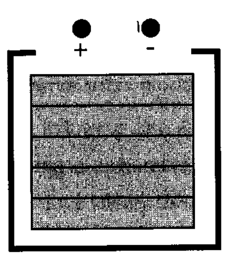
Investigating the solar module - are the current and voltage outputs fixed?

Apparatus required:
- Solar module
- Load measurement box
- Connecting leads

Additional components:
- Lamp 100 – 150 Watt

Safety: Please follow the operating instructions.
The solar module becomes hot in use.
A full risk assessment must be carried out before beginning this experiment.

Introduction



Solar module

A solar cell is a specially designed semiconductor diode which generates an e.m.f. when exposed to light. It can, therefore, be used as a low voltage D.C. power supply, but only up to a limit. A solar module is a number of solar cells connected in series so that the total e.m.f. obtained is the sum of the individual e.m.f.s. However the current obtained is limited by the internal resistance of each solar cell.

The behaviour of a solar module can be seen in its characteristic curve. This plots the current through the load resistor against the e.m.f. (voltage) delivered by the cell while the light intensity is kept constant. This curve will show, quite clearly, that there is, in fact, a particular point where the solar module can deliver maximum power for a given level of light intensity.

Objective

To investigate the behaviour of a solar module when it is driving a current through increasing load resistors and to find the maximum power it can deliver at constant light intensity.

Preparatory work

Answer these questions before beginning any experimental work.

1. Devise and draw a circuit which allows you to measure the e.m.f. generated by the solar cell when it drives a current through a range of load resistors. .
2. Outline what you will do to obtain appropriate data.
3. Explain what is meant by a characteristic curve.

Procedure

- Construct your circuit and check that the apparatus gives readings over a suitable range.
- Vary the value of the load resistor and investigate how the e.m.f. and current vary as the value of the load resistor is changed. Ensure that the light intensity is kept constant throughout the investigation.

Hint: Wait until the solar cell has reached a stable temperature before beginning the experiment.

Product

1. Explain the experimental technique used to obtain the data.
2. Devise and complete a suitable results table to record your data, either on paper or on a computer spreadsheet.
3. Plot the characteristic curve for the solar module.
4. Comment on the shape of the curve.
5. Re-draft the results and plot power against voltage and from this curve identify the Maximum Power Point of the solar module.
6. Comment on any problems you encountered during the experiment, any precautions taken to ensure accuracy and any changes you made to your original plan.
7. Finally evaluate the experimental technique you used and suggest any further improvements for the experiment.

Experiment variations

Determine the influence of the light intensity on the power of the solar module. Record two further characteristic curves, changing the distance between the lamp and the solar module (to e.g. 20 cm and 40 cm).

At a distance of 20 cm the solar module must only be illuminated for the duration of the experiment.

Draw graphs plotting P against V and compare them with the PV diagram at a lamp distance of 30 cm.

Question

- What is the significance of the Maximum Power Point of the solar module? Hint - if you were choosing a solar cell to operate a device, how would you take account of its maximum power point and why?

Extension work

Research what materials a solar cell is made of and how a solar cell generates an e.m.f. when light falls on it.
(further information is available in the 'Research Notes' book).

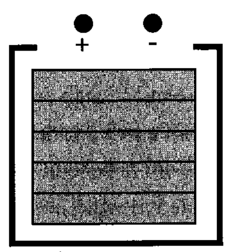
Investigating the solar module – is it really a diode?

Apparatus required:
- Solar module
- Load measurement box
- Connecting leads

Additional components:
- Black cardboard
- Power-supply unit

Safety: Please follow the operating instructions.
A full risk assessment must be carried out before beginning any experiment.

Introduction



Solar module

A solar cell will not produce an e.m.f. itself unless it is irradiated. A power supply can make a current flow through a non-irradiated solar cell and this current will vary as the applied e.m.f. is changed. The characteristic curve, a plot of I against V, of the solar cell will show whether it is acting as a diode when not irradiated.

Objectives

To investigate the behaviour of a solar module when it is not irradiated and to determine whether it acts as a diode.

Preparatory work

Answer these questions before you begin the experimental work.

1. Explain the meaning of the terms 'forward bias' and 'reverse bias' when applied to a diode.
2. Devise and draw a circuit diagram which will allow you to vary the e.m.f. supplied to a solar cell from a D.C. power supply and measure the current which flows through it when it is forward biased.
3. Outline what you plan to do to obtain appropriate data.

Procedure

- Construct your circuit and check that the apparatus gives readings over a suitable range – keeping the applied voltage below 3.0 volts.
- Vary the applied e.m.f. and monitor the changes in current flow. Ensure that the solar cell is not irradiated throughout the experiment.

N.B. the applied voltage must be kept below 3.5 V in forward bias.

- Turn the solar module to 'reverse bias' and monitor the current for various values of applied e.m.f.

N.B. the applied voltage must be kept below 3 V in reverse bias.

Product

1. Draw the circuit diagram and explain the experimental technique used to investigate the behaviour of the solar cell.
2. Devise a suitable results table to record your data, either on paper or on a computer spreadsheet.
3. Plot the characteristic curve for the non–irradiated solar module in forward bias and in reverse bias.
4. Comment on the shape of the curves.
5. Comment on any problems you encountered during the experiment, any precautions taken to ensure accuracy and any changes you made to your original plan.
6. Finally evaluate the experimental technique you used and suggest any further improvements for the experiment.

Questions

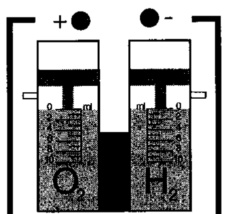
- A semiconductor diode is a 'p-n junction'. Explain what 'p' and 'n' signify in this context and what happens when a p-n junction is created.
- For solar cells connected in series a defective or shaded cell has the same effect as a resistor and may even overheat and be destroyed. Explain how a 'by-pass diode' connected in parallel with the cell will overcome this problem.

Investigating the **characteristic curve of an electrolyser**

Apparatus required:	Additional components:
• Electrolyser	• Lamp 100 – 150 Watt
• Solar module	• Distilled water
• Load measurement box	
• Connecting leads	

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

Introduction


Electrolyser

An electrolyser contains an electrolyte and two electrodes (the positive anode and the negative cathode). When a voltage is applied, the ions (charge carriers) in the electrolyte will be attracted to the electrodes and a current flows. However the voltage has to be high enough (enough energy) to 'split the water' into its ions before a current will flow – the decomposition voltage.

Objectives

To investigate the behaviour of the electrolyser and to find the decomposition voltage where current flow and gas production first begins.

Preparatory work

Answer these questions before you begin the experimental work.

1. Devise and draw a circuit diagram which will allow you to use the solar module to apply a small voltage (less than 2 volts) across the electrolyser. Include a voltmeter and an ammeter to allow you to measure the voltage and current across the electrolyser.
2. Explain how you vary voltage input.
3. Explain how current flows in a liquid electrolyte such as water.

Procedure

- Construct your circuit and check that the apparatus gives readings over a suitable range. Ensure there is no load resistor connected in the circuit.
- Vary the applied e.m.f. and monitor the changes in current flow.

Safety notes:
Wear protective goggles.
Ensure ignition sources are kept at a distance. Ensure the electrolyser is correctly connected to the power supply – positive terminal to positive terminal etc.

Product

1. Draw the circuit diagram and explain the experimental technique used to investigate the behaviour of the electrolyser.
2. Devise a suitable results table to record your data, either on paper or on a computer spreadsheet.
3. Plot the characteristic curve for the electrolyser.
4. Comment on the shape of the curve.
5. Comment on any problems you encountered during the experiment, any precautions taken to ensure accuracy and any changes you made to your original plan.
6. Finally evaluate the experimental technique you used and suggest any further improvements for the experiment.

Questions

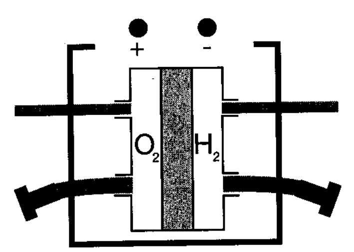
- The theoretical decomposition voltage for water is 1.23 volts. This experiment will have given a value above 1.23 volts and the difference is called the overpotential. What physical factors might obstruct the release of hydrogen and oxygen at the electrodes and cause an overpotential?
- Why must designers of commercial electrolysers be aware of these factors?

Investigating the **characteristic curve of a fuel cell**

Apparatus required:	• 2 short tubes
• Solar module	• 2 long tubes
• Electrolyser	• 2 tubing stoppers
• Fuel cell	**Additional components:**
• Connecting leads	• Lamp 100 – 150 Watt
• Load measurement box	• Distilled water

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

Introduction



Fuel cell

A hydrogen fuel cell produces an emf by combining hydrogen and oxygen chemically. A conventional battery supplies electrical energy in the same way except that the reactants (for example nickel oxyhydroxide and cadmium) are eventually used up and the battery has to be disposed of or recharged.
A fuel cell will provide energy so long as hydrogen and oxygen are supplied to it.
The current and voltage output will depend upon the load applied to the fuel cell and can be seen from its characteristic curve. As the processes in a fuel cell are the reverse of electrolysis it is useful to compare the characteristic curves of the fuel cell and electrolyser.

Objective

To investigate the behaviour of a hydrogen fuel cell - are the current and voltage outputs proportional?

Preparatory work

Answer these questions before beginning any experimental work.

1. Devise and draw a circuit which allows you to measure the e.m.f. generated by the fuel cell when it drives a current through a range of load resistors.
2. Outline what you plan to do to obtain appropriate data.
3. Explain what is meant by a characteristic curve.

Procedure

- In order to use the fuel cell as a power source it must be provided with a supply of hydrogen and oxygen from the electrolyser. This may have been done for you in advance of the experimental session. Alternatively proceed as follows:
  1. Set up the apparatus. **Pay attention to the polarity of the electrolyser!**
  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 the gas storage cylinders of the electrolyser are filled up with distilled water to the 0 ml mark. Adjust a constant current from the solar module to the electrolyser of around 200 and 300 mA. The solar module must be positioned towards the light source such that a clear gas production can be observed.
  4. Purge the complete system comprising of the electrolyser, fuel cell and tubes for 5 minutes with the gases released from the electrolyser. Thereafter put the rotary switch on the load measurement box to 3Ω for 3 minutes. You should already now observe a current at the ammeter of the load measurement box. Purge the system again with the rotary switch in position 'OPEN' for 3 minutes.
  5. Disconnect the solar module and the electrolyser and close both the short tubes at the gas outlets of the fuel cell with stoppers.
  6. Reconnect the solar module to the electrolyser and store the gases in the gas storage cylinders. Interrupt the power supply of the electrolyser when the hydrogen has reached its 10 ml mark.
- Now construct your circuit, as designed previously, using the fuel cell as the voltage source (with the outlets of the electrolyser supplying gas to the fuel cell) and check that the apparatus gives readings over a suitable range.
- Vary the value of the load resistor and investigate how the e.m.f. and current vary as the value of the load resistor is changed.

Product

1. Explain the experimental technique used to acquire the data.
2. Devise and complete a suitable results table to record your data, either on paper or on a computer spreadsheet.
3. Plot the characteristic curve for the fuel cell.
4. Comment on the shape of the curve.
5. Comment on any problems you encountered during the experiment, any precautions taken to ensure accuracy and any changes you made to your original plan.
6. Finally evaluate the experimental technique you used and suggest any further improvements for the experiment.

Question

- The maximum voltage achieved from this fuel cell on 'open circuit' is about 0.9 V. This is less than the theoretical value. What physical factors might cause this reduction? (Hint: compare this with the electrolyser.)

Extension work

Plot power against current for the fuel cell. Why do you think that, in practice, we try to draw as much current as possible from a fuel cell?

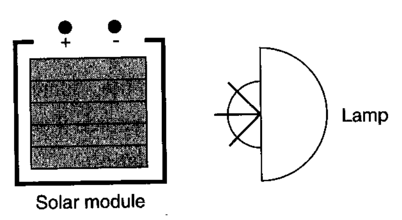
student guide

Investigating how solar cell photocurrent varies with **distance to light source**

Apparatus required:	Additional components:
• Solar module • Load measurement box • Connecting leads	• Lamp 100 – 150 Watt • Ruler

Safety: Please follow the operating instructions.
Solar module becomes hot
A full risk analysis must be undertaken before beginning any experiment.

Introduction



A solar cell is a specially designed semiconductor diode which generates an e.m.f. when exposed to light. The solar cell absorbs light energy and converts it to electrical energy so the amount of light falling on the solar cell will affect the current output.
A solar module is a number of solar cells connected in series.

Objectives

To investigate how the behaviour of a solar cell varies with the amount of light falling on it, e.g. due to changing the distance between the module and the light source.

E5

Preparatory work

Answer these questions before you begin any experimental work.

1. Devise and draw a circuit which allows you to measure the current output from the solar module when illuminated.
2. Outline what you plan to do to vary the amount of light falling on the solar module and, therefore, to obtain appropriate data.

Procedure

- Construct your circuit and check that the apparatus gives readings over a suitable range.
- Vary the amount of light falling on the solar module and measure the corresponding current output. Ensure that there is no load resistor across the solar module.

Hint: Wait until the solar module has reached a stable temperature before beginning the experiment.

Product

1. Draw the circuit diagram and explain the experimental technique used to acquire the data.
2. Devise and complete a suitable results table to record your data, either on paper or on a computer spreadsheet.
3. Plot the data for current output against distance.
4. Comment on the shape of the curve.
5. There is an 'inverse square law' relationship between light intensity and separation distance. Use your data to find out whether the inverse square law holds for the relationship between photocurrent and light source distance.
6. Comment on any problems you encountered during the experiment, any precautions taken to ensure accuracy and any changes you made to your original plan.
7. Finally evaluate the experimental technique you used and suggest any further improvements for the experiment.

Question

- Why is life on earth possible but not on other planets of the solar system?
(Hint: consider the radiation emitted from the sun and the respective distances of the planets).

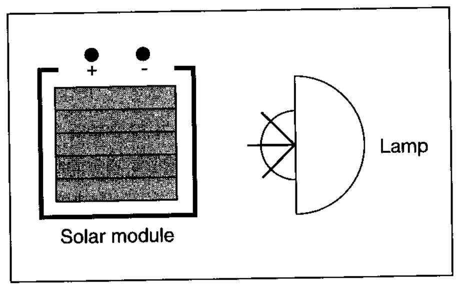
Investigating how solar cell photocurrent varies with **angle of incidence of light source**

Apparatus required:
- Solar module
- Load measurement box
- Connecting leads
- Laminated protractor

Additional components:
- Lamp 100 – 150 Watt

Safety: Please follow the operating instructions.
The solar module becomes hot.
A full risk analysis must be undertaken before beginning any experiment.

Introduction



A solar cell is a specially designed semiconductor diode which generates an e.m.f. when exposed to light. The solar cell absorbs light energy and converts it to electrical energy so the amount of light falling on the solar cell will affect the current output.
A solar module is a number of solar cells connected in series.

Objectives

To investigate the behaviour of a solar module when the amount of light falling on it varies due to changing the angle of inclination of the solar module to the light source

Preparatory work

Answer these questions before you begin any experimental work.

1. Devise and draw a circuit which allows you to measure the current output from the solar module when illuminated.
2. Outline what you plan to do to vary the amount of light falling on the solar module due to varying the angle of inclination of the solar module and, therefore, to obtain appropriate data.

Procedure

- Construct your circuit and check that the apparatus gives readings over a suitable range.
- Vary the amount of light falling on the solar module and measure the corresponding current output. Ensure that there is no load resistor across the solar module.

Hint: Wait until the solar module has reached a stable temperature before beginning the experiment.

Product

1. Draw the circuit diagram and explain the experimental technique used to acquire the data.
2. Devise and complete a suitable results table to record your data, either on paper or on a computer spreadsheet.
3. Plot the data for current output against angle of inclination of the solar module.
4. Comment on the shape of the curve.
5. There is a 'cosine' relationship between light intensity and angle of inclination of the solar module. Use your data to find out whether the photocurrent depends on the cosine of the angle of inclination.
6. Comment on any problems you encountered during the experiment, any precautions taken to ensure accuracy and any changes you made to your original plan.
7. Finally evaluate the experimental technique you used and suggest any further improvements for the experiment.

Question

- Why should installers of solar modules on houses be interested in how photocurrent varies with angle of inclination?

Extension work

Research the optimum angle at which solar modules should be installed in this country and explain your findings.

Investigating fuel cells – are they best connected in series or in parallel?

Apparatus required:

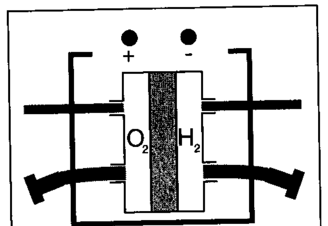
- Solar module
- Electrolyser
- Fuel cell
- Load measurement box
- Connecting leads
- 2 long tubes
- 2 short tubes
- 2 tubing stoppers

Additional components:

- Fuel cell (i.e from additional science kit solar hydrogen technology or extension kit dismantlable fuel cell)
- 1 connecting lead
- 2 long tubes
- Lamp 100 – 150 Watt
- Distilled water

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

Introduction



Fuel cell

A hydrogen fuel cell produces an emf by combining hydrogen and oxygen chemically. A conventional battery supplies electrical energy in the same way except that the reactants (for example nickel oxyhydroxide and cadmium) are eventually used up and the battery has to be disposed of or recharged. A fuel cell will provide energy so long as hydrogen and oxygen are supplied to it. The current and voltage output will depend upon the load applied to the fuel cells and whether they are connected in series or parallel. This can be seen from the characteristic curves and can be compared with the characteristic curve obtained from a single fuel cell.

Objectives

To investigate the behaviour of fuel cells connected in series and parallel.

E7

Preparatory work

Answer these questions before beginning any experimental work.

1. Devise and draw a circuit which allows you to measure the e.m.f. generated by two fuel cells connected in series when they drive a current through a range of load resistors. Include an ammeter in the circuit to monitor the current flowing through the load resistor circuit.
2. Devise and draw a circuit to perform a similar investigation on two fuel cells connected in parallel.
3. Outline what you plan to do to obtain appropriate data.
4. Explain what is meant by a characteristic curve.

Procedure

- In order to use the fuel cells as a power source they must be provided with a supply of hydrogen and oxygen from the electrolyser. This may have been done for you in advance of the experimental session. Alternatively proceed as follows:

1. Set up the apparatus as shown. **Check the polarity of the electrolyser!**
2. Check that the gas tubes between the electrolyser and fuel cells 1 and 2 are correctly connected. Adjust the rotary switch on the load measurement box to 'OPEN'.
3. Make sure both of the gas storage cylinders of the electrolyser are filled with distilled water up to the 0 ml mark. Using the illuminated solar module, set a constant current to the electrolyser of between 200 and 300 mA. The solar module must be positioned towards the light source in such a way that gas production can be clearly observed .
4. Purge the complete system (consisting of the electrolyser, fuel cells and tubes) for 10 minutes with the gases produced. Then set the rotary switch on the load measurement box to 3 ohms for 3 minutes. The ammeter of the load measurement box should now already show a current. Purge the system again with the rotary switch in the 'OPEN' position for 5 minutes.
5. Stop the power supply to the electrolyser for a short time and use the stoppers to close the two short tubes at the gas outlets of fuel cell 2.
6. Reconnect the solar module to the electrolyser and store the gases in the gas storage cylinders of the electrolyser. Interrupt the power supply when the hydrogen side of the electrolyser has reached the 10 ml mark.
7. Remove the connecting leads between the solar module and the electrolyser and use them to connect the voltmeter of the load measurement box to the fuel cell. You can now record the characteristic curve of two fuel cells connected in series.

- Now construct your circuit as designed previously using the fuel cells in series as the voltage source (with the outlets of the electrolyser supplying gas to the fuel cell) and check that the apparatus gives readings over a suitable range.
- Vary the value of the load resistor and investigate how the e.m.f. and current vary as the value of the load resistor is changed. Also take measurements using the motor and lamp as loads.
- Repeat your investigation for two fuel cells connected in parallel.

Product

1. Explain the experimental technique used to obtain the data.
2. Devise and complete a suitable results table to record your data, either on paper or on a computer spreadsheet.
3. Plot the characteristic curve for the fuel cells in series and for fuel cells in parallel.
4. Comment on the shape of the curve in comparison with the curve obtained from a single fuel cell in experiment 4. Comment also on the values obtained for the motor and lamp
5. Comment on any problems you encountered during the experiment, any precautions taken to ensure accuracy and any changes you made to your original plan.
6. Finally evaluate the experimental technique you used and suggest any further improvements for the experiment.

Question

- A lamp cannot be lit using a single fuel cell but lights satisfactorily when supplied by two fuel cells in series. It does not however light when supplied by two fuel cells connected in parallel. Explain these observations.

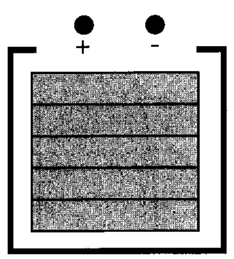
Investigating solar modules – are they best connected in series or in parallel?

Apparatus required:
- Solar module
- Connecting leads
- Load measurement box

Additional components:
- Lamp 100 – 150 Watt
- Second solar module from other science kit

Safety: Please follow the operating instructions.
The solar modules become hot.
A full risk analysis must be undertaken before beginning any experiment.

Introduction



Solar module

A solar cell is a specially designed semiconductor diode which generates an e.m.f. when exposed to light. The solar cell absorbs light energy and converts it to electrical energy so the amount of light falling on the solar cell will affect the current output.
A solar module is a number of solar cells connected in series.

Objective

To investigate the behaviour of solar modules when connected in series and in parallel.

Preparatory work

Answer these questions before beginning any experimental work.

1. Devise and draw a circuit which allows you to measure the e.m.f. generated by two or more solar modules connected in series when connected across a load resistor. Include an ammeter in the circuit to monitor the current flowing through the load resistor circuit.
2. Devise and draw a circuit to perform a similar investigation on two solar modules connected in parallel.
3. Outline what you plan to do to obtain appropriate data.
4. Explain what a characteristic curve is.

Procedure

- Construct your circuit using the solar modules as the voltage source and check that the apparatus gives readings over a suitable range.
- Vary the value of the load resistor and investigate how the e.m.f. and current vary as the value of the load resistor is changed.
- Repeat your investigation for two solar modules connected in parallel.

Product

1. Explain the experimental technique used to obtain the data.
2. Devise and complete a suitable results table to record your data, either on paper or on a computer spreadsheet.
3. Plot characteristic curves for each experimental arrangement.
4. Analyse and comment on the results.
5. Comment on any problems you encountered during the experiment, any precautions taken to ensure accuracy and any changes you made to your original plan.
6. Finally evaluate the experimental technique you used and suggest any further improvements for the experiment.

Questions

- Why are solar cells connected in series rather than in parallel to form solar modules?
- Why is it more efficient (i.e. involves less energy loss) to produce a low current from solar cells?
- For solar cells connected in series a defective or shaded cell has the same effect as a resistor and may even overheat and be destroyed. Explain how a 'by-pass diode' connected in parallel with the cell will overcome this problem.
- After evaluating this experiment, you might like to solve the following theoretical exercise:
  The following loads are to be connected to a solar plant:
  1. Lamp (100 mA, 12 volts)
  2. Model car with motor (200 mA, 1.5 volts)
  3. Load 12 W.

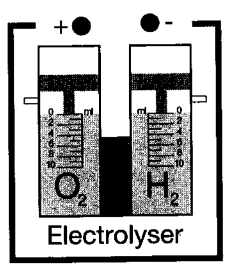
  Indicate the number of solar cells required and possible ways of connecting them in order to meet the load's power-consumption needs.

Investigating the efficiency of the **electrolyser-fuel cell system**

Apparatus required:	**Additional components:**
• Electrolyser	• Connecting leads
• Solar module	• Lamp 100 – 150 Watt
• Fuel cell	• Ammeter
• Load measurement box	• Voltmeter
• Connecting leads	• Distilled water
• 2 long tubes	
• 2 short tubes	

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

Introduction



The electrolyser-fuel cell system is a convenient way of storing solar generated electricity. The electrolyser produces supplies of hydrogen and oxygen which can be fed to the fuel cell when power is required. As with any power conversion there are energy losses - less electricity is supplied than was first generated. The efficiency also varies according to the load resistor through which the fuel cell is having to drive the current.

Objectives

To investigate the efficiency of the electrolyser-fuel cell system by comparing the power input from solar module with the power supplied from the fuel cell to a range of load resistors.

Preparatory work

Answer these questions before beginning the experimental work.

1. Devise and draw a circuit which allows you to measure the power output of the solar module while it is connected to the electrolyser.
2. Devise and draw a circuit to measure the power output of the fuel cell when loaded with a range of load resistors.
3. Outline what you plan to do to obtain appropriate data which will allow you to calculate the efficiency of the system.
4. Explain what is meant by efficiency and how it will be calculated in this case.

Procedure

- In order to use the fuel cell as a power source it must be provided with a supply of hydrogen and oxygen from the electrolyser. This may have been done for you in advance of the experimental session. Alternatively proceed as follows:
  1. Set up the apparatus. **Pay attention to the polarity of the electrolyser!**
  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 the gas storage cylinders of the electrolyser are filled up with distilled water to the 0 ml mark. Adjust a constant current from the solar module to the electrolyser of around 200 and 300 mA. The solar module must be positioned towards the light source such that a clear gas production can be observed.
  4. Purge the complete system comprising of the electrolyser, fuel cell and tubes for 5 minutes with the gases released from the electrolyser. Thereafter put the rotary switch on the load measurement box to 3Ω for 3 minutes. You should already now observe a current at the ammeter of the load measurement box. Purge the system again with the rotary switch in position 'OPEN' for 3 minutes.
- Now construct your circuit to enable you to measure the power fed to the electrolyser from the solar module and, simultaneously, the power output from the fuel cell when loaded with a range of resistors.
- Vary the value of the load resistor and investigate how the power varies as the value of the load resistor is changed.

Product

1. Draw the circuit diagram and explain the experimental technique used to acquire the data.
2. Devise and complete a suitable results table to record your data, either on paper or on a computer spreadsheet.
3. Plot the power output of the fuel cell against current output and identify any trends in the data.
4. Calculate the maximum efficiency achieved by the system and comment on this value.
5. Comment on any problems you encountered during the experiment, any precautions taken to ensure accuracy and any changes you made to your original plan.
6. Finally evaluate the experimental technique you used and suggest any further improvements for the experiment.

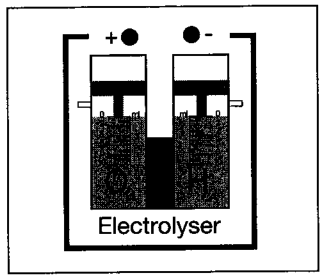
Adjusting the **electrolyser to the solar module**

Apparatus required:
- Solar module
- Electrolyser
- Connecting leads
- Load measurement box

Additional components:
- Lamp 100 – 150 Watt
- Distilled water

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

Introduction



A solar module needs to be adapted to the power of the load if it is to work at maximum efficiency. In practice this means that the size of a solar module has to be correctly chosen to work efficiently with the power consumption required by the load.

Objectives

To identify the matching point for the solar module and the electrolyser and to see how it varies with light intensity.

Preparatory work

Answer these questions before beginning any experimental work.

1. Devise and draw circuits which will allow you to measure the i) power output of the solar module across a range of load resistors and ii) the power drawn by the electrolyser for a range of input currents from the solar module.
2. Outline the procedure you will undertake to acquire appropriate data which will allow you to draw characteristic curves for the two devices on the same axes.
3. Explain what is meant by a characteristic curve for these two devices.

Procedure

- Connect your circuit and take a series of readings of current and voltage output from the solar module for a range of load resistors as in experiment 1.
- Take a second series of readings for the current and voltage across the electrolyser as the current fed to it from the solar module is varied, as in experiment 3.

Product

1. Draw the circuit diagrams and explain the experimental technique used to acquire the data.
2. Devise and complete a suitable results table to record your data, either on paper or on a computer spreadsheet.
3. Plot the characteristic curve for both devices on the same axes.
4. Plot the PV curves for both devices on the same axes. Comment on any significant points in your data which relate to the optimum adjustment of these two devices.
5. Comment on any problems you encountered during the experiment, any precautions taken to ensure accuracy and any changes you made to your original plan.
6. Finally evaluate the experimental technique you used and suggest any further improvements for the experiment.

Experimental variation

Repeat the experiment for the solar module at a range of distances from the light source.

Impact of internal resistance on the **characteristic curve of the fuel cell**

Apparatus required:

- Dismantlable fuel cell with 0.3 mg/cm^2 Pt membrane, Hydrogen and Oxygen end plates, assembled according to assembly instructions (standard set-up)
- Plug-in resistance 0.47Ω

Components from solar hydrogen technology science kit:

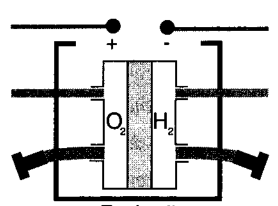
- Solar module
- Electrolyser
- Load measurement box
- Connecting leads
- 2 long tubes
- 2 short tubes
- 2 tubing stoppers

Additional components:

- Lamp 100 – 150 Watt
- Distilled water

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

Introduction



Fuel cell

The dismantlable fuel cell works as a typical hydrogen fuel cell. It produces an emf by combining the hydrogen and oxygen from electrolysis chemically. It will provide energy so long as hydrogen and oxygen are supplied to it.

The current and voltage output will depend upon the internal resistance of the fuel cell as shown by the characteristic curves. The plug-in resistance simulates an increased resistance of the fuel cell.

Objective

To investigate the effect of the internal resistance of the fuel cell on its operation.

Preparatory work

Answer these questions before beginning any experimental work.

1. Devise and draw a circuit which allows you to measure the e.m.f. generated by the fuel cell when it drives a current through a range of load resistors. Include an ammeter in the circuit to monitor the current flowing through the load resistor circuit.
2. Outline the procedures you will undertake to acquire appropriate data.

Procedure

- In order to use the fuel cell as a power source it must be provided with a supply of hydrogen and oxygen from the electrolyser. This may be undertaken by a teacher or technician in advance of the experimental session. Alternatively proceeds as follows:
  1. Set up the apparatus. **Pay attention to the polarity of the electrolyser!**
  2. Check that the gas tubes are correctly connected between the electrolyser and the fuel cell. Adjust the rotary switch of the load measurement box to 'OPEN'.
  3. Make sure both the gas storage cylinders of the electrolyser are filled up with distilled water to the 0 ml mark. Adjust a constant current from the solar module to the electrolyser of around 250 and 300 mA. The solar module must be positioned towards the light source such that a clear gas production can be observed.
  4. Purge the complete system comprising of the electrolyser, fuel cell and tubes for 5 minutes with the gases released from the electrolyser. Thereafter put the rotary switch on the load measurement box to 3Ω for 3 minutes. You should already now observe a current at the ammeter of the load measurement box. Purge the system again with the rotary switch in position 'OPEN' for 3 minutes.
  5. Disconnect the solar module and the electrolyser and close both the short tubes at the gas outlets of the fuel cell with stoppers.
  6. Reconnect the solar module to the electrolyser and store the gases in the electrolyser's gas storage cylinders. Interrupt the power supply of the electrolyser when the hydrogen has reached its 10 ml mark.
- Construct your circuit using the fuel cell as the voltage source (with the outlets of the electrolyser supplying gas to the fuel cell) and check that the apparatus gives readings over a suitable range.
- Vary the value of the load resistor and investigate how the e.m.f. and current vary as the value of the load resistor is changed.
- Plug in the additional internal resistance and repeat the experiment to allow you to draw a second characteristic curve.

Product

1. Explain the experimental technique you used to acquire the data.
2. Devise and complete a suitable results table to record your data, either on paper or on a computer spreadsheet.
3. Plot the characteristic curve for the fuel cell at both levels of internal resistance.
4. Comment on the shape of the curves.
5. Plot curves of power against current for the fuel cell at each value of internal resistance
6. Comment on any problems you encountered during the experiment, any precautions taken to ensure accuracy and any changes you made to your original plan.
7. Finally evaluate the experimental technique you used and suggest any further improvements for the experiment.

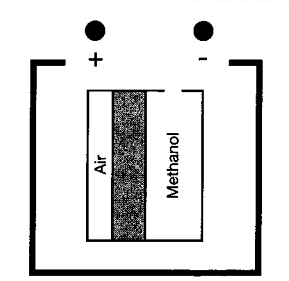
The direct methanol fuel cell – characteristic curve

Apparatus required:
- Methanol fuel cell
- Stock bottle with 1M methanol solution
- Pipe for stock bottle
- Load measurement box
- Connecting leads
- Stoppers for tank

Additional components:
- Methanol
- Distilled water

Safety: Please follow the operating instructions.
Methanol is a poison and must only be used by trained operators.
Follow setting up instructions carefully.
Wear protective goggles and keep ignition sources at a distance when experimenting.
A full risk analysis must be undertaken before beginning any experiment.

Introduction



Methanol fuel cell

A direct methanol fuel cell produces an emf by using methanol as a fuel and oxidising it directly to carbon dioxide. The fuel cell will provide energy so long as liquid methanol is supplied to it. This type of fuel cell is favoured for many applications as carrying methanol in a fuel tank is much more straight forward than carrying hydrogen.

The current and voltage output of this fuel cell also depends upon the load applied to the fuel cell and can be seen from its characteristic curve.

Objective

To investigate the behaviour of a methanol fuel cell.

Preparatory work

Answer these questions before beginning any experimental work.

1. Devise and draw a circuit which allows you to measure the e.m.f. generated by the fuel cell when it drives a current through a range of load resistors. Include an ammeter in the circuit to monitor the current flowing through the load resistor circuit.
2. Outline the procedures you plan to undertake to obtain appropriate data.
3. Explain what is meant by a characteristic curve.

Procedure

- In order to use the fuel cell as a power source it must be provided with a supply of methanol. This will be undertaken by a trained technician or teacher before the session. A complete set of instructions is provide with the kit
- Construct your circuit using the fuel cell as the voltage source and check that the apparatus gives readings over a suitable range
- Vary the value of the load resistor and investigate how the e.m.f. and current vary as the value of the load resistor is changed.
- After recording the characteristic curve, reset the rotary switch of the load measurement box back to 'OPEN'. When you want to terminate the experiments, remove the stoppers from the tanks and dispose of the methanol solution safely.

Product

1. Explain the experimental technique used to acquire the data.
2. Devise and complete a suitable results table to record your data, either on paper or on a computer spreadsheet.
3. Plot the characteristic curve for the fuel cell.
4. Comment on the shape of the curve.
5. Comment on any problems you encountered during the experiment, any precautions taken to ensure accuracy and any changes you made to your original plan.
6. Finally evaluate the experimental technique you used and suggest any further improvements for the experiment.

Question

- The typical voltage achieved from this fuel cell is between 0.2 and 0.6V. The higher the current drawn, the lower the output voltage. What physical factors might cause this reduction?
(Hint: compare this with the hydrogen fuel cell)

Extension work

Plot power against current for the fuel cell. Why do you think that, in practice, we try to draw as much current as possible from a fuel cell even though this means that the fuel cell is not operating at maximum efficiency?

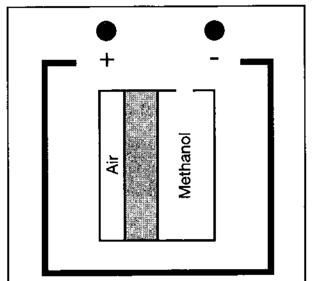
The direct methanol fuel cell – in series and parallel

Apparatus required:
- Methanol fuel cell
- Stock bottle with 1M methanol solution
- Pipe for stock bottle
- Load measurement box
- Connecting leads
- Tank stoppers

Additional components:
- Further methanol fuel cell with stoppers
- Connecting leads
- Methanol
- Distilled water

Safety: Please follow the operating instructions.
Methanol is a poison and must only be used by trained technicians and teachers.
Wear protective goggles and keep ignition sources at a distance when experimenting.
A full risk analysis must be undertaken before beginning any experiment.

Introduction



Methanol fuel cell

A direct methanol fuel cell produces an emf by using methanol directly as a fuel and oxidising it to carbon dioxide. A fuel cell will provide energy so long as liquid methanol is supplied to it. This type of fuel cell is favoured for many applications as carrying methanol in a fuel tank is much more straight forward than carrying hydrogen.

The current and voltage output will depend upon the load applied to the fuel cells and whether they are connected in series or parallel. This can be seen from the characteristic curves and can be compared with the characteristic curve obtained from a single fuel cell.

Objective

To investigate the behaviour of methanol fuel cells in series and parallel.

Preparatory work

Answer these questions before beginning any experimental work.

1. Devise and draw a circuit which allows you to measure the e.m.f. generated by two fuel cells connected in series when they drive a current through a range of load resistors. Include an ammeter in the circuit to monitor the current flowing through the load resistor circuit.
2. Devise and draw a circuit to perform a similar investigation on two fuel cells connected in parallel.
3. Outline the procedures you will undertake to acquire appropriate data.
4. Explain what is meant by a characteristic curve.

Procedure

- In order to use the fuel cells as a power source they must be provided with a supply of methanol. This will be undertaken by a trained technician or teacher before the session.
- Construct your circuit using the fuel cells in series as the voltage source and check that the apparatus gives readings over a suitable range.
- Vary the value of the load resistor and investigate how the e.m.f. and current vary as the value of the load resistor is changed.
- After recording the characteristic curve, reset the rotary switch of the load measurement box back to 'OPEN'. When you want to terminate the experiments, remove the stoppers from the tanks and dispose the methanol solution safely.
- Repeat your investigation for two fuel cells connected in parallel.

Product

1. Explain the experimental technique you used to obtain the data.
2. Devise and complete a suitable results table to record your data, either on paper or on a computer spreadsheet.
3. Plot the characteristic curve for the fuel cells in series and for the fuel cells in parallel.
4. Comment on the shape of the curve in comparison with the curve obtained from a single fuel cell in experiment 12.
5. Comment on any problems you encountered during the experiment, any precautions taken to ensure accuracy and any changes you made to your original plan.
6. Finally evaluate the experimental technique you used and suggest any further improvements for the experiment.

Question

- A lamp will need 4 of these direct methanol fuel cells to light satisfactorily whereas it is possible to light a lamp with 2 hydrogen fuel cells. Explain why there is a difference and why direct methanol fuel cells are still popular.

Part 2

Written assignments

Written assignments targeting key skills

Using these assignments:

These assignments cover a range of more general topics and lend themselves to class work or homework to consolidate the theory covered previously. Each one is self-contained and they may be used in any order or combination. They aim to provide opportunities for the development of communication skills by offering extended reading and questions requiring extended written answers. Team working skills are developed in poster preparation and debate/discussion exercises.

Note:

Some of these articles are common to the chemistry book 'Chemistry through Hydrogen - Clean Energy for the Future' - identified with **C.**

Contents:

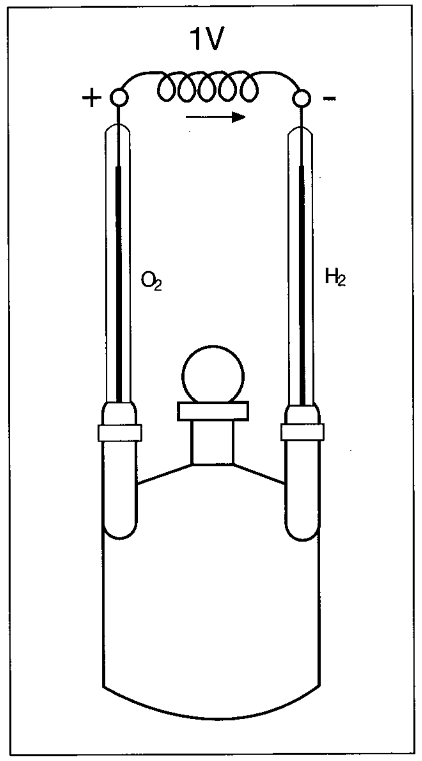
Fuel cells – past and present

In 1839 William Grove, a 28 year old Scottish Physicist who later went on to become a barrister and judge, demonstrated the world's first 'fuel cell' (or 'gas battery' as he called it) at The Royal Institution in London.

Grove, a friend of Michael Faraday, had been experimenting on electrolysis of sulphuric acid. This involves putting a voltage across the two platinum electrodes which causes the positive hydrogen ions and the negative sulphate ions in the electrolyte to drift to the cathode and anode respectively.

What surprised him was that when he disconnected the apparatus it seemed to work backwards and he observed that he was now generating a voltage of around 1 volt. It seemed that the hydrogen molecules were returning to the electrode and giving up their electrons. These electrons were travelling round the circuit to the positive electrode and there they were ionising the oxygen. On the way round the circuit the electrons could power electrical apparatus.

Grove's fuel cell 1839 (the gas battery)



Unfortunately the materials that Grove used were unstable and when Werner von Siemens developed rotary electrical generators the interest in fuel cells dwindled. It wasn't until the 'space race' between the USA and former Soviet Union in the 1960s that fuel cells were revived and they have been used in every manned space flight since.

The National Aeronautics and Space Administration (NASA) developed fuel cells as the ideal supply of both power and drinking water. They used an alkaline fuel cell which enables hydrogen and oxygen to be brought together in an alkaline electrolyte where they recombine to produce pure water as well as generating a small voltage. If larger voltages are required then the fuel cells are simply stacked together like a club sandwich - connected in series the total output is the sum of the individual voltages.

The high cost of the platinum catalysts used in fuel cells restricted them to space and military applications for many years. However recent work on catalytic converters for cars has resulted in deposition techniques where much less platinum is required. For example particles only 10 atoms in diameter can now be deposited on the electrodes of modern fuel cells. In 1986 a fuel cell needed about 16 grams of platinum per kilowatt of power produced. This would cost $180 at today's prices. Modern fuel cells work out to $6 - $8 of platinum per kilowatt. Further improvements might reduce the amount required but researchers have yet to find a suitable substitute for platinum at either electrode.

As fuel cells generating 250 kW or more of electrical energy are now entering the market, renewable energy systems are poised to provide large amounts of continuous power with no polluting emissions. ✪

notes

Questions

1. Explain what an ion is.
2. Electrolytes conduct electricity. Describe the difference between electrolytes and metallic conductors in the way they conduct?
3. During electrolysis why do the ions drift to the anode and cathode as described?
4. The theoretical maximum output of fuel cells is 1.23 V. If seven fuel cells, each capable of working at 60% of the theoretical maximum, are connected in series, what will be the total output voltage?
5. Using the information in the text, calculate the amount of platinum required in a modern fuel cell to generate the 10 kW needed to power a typical household.
6. Calculate by what factor the amount of platinum used has been reduced since 1986.
7. Spot the deliberate mistake in the wording of the final paragraph and rewrite it using correct terminology.

... in conclusion

To the student

We hope that through using this book, together with its companion books and the Heliocentris kits, you have learned a lot about the trapping and use of solar energy, about fuel cell technology, and about the hydrogen economy. We have explained why we believe that knowledge about these matters is vitally important for the future of our planet and for all who live on it.

We also hope that all the material has helped you in your learning of important sections of physics and chemistry, and that it will serve you well in any exams you have to take, and also in any projects which you may have to do.

We believe in the absolute need for as many people as possible to understand basic scientific principles; and we believe also that solar energy and hydrogen will play a major part in everyone's future.

And it is perhaps our greatest wish that you have enjoyed the work and will wish to learn more, and that some of you may eventually contribute – by working in the fields of renewable energy sources and sustainable development as scientists, engineers, or economists - to making the world a healthier, happier and safer place for our successors to live in.

The following list of books and other resources will help if you wish to find out more:

Books:

K. Kordesh and G. Simader, *Fuel Cells and their Applications*, New York: VCH, 1996.

A. Appleby, F. Foulkes, *Fuel Cell Handbook*, Van Nostrand and Reinhold, 1989.

J. Hirschnhofer *et al*, *Fuel Cells: A Handbook*, Morgantown Energy Technology Center, 1994.

Michael Peavy, *Fuel from Water: Energy Independence With Hydrogen*, Merit Products, 1998.

L. Blomen, M. Mugerwa (eds.), Fuel Cell Systems, Plenum Publishing Corp, 1994.

Jim Motavalli, *Forward Drive: The Race to Build the Car of the Future*, Sierra Cub Books, 2000.

Tom Koppel, *Powering the Future: The Ballard Fuel Cell and the Race to Change the World*, John Wiley and Sons, 1999.

James S. Cannon, Sharene L. Azimi (Editor), *Harnessing Hydrogen: The Key to Sustainable Transportation*, Inform, 1995.

J. O'M. Bockris, *Energy Options - Real Economics and the Solar-Hydrogen Systems*, Halsted Press, New York, 1980.

D. Hart, *Hydrogen power: the commercial future of the ultimate fuel*, Financial Energy Publishing, London, 1997.

P. Hoffmann, *The Forever Fuel: The story of hydrogen*, Westview Press, Boulder, Colorado, 1982

P. Hoffmann, *International Directory of Hydrogen Energy and Fuel Cell Technology*, The Hydrogen Letter Press, Rhinecliff, New York

J. M. Ogden, R. H. Williams, *Solar Hydrogen: Moving Beyond Fossil Fuels*, World Resources Institute, Washington, DC, 1989

H. W. Pohl, *Hydrogen and Other Alternative Fuels for Air and Ground Transportation*, Wiley, Chichester, 1995

Edward W. Justi, *Solar Hydrogen Energy System*, Plenum Publishing Corp, 1987

Journals/Magazines:

Hydrogen and Fuel Cell Letter, **www.mhv.net/hfcletter/.**

New Scientist, **www.newscientist.com.**

Green Chemistry, **www.chemsoc.org/greenchem.**

Education in Chemistry, **www.chemsoc.org/gateway/eic.htm.**

Scientific American, **www.sciam.com.**

Fuel Cell Industry Report, Scientific American Newsletters, New York.

International Journal of Hydrogen Energy, Pergamon.

Fuel Cell News, Fuel Cell Institute, Washington DC.

Articles:

H. Colell and B.Cook, Fuel Cells – power for the future, *Education in Chemistry*, **36** (5), 1999, pp. 123.

T. Ralph and G. Hards, Powering the cars and homes of tomorrow, *Chemistry and Industry*, 4 May 1998, p337.

The third age of fuel/At last, the fuel cell, *The Economist*, 25-31 October 1997, p16 and p89.

The future of fuel cells, etc, *Scientific American*, July 1999, p56 - 75

A. Wilson and N. Malin, 'Fuel Cells: A Primer on the Coming Hydrogen Economy.', *Environmental Building News* (8:4) April 1999 pp. 1, 7-12, April 1999. Available from Environmental Building News, Brattleboro, Vermont, USA.

C. Christenson, 'Fuel Cell System Technologies and Application Issues.' *Energy Business & Technology Sourcebook*, 1996 pp. 258-261, 1996. Available from Fairmont Press.

R. Barlow, "Residential Fuel Cells: Hope or Hype?," Home Power (No. 72), Aug/Sept 1999 pp. 20-29. Available from Home Power, Ashland, Oregon, USA.

Useful Organisations:

• U.S. Environmental Protection Agency (material on global warming) – **www.epa.gov/global warming** • U.S. Union of Concerned Scientists – **www.ucsusa.org** • Austrian Energy Agency (European fuel cell strategy, in English) – **www.eva.wsr.ac.at/opet/fcstrategy.htm** • Friends of the Earth – **www.foe.co.uk** • Royal Society of Chemistry Green Chemistry Network – **www.chemsoc.org/gcn** • British Association for the Advancement of Science – **www.britassoc.org.uk**

Fuel Cell Internet Resources:

A list of internet links for further research on hydrogen technology and fuel cells.

heliocentris Energiesysteme GmbH – **http://www.heliocentris.com** • Los Alamos National Laboratory – **http://education.lanl.gov/resources/h2/** • Center for Renewable Energy and Sustainable Technology (CREST) – **http://solstice.crest.org/index.shtml** • Energy Efficiency and Renewable Energy Network (EREN), U.S. Department of Energy – **http://www.eren.doe.gov/** • American Hydrogen Association – **http://www.clean-air.org** • Electric Power Research Institute – **http://www.epri.com** • Electrochemical Analysis and Diagnostic Laboratory – **http://www.cmt.anl.gov** • Fuel Cell Commercialization Group – **http://www.ttcorp.com/fccg** • National Renewable Energy Laboratory (NREL) – **http://www.nrel.gov** • National Energy Technology Laboratory (NETL) – **http://www.fetc.doe.gov** • National FuelCells Research Center – **http://www.nfcrc.uci.edu** • Office of Scientific and Technical Information, U.S. Department of Energy – **http://apollo.osti.gov/html/osti/** • Fuel Cells 2000 – **http://www.fuelcells.org** • E-sources: online journal on energy and environment – **http://www.e-sources.com/**