The detonating gas cell

Time required: approx. 30-40 min

Aims of the experiment

- To construct a detonating gas cell in order to understand the principle of a fuel cell.
- To understand the fundamentals of fuel cell technologies.
- Difference between primary, secondary and tertiary elements.

Principles

The principle of the fuel cell was developed in 1839 by *Christian Friedrich Schönbein*. He immersed two platinum wires into hydrochloric acid and then sparged oxygen and hydrogen around them. In this process, he noticed an electric current. Many researchers were fascinated by this phenomenon and hoped it would lead to great revolutionary changes. Unfortunately this discovery was forgotten since *Werner von Siemens*' dynamo engine, in combination with the steam engines that use fuel, were less complicated and simpler. In the meantime, interest has rekindled. Many research groups are developing better and more powerful fuel cells. In the automobile industry (s. NeCAR® 1-5) and in space technology (s. Apollo-Mission/Space Shuttles), there are stronger fuel cells in use.

The fuel cell belongs to the class of tertiary elements. This means that the electrical energy from the chemical reaction between the fuel and the oxygen is put directly to work. Moreover, the fuel is fed continuously so that continuous current flow is ensured. The oxygen usually comes from the ambient air.

This offers the advantage that the cell can provide continuous power (see primary elements) and does not have to be charged as long as fuel is being fed to it (see secondary elements).

Fig. 1: Set-up and materials for the experiment

Fuels operate at an efficiency of about 60 – 70 % (internal combustion engines only 30 %). Theoretically, however, almost 100% should be possible, which is why research groups are currently working on this topic. There are many kinds of fuel cells that operate under various conditions.

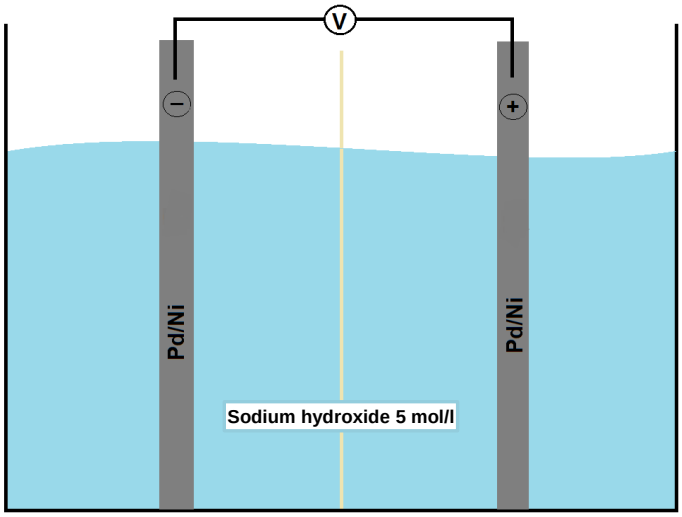

Fig. 2: Sketch of the experiment. Extraction of power from the fuel cell previously generated.

But what does actually happen in a fuel cell and how is power generated?

In alkaline fuel cells, also called detonating gas or low-temperature fuel cells, a potassium hydroxide solution is used as an electrolyte. As a fuel, hydrogen is used directly, which is fed to the anode. There, hydrogen is oxidised to form protons. The hydroxide ions that are present, which are formed from oxygen at the cathode through reduction, cause this to react to form water. Classical fuel cells use graphite electrodes because of its very adsorptive surface. The following reaction occurs:

			Redox potential
Anode	$2\,\overset{0}{H_2} + 4\,OH^-$	$\rightarrow\ 4\,\overset{+I}{H_2O} + 2\,e^-$	- 0.83 V
Cathode	$\overset{0}{O_2} + H_2O + 2\,e^-$	$\rightarrow\ 2\,\overset{-II}{OH^-}$	+ 0.40 V
Total	$2\,H_2 + O_2$	$\rightarrow\ 2\,H_2O$	+ 1.23 V

In this experiment, a detonating gas cell will be generated through hydrolysis. This will then be examined with regard to EMF and lifespan. The fed in oxygen and hydrogen is generated *in situ* on palladium.

Risk assessment

Caution! Hydrochloric acid is corrosive and causes serious skin and eye damage. Wear laboratory coat and goggles.

Palladium chloride causes serious eye irritation.

Hydrochloric acid, concentrated, 25%	
  **Signal word:** **Hazard**	**Hazard warnings** H314 Causes severe skin burns and eye damage. H335 May cause respiratory irritation. H290 May be corrosive to metals. **Safety information** P280 Wear protective gloves and goggles/face protection. P301 + P330 + P331 IF SWALLOWED: Rinse mouth. Do NOT induce vomiting. P309 + P310 IF exposed or you feel unwell: Immediately call a POISON CENTER or doctor/physician. P305+P351+P338 IF IN EYES: Rinse carefully with water for several minutes. Remove contact lenses if present and if possible to do so. Continue rinsing.
Palladium chloride solution	
 **Signal word:** **Caution**	**Hazard warnings** H315 Causes skin irritation. H317 Can cause allergic skin reactions. H319 Causes serious eye irritation. **Safety information** P280 Wear protective gloves. P302+P352 IF ON SKIN: Wash with plenty of water and soap. P305+P351+P338 IF IN EYES: Rinse carefully with water for several minutes. Remove contact lenses if present and if possible to do so. Continue rinsing.

Equipment and chemicals

1	Electrochemistry demonstration unit, CPS	664 4071
1	Panel frame C50, two-level, for CPS	666 425
1	Electrochemistry table, CPS	666 472
1	Electrochemistry accessories set	664 401
1	Electrolysis cell	from 664 401
1	Drip pan	from 664 401
4	Paper diaphragm	from 664 401
2	Crocodile clips	from 664 401
5	Connecting leads	from 664 401
2	Nickel wire mesh electrodes	from 664 401
1	Tweezers	from 664 401
1	Petri dish, 120 mm	602 740
2	Dropping pipette, glass	665 9531
2	Rubber bulbs	665 9541
1	Measuring cylinder, 10 ml	665 751
1	Measuring cylinder, 100 ml	665 754
1	Laboratory bottle to DIN standard, 250 ml	602 346
1	Mini magnetic stirrer with stirring magnet	607 105
1	Scales	ADACB501
1	Watch glass dish, 125 mm	664 157
1	Wash bottle, 250 ml	661 242
1	Acetone, 250 ml	670 0400
1	Water, pure, 1l	675 3400
1	Potassium hydroxide, flakes, 250 g	672 6400
1	Hydrochloric acid, conc. 25%, 250 ml	674 6750
1	Palladium chloride solution, 50 ml	674 0430

Set-up and preparation of the experiment

Set-up of the experiment

Suspend the demonstration unit (Fig. 3) and the electrochemistry table in the panel frame. Place the drip pan in the centre of the electrochemistry table. Fix the two half cells of the electrolysis cell with the screws so that a gap about 0.5 cm wide remains open. In this gap, place two paper diaphragms one atop the other and screw the two half-cells tight. The electrolysis cell should now be sealed.

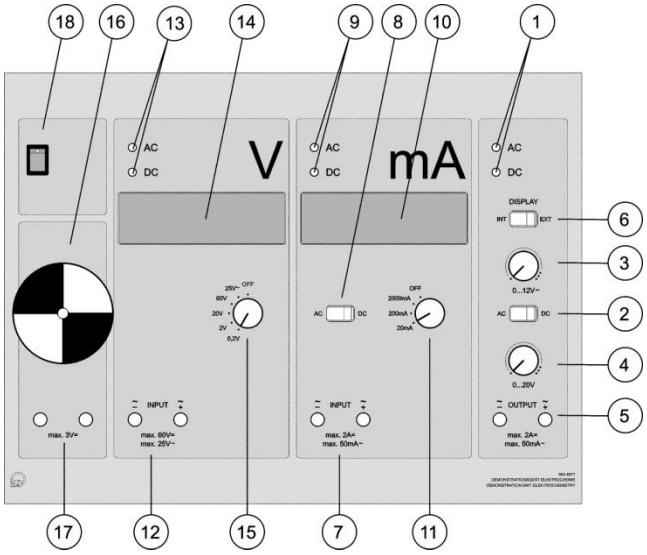

Fig. 3: Sketch of the demonstration unit.

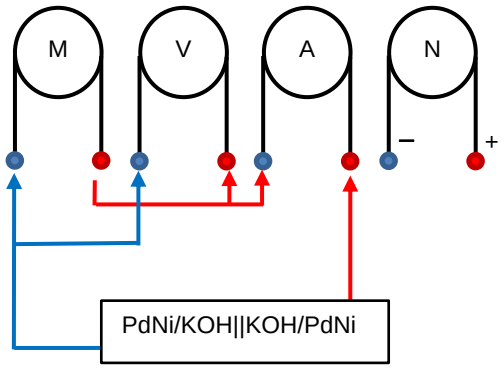

Fig. 4: Circuit of the experiment during power draw at the fuel cell.

Palladium plating the nickel wire mesh electrode

The nickel wire mesh electrode has very low adsorption capacity for gases. Also, nickel surfaces are very catalytically inefficient compared to palladium surfaces. Therefore, the nickel wire mesh electrode will be coated with palladium.

First the surface is de-greased. To do so, the nickel wire mesh electrode is immersed in acetone. For this purpose, coat the electrodes with acetone in a petri dish. The electrodes are turned over several times using the tweezers. The electrodes are now rinsed with distilled water and placed on a paper towel. From now on, the electrodes must only be handled using the tweezers.

Allow the petri dish to dry or wipe with a cloth.

In order to achieve better adhesion of the palladium, the electrodes are etched. To do this, the electrodes are placed in the petri dish again and coated with concentrated hydrochloric acid. After 5 seconds, the electrodes are turned. Overall, the electrodes remain in the hydrochloric acid for 10 - 15 seconds. Rinse the electrodes with distilled water and place on a paper towel to dry. Rinse the petri dish and re-rinse with distilled water.

The actual palladium coating is done using approx. 0.5% hydrochloric palladium chloride solution. Measure 7 ml of hydrochloric palladium chloride solution (1%) into a measuring cylinder (10 ml) and transfer it to the dried petri dish. Now add 7 ml of distilled water and stir. If the solution does not mix well with water, add 2 - 3 drops of conc. hydrochloric acid. Allow the electrodes to sit for a few minutes in this solution. Turn the electrodes 2 – 3-times. Palladium coating is deemed successfully applied when the electrodes have gone from a silver colour to a dark grey colour.

The electrodes can be stored for an extended time in distilled water. If there is palladium chloride residue in the petri dish, it can be stored in the storage liquid. If during the experiment palladium detaches from the electrode, this is not of concern. Only when the experiment no longer provides correct values should the palladium coating be repeated.

Preparing the 5 molar potassium hydroxide solution

In a laboratory bottle (250 ml), add 140 ml of distilled water using a measuring cylinder (100 ml) and a stirring magnet. Place the bottle on a magnetic stirrer and adjust the stirrer to an average speed. Weigh 56.1 g of potassium hydroxide flakes into a watch glass dish on the scales. Now, add the potassium hydroxide flakes in portions into the stirring water using the spatula.

CAUTION: Do not add the flakes too quickly since potassium hydroxide dissolved in water generates a lot of heat.

When the flakes have completely dissolved, fill the solution up to the 200 ml mark with distilled water. The solution can be stored in the laboratory bottle. Do not forget to label the bottle!

Performing the experiment

The palladium-coated electrodes are placed in the third outermost grooves of the half cells using the tweezers. Connect the outlet jacks of the power supply (5) (see Fig. 3) to the electrodes using the connecting leads. Set the selector switch (6) to an internal power source. Set the changeover switch (2) to direct current (DC) on the power supply. Also set the changeover switch (8) and rotary controller (15) to direct current (DC). Turn on the measurement display using the changeover switch (8). Measure 70 ml of 5 molar potassium hydroxide solution into a measuring cylinder and transfer to a half cell. Then, measure another 70 ml of potassium hydroxide solution in the measuring cylinder and add to the other half cell.

Preparing the detonating gas (fuel) cell through electrolysis

Set a direct current voltage of 2.5 V at the power supply (5) using the rotary controller (4). The gases generated can be investigated with a glowing splint test. To this end ignite the splint and hold the embers over the gases. The electrolysis is ended after 90 seconds by shutting off the demonstration unit.

Energy conversion from the fuel cell

Connect the palladium-coated nickel electrodes to the outlet jacks of the voltmeter (12) and of the amperemeter (7). Set the selector switch (6) to an external power source. Turn on the demonstration unit using the switch (18). Now, the clamping voltage can be read off on the voltmeter. Connect the motor. To do so, connect one output jack each (see Figure 4 for more on this). Record the time up until the electric motor comes to a standstill. Renewed electrolysis can re-activate the cell. Repeat the electrolysis of the detonating gas cell with 3.3 volts for 3 minutes and record the time of the electric motor.

Observation

During electrolysis, significant gas generation occurs.

The motor turns strongly as it draws current and slows down over time until it comes to a stop. The glowing splint test was successful. In the anode space, the splint glows strongly.

Evaluation

Two different electrolysis times and voltages were carried out. The following table contains the experimental values.

Tab. 1: Measurements and electrolysis times for a detonating gas cell.

No.	Electrolysis time	Voltage during electrolysis	Clamping voltage	Time until the motor came to a stop
1	2 min	2.5 V	1.3 V	103 sec.
2	3 min	3.3 V	1.3 V	220 sec.

Results

From the measurement results it can be concluded that a longer period of electrolysis or a greater charging voltage will lead to longer current yields.

Further, the clamping voltage is 1.3 V, which seems reasonable for everyday use.

Since the fuel cell is a tertiary element, the fuel must be continuously fed. This makes engine options for use in automobiles more difficult, for example. If the fuel cell is driven by hydrogen, as in this experiment, a highly explosive and pressurised hydrogen supply vessel would have to be stored permanently in the vehicle. Therefore, the development of such fuel cell-driven technologies is still in the research phase. Current alternatives include methanol-driven fuel cells, and solid-adapted fuel cells, but these continue to require higher temperatures for smooth operation.

Cleaning and disposal

Potassium hydroxide solution can be disposed of in the laboratory drain with significant dilution. Remove the electrodes using the tweezers and rinse thoroughly multiple times with distilled water. Store the electrodes in the storage solution. Rinse the electrolysis cell multiple times using tap water. Then, remove the diaphragm by removing the screws and rinse the electrolysis cell multiple times with distilled water and allow to dry.