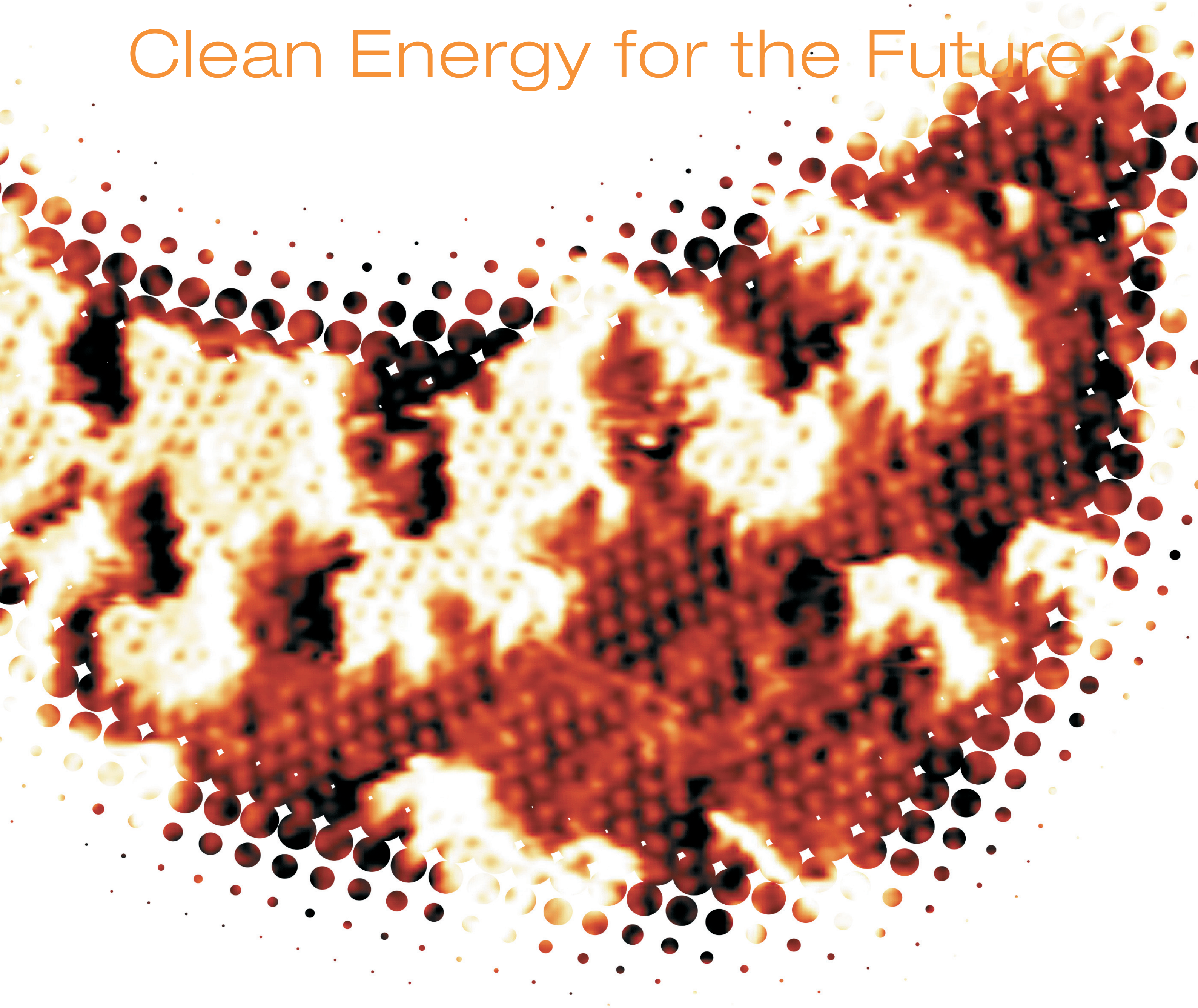
Chemistry through Hydrogen

Clean Energy for the Future



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Contents

Part 1

Experimental sessions

These sessions cover a range of topics from post-16 Chemistry specifications addressed within the context of sustainable energy supplies.

Using this section:

The laminated sheet provided with each kit may be photocopied and issued to students for guidance.

The Student Guides. Students are guided in planning, undertaking and evaluating the experiment. Preparatory and follow-up questions ensure that the experimental work has a firm theoretical basis and is set in a real-life context. The students develop experimental skills of circuit design and assembly as well as laboratory, IT, data analysis and report writing skills. The guides may be photocopied for student use.

The Teacher Guides offer specific information regarding the learning objectives of each experiment, details of the experimental set-up and the anticipated learning outcomes. There is also a full explanation of the underpinning theory and how to interpret the data. If students require additional support when undertaking their investigation then photocopied sub-sections of the teacher guides may be offered at the teacher's discretion, for example to prompt students or specify precisely the circuit design or how the experiment might be done.

Key chemistry specification requirements targeted:

- Electrolysis and oxidation and reduction
- Catalysis
- Quantitative chemistry
- Group 4 and d-block chemistry
- Economic and environmental factors

Subject specific experimental skills:

- Basic circuit design and assembly
- Adapting apparatus to fit the task
- Recording, analysing and interpreting data
- Manipulation of variables and optimisation
- Evaluation of techniques and the quality of results
- Manipulation of gases

Contents:

E5. The Faraday efficiency of the electrolyser pg36–41

The actual volume of hydrogen produced during electrolysis is compared with the volume theoretically obtainable. Repeated runs and precision in calculation are stressed. Experimental technique is evaluated.

E6. The characteristic curve of a fuel cell pg42–47

The PEM fuel cell is introduced. Students investigate how the voltage and current vary as the value of the resistance load changes. As the hydrogen fuel cell is the reverse of the electrolyser, the two characteristic curves may be compared. Results are displayed graphically and experimental technique is evaluated.

E7. The efficiency of the fuel cell pg48–53

Students compare the actual volume of hydrogen used by the fuel cell with the theoretical volume required for production of a certain amount of electricity. Extension work on energy efficiency, and also on the link between the power developed by the cell and its efficiency, is suggested. Precise calculation is required. Experimental technique is evaluated.

E8. Faraday's first law using a fuel cell pg54–59

Students test the application of Faraday's first law to a fuel cell by investigating how the volume of hydrogen used by the cell varies: (1) with time, keeping the current constant; (2) with the current produced by the cell, during a constant time interval. Results are analysed graphically and experimental technique is evaluated.

E9. The rates of reactions at the electrode pg60–61

Results of previous experiments are used to broaden students' experience of calculation; for example, to find the rate of discharge of hydrogen ions at the cathode, the rate of production of hydrogen at the membrane, and the rate of production of water in the cell.

E10. The characteristic curve of the methanol fuel cell pg62–67

The methanol fuel cell is introduced. Students investigate how the voltage and current vary as the value of the resistance changes. Results are displayed graphically, and compared with the characteristic curve for the hydrogen fuel cell. Experimental technique is evaluated.

E11. The effect of varying concentrations on the methanol fuel cell pg68–73

Students investigate the behaviour of the methanol fuel cell when different concentrations of aqueous methanol are used. The characteristic and power curves are displayed graphically. Students are encouraged to consider the processes within the fuel cell which lead to the observed shape of the curves. Experimental technique is evaluated.

E12. The dismantlable fuel cell: Impact of catalyst load on the characteristic curve pg74–79

The dismantlable fuel cell is introduced. Students gain experience in manipulation as they dismantle and reassemble the cell. The characteristic curves of the cell are found for different catalyst loads on the membrane and displayed graphically. Students are encouraged to consider the implications of their observations for commercial fuel cells. Experimental technique is evaluated.

E13. Impact of the gas supply on the characteristic curve of the fuel cell pg80–85

Students use the dismantlable fuel cell to control the rate at which oxygen can reach the cathode, and display the resulting characteristic curves graphically. They are encouraged to consider the implications of their observations for commercial fuel cells. Experimental technique is evaluated.

experimental sessions continued

E14. Team project: Comparing the hydrogen and methanol fuel cells pg86–87

One group of students investigates the hydrogen fuel cell and another the methanol fuel cell. (Alternatively, the results from previous experiments may be used). A list of points to use in comparing the two cells is drawn up, and each point discussed and its importance assessed, including the implications for commercial use of the cells. A report is then written by each student.

E15. Theoretical principles behind fuel cells pg88–93

A resource for experiments 6-14. Aspects covered include the general characteristics of the fuel cell, the principles of operation, the structure of the membrane/ electrode assembly, the significance of the shape of the characteristic curve, and the implications for commercial use.

Faraday's first law **using a fuel cell**

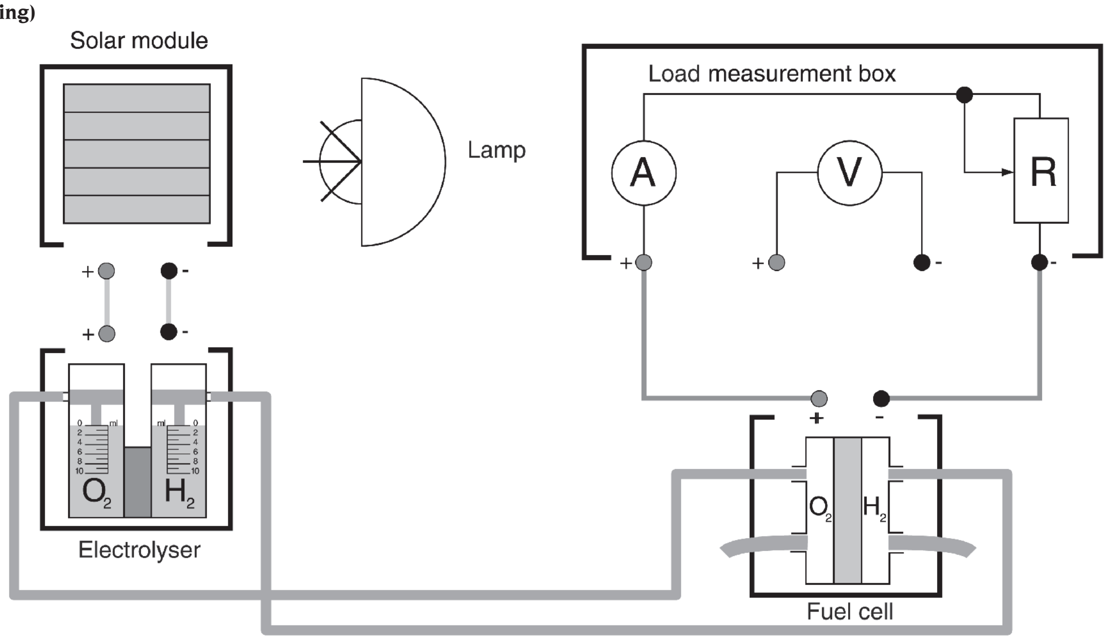
Apparatus required:

- Solar module
- Electrolyser
- Fuel cell
- Load measurement box
- Connecting leads
- Stop watch
- 2 long tubes
- 2 short tubes
- 2 tubing stoppers

Additional components:

- Lamp 100 – 150 Watt
- Distilled water

Fig. 1 (purging)

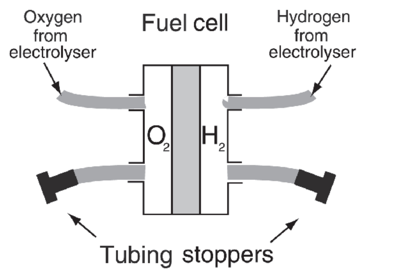


Safety: Please follow the operating instructions.
Wear protective goggles and keep ignition sources at a distance when experimenting.
Solar module becomes hot.
A full risk analysis must be undertaken before beginning any experiment.

Instructions:

1. Set up the apparatus as shown in fig.1. Make sure all connections have the correct polarity.
2. Check that the gas tubes are correctly connected between the electrolyser and the fuel cell. Adjust the rotary switch to 'OPEN'.
3. Make sure both gas storage cylinders of the electrolyser are filled up with distilled water to the 0 ml mark. Adjust the solar module so that there is a constant current to the electrolyser of between 200 to 300 mA. The solar module and the light source must be positioned so that steady gas production can be observed.
4. Purge the complete system, consisting of the electrolyser, fuel cell and tubes, for 5 minutes with the gases released from the electrolyser. Then put the rotary switch on the load measurement box to 3Ω for 3 minutes. The ammeter display of the load measurement box should show that a current is flowing. Purge the system again with the rotary switch 'OPEN' for 3 minutes.
5. Disconnect the solar module from the electrolyser, and close both the short tubes at the outlet nozzles of the fuel cell using the stoppers (see fig.2).
6. Reconnect the electrolyser with the solar module. The electrolyser will now store gas in the storage cylinders. Disconnect the electrolyser's power supply when the hydrogen has reached the 10 ml mark.
7. Since the whole system always has a certain leakage rate because of its tubes and seals, a blank measurement must be made first. Record the loss of hydrogen from the hydrogen storage cylinder, without load at the fuel cell, over a period of 5 minutes. Determine the leakage rate in cm^3 of hydrogen per minute.
8. Reconnect the electrolyser to the solar module and refill the hydrogen storage cylinder up to the 10 ml mark. Then disconnect the power supply to the electrolyser again.
9. In order to examine the **first part of Faraday's first law**, set a constant current by adjusting the rotary switch of the load measurement box to a resistance of 3Ω. Now record the volume of hydrogen consumed by the fuel cell from the electrolyser's hydrogen storage cylinder for 4 minutes (60 to 240 s in 60 s steps). Record your results in table 1. Then rotate the switch to the 'OPEN' position.
10. Reconnect the electrolyser to the solar module and refill the hydrogen storage cylinder up to the 10 ml mark. Then disconnect the solar module again.
11. In order to examine the **second part of Faraday's first law**, use the rotary switch to successively set different current levels by selecting different resistances (10, 5, 3 and 1Ω). For each resistance value, record in table 2 the volume of hydrogen consumed by the fuel cell from the electrolyser's hydrogen storage cylinder during 120 s. After each individual measurement, adjust the rotary switch to the 'OPEN' position and refill the hydrogen storage cylinder to the 10 ml mark as described in section 8.
12. After the final measurement, adjust the rotary switch to 'OPEN' and remove the stoppers from the tubes of the fuel cell.
13. Correct the measured values by subtracting the leakage rate.

Fig. 2 (storing)



teachers guide continued

Table of results: Fuel cell without load - blank measurement (draw out your own tables)

Volume of hydrogen lost from storage in 5 min =	cm^3
Leak rate of system =	cm^3/min

Table 1:

R =	Ω = constant
I =	mA = constant

Time/s	Vol_{H_2}/cm^3	Vol_{H_2}(corrected)/cm^3

Table 2:

t =	s = constant

Resistance/Ω	Current/mA	Vol_{H_2}/cm^3	Vol_{H_2}(corrected)/cm^3

Evaluation:

1. Plot the recorded data from results tables 1 and 2 (hydrogen consumption versus time and hydrogen consumption versus current).
2. Investigate the connection between the volume of hydrogen consumed and the quantity of electricity (in Coulombs) produced (Faraday's first law).

Et8

Learning objectives

- **that the volume of hydrogen used by a fuel cell is proportional to time, with the current being constant**
- **... and is also proportional to current, during a constant time interval**
- **... and that therefore a fuel cell obeys a form of Faraday's first law**

Interpretation

Graph 1 shows that the volume of hydrogen consumed is proportional to the time (at a constant current).
Therefore: Vol $\propto$ t

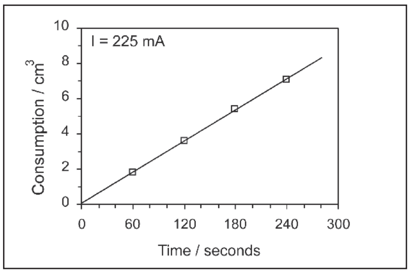
Graph 2 shows the straight line relationship between the volume of hydrogen consumed and the various currents produced (at constant time).
Therefore: Vol $\propto$ I

If Vol $\propto$ t and Vol $\propto$ I, then: Vol $\propto$ It

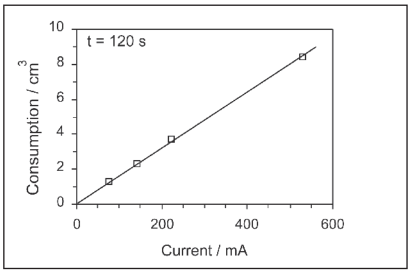
It follows that because:
It = charge (Coulombs), volume of hydrogen consumed $\propto$ amount of electricity produced.

Faraday's first law relates to electrolysis, and states:
The amount of a substance produced by a cathode or anode reaction in electrolysis is directly proportional to the quantity of electricity passed through the electrolytic cell.

Sample results:



(1) Consumption of hydrogen as a function of time – Faraday's first law (part1)



(2) Consumption of hydrogen as a function of current produced by the fuel cell – Faraday's first law (part 2)

We can now see that an exactly similar law applies to the opposite process to electrolysis, which occurs in the hydrogen fuel cell:
The amount of hydrogen which is consumed in a fuel cell is proportional to the quantity of electricity produced.

notes

Faraday’s first law **using a fuel cell**

Apparatus required:

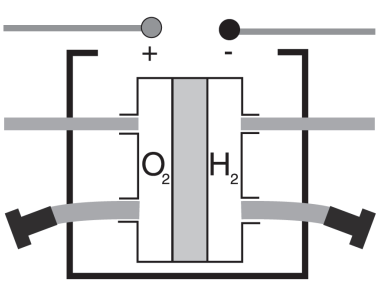
- Solar module
- Electrolyser
- Fuel cell
- Load measurement box
- Connecting leads
- 2 long tubes
- Stop watch
- 2 short tubes
- 2 tubing stoppers

Additional components:

- Lamp 100 – 150 Watt
- Distilled water
- Photocopy of the diagram on the laminated sheet in the hydro-Genius kit

Safety: Please follow the operating instructions.
Wear protective goggles and keep ignition sources at a distance when experimenting.
Solar module becomes hot.
A full risk analysis must be undertaken before beginning any experiment.

Introduction



Faraday’s first law states: The amount of a substance produced at a cathode or anode during electrolysis is directly proportional to the quantity of electricity passed through the electrolytic cell.

A re-worded form of the law should apply to a hydrogen fuel cell: The amount of hydrogen which is consumed in a fuel cell is directly proportional to the quantity of electricity produced.

Objective

To investigate how the volume of hydrogen used by the fuel cell varies: (1) with time, the current produced being kept constant; (2) with the current produced, during a constant time interval; and so to test whether Faraday's first law applies to the fuel cell.

E8

Procedure

- Assemble the appropriate components, as shown in the teacher's notes, with a lamp, and use the gases produced by the electrolyser to remove all air from the apparatus ('purging').
- **All connections must be correctly made, with the correct polarity. Check with your teacher before proceeding.**
- Purge the complete system for 5 minutes with the switch at 'OPEN'. Put the switch box to 3Ω for 3 minutes: the ammeter display should show that a current is flowing. Switch back to 'OPEN' and purge for 3 more minutes.
- Store gases in the electrolyser, close the exit tubes from the fuel cell, and measure the rate at which hydrogen leaks from the apparatus over a period of 5 minutes. This leakage rate must be allowed for in subsequent calculations.
- Using gases stored in the electrolyser to power the cell, set a constant current by using a resistance of 3Ω, and investigate the rate at which hydrogen is used from the storage cylinder. (Starting with hydrogen at 10 ml mark, measure the volume used after each minute for 4 minutes).
- Then (refilling the hydrogen storage, with the switch at 'OPEN', before each run) use different resistances (10, 5, 3, 1Ω) to investigate how the volume of hydrogen consumed varies with the current produced by the cell, using a constant time interval (say, 2 minutes).

Results, records and evaluation

1. Draw a circuit diagram and explain its arrangement.
2. Construct suitable tables for recording data, either on paper or as a spreadsheet.
3. Use your results to plot graphs of (1) volume of hydrogen consumed vs time (at constant current) and (2) volume of hydrogen consumed vs current (for a constant time interval).

Questions

- Write equations to represent the reactions occurring at the anode and cathode in each of the electrolyser and the hydrogen fuel cell.
- Use the equations to explain *why* you expected Faraday's first law to apply to the fuel cell.

4. Use these graphs to test the validity of Faraday's first law for the fuel cell,
5. Evaluate the techniques used in your experiment, identify any precautions taken, and describe any difficulties you encountered and how they were overcome.
6. Suggest any ways in which the experimental procedure might be improved.

Extension work

Use your results and the electrode equation in the fuel cell to calculate the number of moles of hydrogen required to produce 96,500 C of electric charge. (1 mole of any gas occupies 24,000 cm^3 at room temperature and pressure; the Faraday constant = 96,500 C mol^{-1}).

Comment on the result of your calculation.