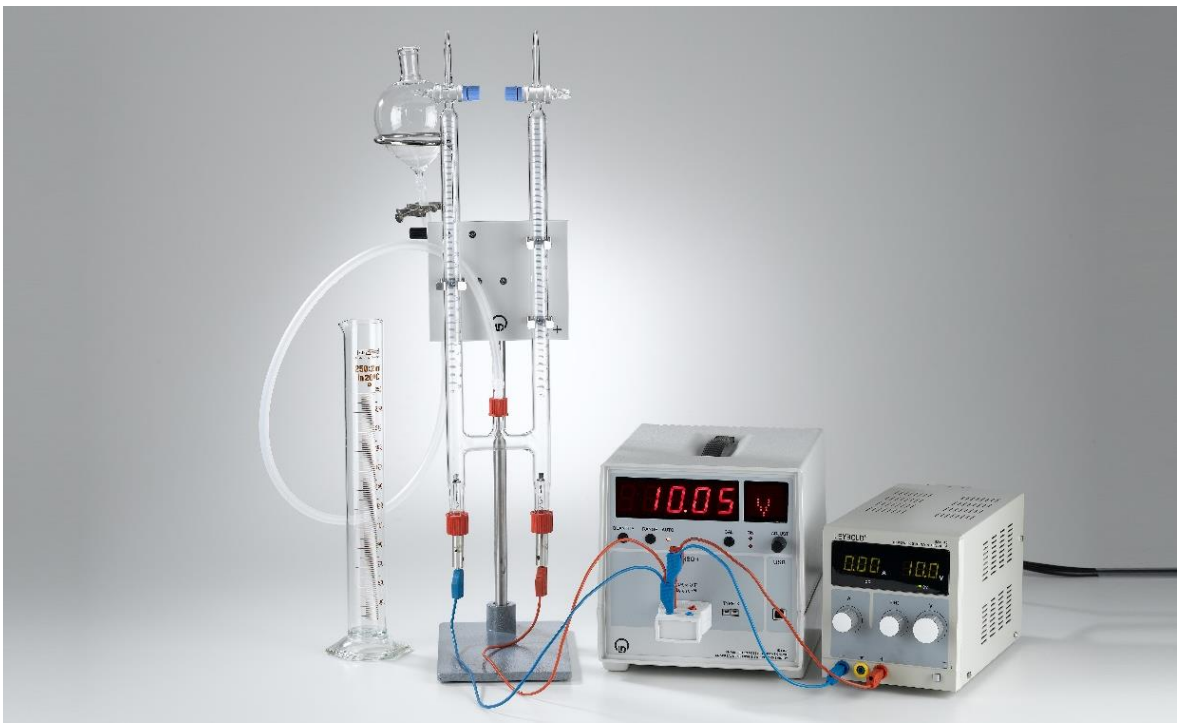

Fig. 1: Set-up of the experiment.

Risk assessment

Protective clothing must be worn while working with sulfuric acid. In this experiment, pure hydrogen and oxygen are formed, which are extremely flammable gases. Wear protective goggles when releasing the gases.

Sulfuric acid = 1 mol/l	
 **Warning**	**Hazard statements** H290: May be corrosive to metals. H315 Causes skin irritation. H319 Causes serious eye irritation. **Precautionary statements** P280: Wear protective gloves/protective clothing/eye protection/face protection. P302+P352: IF ON SKIN: Wash with plenty of soap and water. P305+P351+P338: IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing. P337+P313 If eye irritation persists: Get medical advice/attention.

Equipment and chemicals

For set-up in the CPS
1 Electrolysis apparatus, CPS 666 446
1 Panel frame C50, two-level, for CPS 666 425

For set-up with stand material
1 Water electrolysis apparatus..... 664 350

For both variants:
1 DC Power Supply 0...16 V/0...5 A 521 546
1 Connecting leads 19 A, 100 cm, pair..... ..... 501 46
1 Connecting leads 19 A, 50 cm, pair 501 45
1 Universal measuring instrument, Chemistry 531 836
1 UIP sensor S..... 524 0621
1 Measuring cylinder, Boro 3.3, 100 ml..... 602 953
1 Funnel PP, 50 mm diam. 665 008
1 Test tubes DURAN, 20 x 180 mm, 100 pcs 602 004
1 Teclu burner, universal 656 017
1 Safety gas hose with clamp, 0.5 m 607 020
1 Gas igniter, mechanical 666 731
1 Wooden turnings, 200 pcs 661 083ET20
1 Sulfuric acid, diluted, 500 ml 674 7920

Set-up and preparation of the experiment

Set-up of equipment

Set-up in the CPS

1. The apparatus is mounted on a CPS plate. For the experiment, insert the plate into the panel frame.

Set-up with stand material

1. The equipment is set up as shown in Fig. 1.
2. For this, insert the stand rod into the base and fasten.
3. Three bossheads S are fastened to the stand rod.
4. One is used for fastening the stand ring for the topping-up reservoir.
5. A universal clamp is inserted into each of the others, which is used to hold both side arms of the water electrolysis apparatus.

Set-up for both variants

1. Both platinum electrodes are screwed on to the bottom of the glass apparatus. For this, unscrew both plastic caps.
2. Push the plastic caps and the seals up to the metallic end of the electrodes and screw the plastic caps back onto the glass apparatus.
3. Mount the glass apparatus on the CPS plate and insert the topping-up reservoir into the holder.
4. Connect the PVC hose to the topping-up reservoir and connect with the electrolysis apparatus via the free screw connection.
5. Using two connecting leads, the platinum electrodes are connected to the universal measuring instrument via the UIP sensor S and the inputs for voltage measurement *V*.
6. Another connecting lead is inserted into each of the two connecting leads in the UIP sensor S, which is connected to the respective input for cathode/anode of the DC power supply.

Preparation of the experiment

1. Since distilled water alone has too low a conductivity, the apparatus has to be filled with diluted sulfuric acid. The 2 normal (= 1 molar) sulfuric acid is diluted further before the experiment. For this, 150 ml distilled water is mixed with 50 ml sulfuric acid in the measuring cylinder.

Note: The water must be poured in first, and then the acid added. Never do this the other way around.

3. The apparatus is filled with the diluted acid via the topping-up reservoir. For this, open the stopcocks at both side arms. When filling, ensure that there are no air bubbles at the electrodes. Then close the two stopcocks again.

Performing the experiment

1. To start the experiment, the DC power supply is switched on and a voltage of 10 V is set.
2. Rising air bubbles should be visible at both platinum electrodes, which accumulate in both side arms.
3. The experiment can be concluded after approx. 15 min. For this, switch off the DC power supply.
4. Now the respective volumes of formed gas can be read off at the anode and cathode.
5. The gas volumes must be read off while under external pressure. The topping-up reservoir is therefore lowered when reading off in such a way that the liquid level in the topping-up reservoir is at the same height as the liquid level of each side arm.

Observation

After switching on the voltage, gas bubbles can be seen rising at both platinum electrodes and accumulating in each side arm. Over time, it is clear that the gas volume in the cathode side arm rises more quickly than the gas volume at the anode.

After the reaction time, which should be around 15 minutes but may be longer, the voltage is switched off and no more gas bubbles rise. When reading off the two gas volumes, it turns out that twice as much gas has formed at the cathode than at the anode.

Evaluation

To check the identity of the formed gas at the cathode, carry out the detonating gas test. This is performed as follows:

a. Hold a test tube upside down over the opening of the stopcock of the apparatus at the cathode to collect the gas from the gas stream.

b. Then seal the test tube with your thumb and slowly bring it towards an open burner flame. At the same time, remove your thumb from the opening of the test tube.

c. If only a brief "plop" is heard, then the tube contains only pure hydrogen.

Before extracting the gas at the anode, a wooden turning is lit and then blown out so that it is still glowing. The gas on the anode side is also extracted with an upside-down test tube and sealed with the thumb. Then the glowing wooden turning is held in the test tube. If it glows visibly or starts burning again, this gas is oxygen.

In order to draw a conclusion on the molecular formula of water, the volumes can now be arranged in relation to one another.

Result

In this experiment, the electrolytic decomposition of water is performed. In the process, water is decomposed into its gaseous constituents. These are determined by different identifications and via the resulting gas volumes arranged in relation to one another in order to be able to determine the molecular formula of water.

The two identification tests indicate that hydrogen is formed at the cathode and oxygen at the anode. The molecular formula of water is thus H_xO_x in the first instance.

When reading off the gas volumes after concluding the experiment, it was determined that twice as much gas was formed at the cathode as was formed at the anode. This means that twice as much hydrogen was formed as oxygen.

The structural formula for water is thus $(H_2O)_{x'}$.

Cleaning and disposal

On conclusion of the experiment, the water electrolysis apparatus can remain full and is thus ready for direct use for a further experiment.

If the apparatus is to be emptied, then the diluted sulfuric acid can be disposed down the drain with lots of water.