Thames & Kosmos

# fuel cell
## car & experiment kit

# Curriculum

***A COURSE IN ENERGY TRANSFER AND ELECTRICITY INCORPORATING BOTH SCIENCE AND TECHNOLOGY IN THE MIDDLE SCHOOL CLASSROOM***

***Targeting Grades 6-9***

**by Derek Brower**


**For use with the Fuel Cell Car & Experiment Kit by Thames & Kosmos**

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Author: Derek Brower; Layout: Dan Freitas; Editing: Ted McGuire

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# Abstract

**A COURSE IN ENERGY TRANSFER AND ELECTRICITY INCORPORATING BOTH SCIENCE AND TECHNOLOGY IN THE MIDDLE SCHOOL CLASSROOM**

This document outlines a course curriculum intended for a middle school physical science class. The purpose of the course is to incorporate science and technology into the teaching of electricity and energy transfer, while introducing students to the topics of alternative energy, namely solar cells and fuel cells. This course consists of seven labs that use a multimeter, a solar cell, and a hydrogen fuel cell to explore the concepts of electricity and energy transfer.

The course is designed to be used with the **Fuel Cell Car & Experiment Kit** manufactured by Thames & Kosmos. This kit can be purchased directly from Thames & Kosmos, or from its dealers and distributors. For information on where to buy the kit, go to the Thames & Kosmos web site, www.thamesandkosmos.com, and click the "Where to Buy" link for a list of dealers.

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## Introduction and Rationale

The Thames & Kosmos Fuel Cell Car & Experiment Kit was originally designed to be used by one or two children at home, or outside of a formal classroom. The manual that accompanies the kit was written for this audience to use for informal science learning. After its introduction, it became clear that the Fuel Cell Car & Experiment Kit could be a valuable teaching aid for use in the science classroom. Thus, this curriculum was developed to revise and supplement the manual provided with the Thames & Kosmos Fuel Cell Car & Experiment Kit so that it is easier to use for both teachers and students in the middle school classroom. The main goal of this curriculum is to provide an engaging middle school physical science course that covers energy transfer, the basics of electricity, and alternative energy technology. The course includes both a lecture component and a lab component using the Fuel Cell Car & Experiment Kit.

## Course Overview

This physical science course is written to be used to instruct students in the areas of electricity, energy transfer, and alternative energy. The course begins by introducing students to key concepts and terminology in these areas. This can be done in a lecture or discussion format and can utilize any physical science textbook for additional student assignments and related activities. An example here might include rubbing a balloon on a student's hair to demonstrate static electricity, or using a toaster to demonstrate the energy transfer of electrical energy to heat energy.

Following the formal instruction, the class is encouraged to address the issues of energy and alternatives to the present sources, especially in the field of transportation. Teachers can raise issues about electric cars and have students research the pros and cons of buying and owning an electric car. Students could also pursue information on other vehicle energy sources such as fuel cells, diesel, natural gas, or even micro-nuclear. The findings could be presented to the class informally or in a formal speech. This would allow all the students to learn from each other's research.

The focus of this course is a series of technology labs. These labs are revised from the lab manual that accompanies the Fuel Cell Car & Experiment Kit from Thames & Kosmos. Having introduced the students to the concepts of electricity and energy transfer, it is good to reinforce the concepts through the use of these lab activities. The descriptions and images in the Thames & Kosmos lab manual are helpful and could be used as background information (especially for the teacher) for these revised labs. Labs one through seven contained herein are designed to stand alone, if necessary, as a unit on solar cells and solar energy.

In labs one through seven (revised from the Thames & Kosmos lab manual introduction through experiment 10), student groups use a solar panel and multimeter to measure, collect, and analyze data. Lab one introduces students to the multimeter and how to measure current, voltage, and resistance. In labs two through six, students use the solar cell to relate brightness to electrical output, measure and differentiate solar radiation, and produce an IV (current/voltage) curve for their solar panel. Although based upon the Thames & Kosmos lab manual, these labs (and lab seven: Electrolysis of Water) are written for use in the physical science classroom and do not require purchasing the Fuel Cell kit. Each of the seven labs has a Teacher Notes page that shares with teachers some instructional strategies and also the answers to the questions in the labs.

Studying the hydrogen fuel cell will require the Thames & Kosmos Fuel Cell Car & Experiment Kit including its lab manual. This curriculum includes supplemental worksheets for many of Thames & Kosmos lab manual experiments 11-33. These experiments use a hydrogen fuel cell (included in the kit) to separate water into hydrogen and oxygen. Some of the experiments are simply directions for setting up the fuel cell. For example, experiment 12 explains how to fill the fuel cell with water and to correctly attach tubes and wires. Other experiments try to answer a simple question. For instance, experiment 20 asks, "How much water was there in the fuel cell?" The Thames & Kosmos lab manual also has color illustrations and diagrams that show the fuel cell assembly and the use of the kit components.

For each experiment in which students collect and/or analyze data, a supplemental worksheet is included in this curriculum. These worksheets help clarify the directions for the experiments, they provide tables for data collection, they help students work through calculations, and they give the teacher tools for student assessment.

The rest of the activities (Thames & Kosmos lab manual experiments 23-33) involve the students actually getting the fuel cell car to run and using the motor (included in the kit) as a crane. These experiments are very practical and show students how to measure the range of the car, the speed of the car, and the mechanical energy of both the car and the crane. Any of the experiments that involve collecting data or performing calculations have supplementary worksheets provided for use in the classroom.

Following the labs and experiments, the students are asked to pick a topic about energy or energy transfer. They will research the topic, organize an outline, develop a visual aid, and present their information to the rest of the class. This final project can be used instead of a final exam for the course. Through the presentations, each student will become a novice in some aspect of alternative energy. As the students listen to each presentation, they will increase their understanding of energy and its use (or misuse) in the world today.

# Course Goals

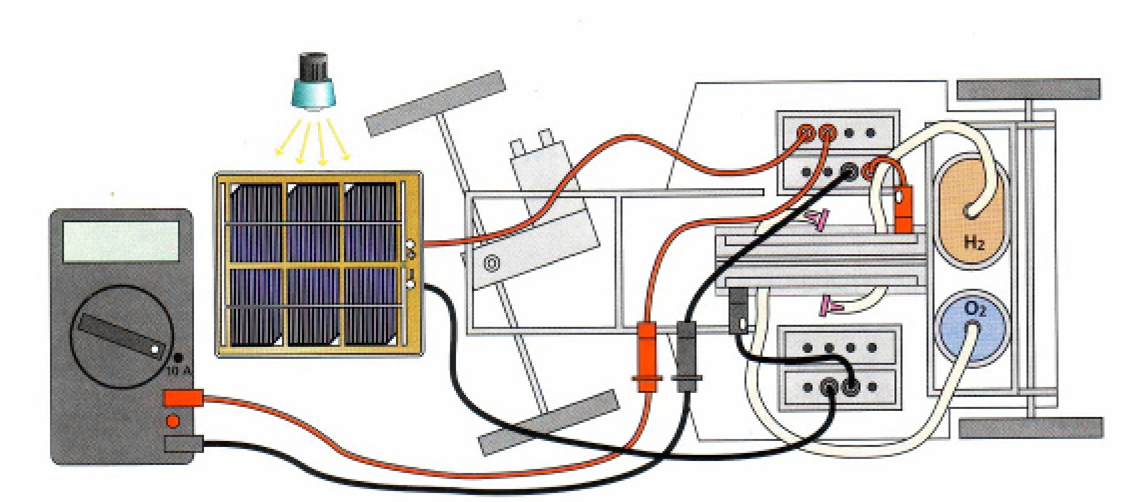
## Course Goal One:
Students will experience a science course that clearly integrates the two disciplines of physical science and technology education. Through the initial lecture and discussion phase, students will learn the basic terminology and concepts of electricity and types of energy. A lab phase will reinforce these concepts by incorporating "learning by doing" with the use of technology.

## Course Goal Two:
Students will have a successful experience with the Thames & Kosmos Fuel Cell Car & Experiment Kit. This kit demonstrates for students how a vehicle could be devised to run on water and the energy from sunlight.

## Course Goal Three:
Students will learn how to use technological devices, tables, and graphs to acquire and analyze the acquired data. Students will use a multimeter to measure voltage, resistance, and current. Students will use a solar cell and fuel cell to actually see and measure energy transfer. Students will graph and calculate results to answer specific questions.

## Course Goal Four:
Students will learn the basics of electricity. Through the lecture/discussion phase, students will receive an introduction to electricity terminology. This provides them with a foundation for further physical studies later on. The inclusion of the experiments and labs, which use many of the terms and concepts, will reinforce the students' learning.

## Course Goal Five:
Students will experience and explore science and technology with hands-on experiments. Students will gain a better understanding of how solar cells and fuel cells work by completing the laboratory components.




*Example of a color diagram from the Fuel Cell Car & Experiment kit lab manual.*
*The lab manual is needed for proper use of this companion curriculum.*

## Student Learning Objectives

### Section I – Electricity (Lecture, Discussion, Demos)

**The Students will be able to:**

- explain static electricity and lightning by explaining charged particles
- define current, amperes, coulombs, alternating current, and direct current
- define electric potential difference and voltage
- calculate and define power and watts
- solve problems using the equation power = current × resistance (P = IR)
- draw symbols and circuit diagrams (both series and parallel)
- perform calculations using Ohm's law
- build a circuit that will light a light bulb
- identify a variety of electrical components including wire, batteries, lamps, etc.

### Section II – Energy Conversions and Introductions to the Labs

**The student will be able to:**

- differentiate and define energy, work, and power
- identify a variety of energy types including light, sound, chemical, and electrical
- identify technology that converts energy from one type to another
- discuss issues (pros and cons) surrounding transportation in the United States of America
- identify options to the current worldwide energy limitations
- explain and define machine efficiency and alternative vehicle power options

## Section III – Using the Labs and Fuel Cell Car & Experiment Kit

The objectives are listed in the table below according to the experiments found in the Thames & Kosmos Fuel Cell Car & Experiment Kit Lab Manual.

| Thames & Kosmos Lab Manual Experiment Number | Corresponding Lab or Worksheet | Topic or Objective<br><br>*Note: Experiments with no data collection do not have corresponding labs or worksheets.* |
|---|---|---|
| Introduction | Lab 1 | Using the multimeter |
| 1 | - | Fuel Cell Car assembly<br>*(see also Appendix A: Fuel Cell Car Quick Start Instructions)* |
| 2 | - | Solar cell overview with information for lab two |
| 3 | Lab 2 | Measuring current and voltage of the solar cell |
| 4 | Lab 3 | Calibration of solar cell as a brightness meter |
| 5 | Lab 3 | Measuring direct and diffuse radiation |
| 6 | Lab 4 | Graphing the daily cycle of solar radiation |
| 7 | Lab 5 | Measuring and graphing an IV curve for the solar cell |
| 8 | Lab 6 | Determining the efficiency of the solar cell |
| 9 | Lab 7 | Splitting water (electrolysis) with the solar sell |
| 10 | Lab 7 | Testing for hydrogen |
| 11 | Worksheet 11 | Calibration of the kit's gas tanks |
| 12 | - | Fuel cell set-up |
| 13 | - | How to split water with the fuel cell |
| 14 | - | Testing for hydrogen and oxygen |
| 15 | Worksheet 15 | Measuring gas generation rates |
| 16 | Worksheets 16,17 | Measuring current and voltage of the fuel cell |
| 17 | Worksheets 16,17 | Calculating the efficiency of the fuel cell |
| 18 | Worksheet 18 | Influence of light intensity on hydrogen generation |
| 19 | Worksheet 19 | Splitting all of the water in the fuel cell |
| 20 | Worksheet 20 | Calculating the amount of water in the fuel cell |
| 21 | Worksheet 21 | Sun power versus lamp power to split water |
| 22 | Worksheet 22 | Recording the rate of gas loss from the tanks |
| 23 | - | Assembling a working fuel cell car |
| 24 | - | Using the electric motor |
| 25 | - | Running the motor with fuel cell attached |
| 26 | - | Using the motor as an electric generator |
| 27 | Worksheet 27 | How far will the car go on a tank of water? |
| 28 | - | Using air as the oxygen source |
| 29 | - | Assembling a crane with hydrogen drive |
| 30 | Worksheets 30, 31 | What is the power of the crane? |
| 31 | Worksheets 30, 31 | How much energy does the crane have? |
| 32 | Worksheets 32, 33 | Measuring voltage and current of the fuel cell |
| 33 | Worksheets 32, 33 | Calculating the efficiency of the fuel cell |

## Section IV - Research Project and Presentations

**Students will be able to:**

- select a topic that relates to transportation and/or alternative energy,
- use the internet and other sources to research a topic for presentation to the class,
- organize and prioritize information into outline form,
- present information to the class in a clear, and concise manner, and
- draw or create a visual aid and use it to enhance the presentation.

# Instructional Strategies

## Introduction

This course is designed to incorporate science concepts and technological applications into the teaching of electricity, energy transfer, and alternative energy options. Although this course is designed for a middle school physical science class, it would work well in a variety of classroom settings. Teachers can change the topics and labs according to their specific classroom needs. The course was tested, in part, on two classes of eighth graders. The following are some strategies that may help in teaching this material.

First, the instructor should introduce the course with the solar panels and fuel cells in hand. Showing the students these devices will get the student's attention and will motivate them to want to learn the concepts and terminology with anticipation for the hands-on laboratories. Some students may have other kits or solar panels at home that they could bring in and use for the lab time.

## Section I – Electricity – Concepts and Vocabulary

Electricity concepts are contained in most physical science textbooks. The material in the teacher's edition of the textbook (or ancillary material) would be a good source of additional demonstrations or activities. It is also a source of handouts, quizzes, and tests. It may be necessary to divide the information into smaller chapters or subunits, but most middle school students should be able to handle the concepts and vocabulary mentioned in the outline. Take special note of the wrap-up possibilities in the course outline of this curriculum. Building circuits, drawing diagrams, calculating amps or watts, using a multimeter, are all excellent tools to reinforce the concepts and terminology in this section.

## Section II – Energy Conversions

The instructor can begin by asking students to write down definitions for power, work, and energy. These definitions can be presented to the class as further discussion moves students to a scientific understanding of the terms. Also, solicit response on different types of energy from the students. Many middle school students have already learned energy types and terms in earlier grades and will just need a reminder. While seated at their desks, students can identify and write down as many energy converters they can think of. By walking around and mentioning a few that a student has written down will trigger others to come up with many more. It is important that students identify the actual types of energy that each device converts from and to, i.e. a blender converts electrical energy to mechanical energy. A classroom of students should identify at least twelve, but twenty or thirty would be more complete.

The other "possible topics" mentioned in the course outline are exactly that. There is opportunity at this point to address such topics as magnets and magnetism, building an electric motor, using a handheld generator, wiring a home, understanding fuses, circuit breakers, and a whole host of other topics. Any topic that the teacher is comfortable teaching that applies and reinforces the electrical concepts would assist students in retaining and enjoy learning the electrical concepts.

It is important to discuss the issue of transportation and society with the students. The teacher should ask some of the questions in the outline. Students could survey family and friends and write an opinion paper about the pros and cons of the current transportation system in their area. What could be done to improve the current situation? Why is it so difficult to convince everyone to drive electric cars? Would everyone driving an electric car solve the problem? Students need to understand that the energy issue is not solved easily. To actually answer these questions, it is important to understand the technology that is currently available. This is the focus of the next section.

## Section III – Labs and the Hydrogen Fuel Cell Car Kit

Is it essential to buy the Fuel Cell kit from Thames & Kosmos to teach this course? This course was developed as a result of the kit, however, most of the course can be taught without actually buying a kit for every student. The first seven labs stand alone with or without the kit. The students must have solar cells and multimeters. Each of these seven labs will require more than a 45 minute class period. Some may take three or four days or at least the lab period of a block schedule.

It would be helpful for the teacher to work through each of the labs before the students. This allows the teacher to recognize any problems and clarify procedures for the students. The Teacher Notes that accompany each lab are written to alert the teacher to potential problems, give answers to lab questions, and to help the labs go smoothly in a science classroom setting. These Teacher Notes were the result of field testing the labs with a group of eighth grade physical science students. Also, students should work together in groups of two to four. Holding solar cells and collecting data at the same time will be too much for one student.

After completing the seven labs, the rest of the experiments will require both a fuel cell and the lab manual which accompanies the Thames & Kosmos Fuel Cell Car & Experiment Kit. This lab manual gives diagrams and explanations for the experiments using the fuel cell. To make the data collection and analysis easier for students to understand, there are worksheets included here which correspond to certain experiments in the lab manual. Many of the experiments mentioned are simply instructions for assembly and only those experiments that gather data have worksheets. Some worksheets require data from earlier worksheets, but that is indicated on the worksheets. Options for the number of kits to buy are provided in the section titled Facilities and Resources.

### Section IV - Research Project and Presentations

Topics for the research projects are listed in the course outline, however this is not an exhaustive list. Teachers can add to it and solicit other topics from their students. It is good to schedule some class time at the library or on the internet for the students to gather information. Students can work in pairs or as individuals. Using pairs will require more organization and monitoring for the teacher to make sure all students are included in the learning experience. Requiring an outline of information half way through will help students with organization and to monitor student progress. To keep students on task, it is good to incorporate points for "use of class time" into the research grade. This is shown on the Research and Speech Rubric located here in the Assessment Strategies section.

Presentations will take longer than expected, so be sure to allocate adequate time. It may take three to five days, depending upon class size, length of speeches, and transition time. During the presentations, there are methods to keep the rest of the students' interest: 1) include "listening" points in the presentation grade, 2) include a test (questions submitted by the presenters), 3) write your own test based upon the presentations, or 4) students hand in notes taken during presentations for a grade. Requiring a visual aid will incorporate another dimension to the students' learning.

## Facilities and Resources

Teaching this course will not require any unique facilities that are not already available in schools throughout the world. There needs to be room for students to move around as they get materials and set up investigations. Secondly, there needs to be work space, such as tables, for students to work in groups of two to four. The test site used a science classroom with tables. For the use of the solar panels, there needs to be direct sunlight coming in through the windows, or the freedom for students to go outside and use direct sunlight for the solar panels. During labs that produce hydrogen gas, it would be safer to work outside or to have some airflow in the room.

Resources needed for the course will include a variety of items not found in most science labs. First, it would be necessary to purchase the Thames & Kosmos Fuel Cell Car & Experiment Kit. This kit is the foundation of the whole course and will be a resource for the teacher throughout all of the lessons and labs. Using the materials contained here, the teacher could get by with one kit. However, to maximize student participation, a kit for each group would be the ideal. The kit includes a lab manual, a car, a fuel cell, a solar panel, a multimeter, and the other material needed for all of the activities. It is produced by Thames & Kosmos and can be bought on their web site, www.thamesandkosmos.com, or through one of the dealers or distributors listed on their web site.

If the budget only allows for one kit, it is possible to get by with a lower cost option. This option would require one kit for the teacher. The first seven labs are revised in this project to be completed using a multimeter, a solar panel, and miscellaneous items such as wires, bulbs, resistors, meter sticks and test tubes. The kit is needed to demonstrate the fuel cell and for the students to do experiments 11 through 33. In these experiments, students can collect data from the one kit (by teacher demo or taking turns) and use the worksheets for calculations and answering questions. A variety of solar panels and multimeters can be purchased from educational supply companies.

# Course Outline

## I. Electricity – Concepts and Vocabulary (teacher lecture notes)

A. Electric Charge
1. Static electricity
2. Demo: balloon/hair rub or wool/vinyl rub (the rubbing removes electrons to cause a net charge)
3. Opposites attract and likes repel $+ \rightarrow \leftarrow -$ $+ \leftarrow \rightarrow +$
4. Article on lightning – National Geographic, July 1993

B. Electric Current
1. Flow of electrons (measured in coulombs) - to +
2. Flow of charge (old method) + to -
3. In metal, it is a flow (or migration) of free electrons
4. Current measured in amperes (Amps)
5. 1 amp = 1 coulomb / second; a measure of rate of flow
6. 2 amps = 2 coulombs / second or 1 coulomb / half second
7. AC (Alternating Current) – from a wall socket (flows in two directions, back and forth)
8. Draw sine wave for AC with plus and minus values and cycles/sec.
9. DC (Direct current) – from a battery, solar cell, fuel cell

C. Voltage
1. Electric potential energy or potential difference
2. More electrons at one pole (-) than another (+)
3. Causes the current to flow (like a hill causes a ball to roll)
4. Measured in volts

D. Power
1. Power is the rate of energy produced or consumed
2. Measured in Watts; 1 Watt = 1 Joule / second
3. Power Equation; $P = IV$; Power = current × voltage
4. 100 W bulbs consume energy at a rate of 100 joules/sec.

E. Circuits
1. A circuit is a path that electricity follows
2. Define conductors and insulators
3. Draw symbols and circuit diagrams
4. Series and parallel circuits
5. Complete circuit vs. short circuit

F. Resistance
1. Resists the flow of electricity – much like electrical friction
2. Measured in Ohms
3. Ohms law; $V = IR$
4. Resistors in series and in parallel
5. Reading the bands on resistors
6. Bulbs are also a type of resistor
7. Anything that uses electricity is a resistor

G. Reinforcement Activities
1. Build circuits with bulbs, battery, and switch
2. Draw diagrams and build series and parallel circuits
3. Why are there 6-8 batteries in a boom box? (1.5 V → 12 V)
4. 1000 W microwave plugged into 120 V: what is the current?
5. Intro to multimeters – Use lab 1 included in this unit
6. Conclude with a test on this material to check for understanding

## II. Energy Conversions and Introductions to the Labs

A. Define terms and differentiate between energy, work, and power.

B. Discuss types of energy
1. Light
2. Sound
3. Electricity
4. Mechanical
5. Chemical
6. Gravitational potential
7. Heat
8. Nuclear
9. Wind
10. Tidal

C. Discuss technology that converts energy from one type to another
1. Solar cell, light bulb
2. Generators, motors
3. Batteries, fuel cells
4. Hydroelectric dam
5. Gasoline engine, heater
6. Telephone, speaker

D. Other possible topics to study or discuss
1. Magnets and magnetism
2. Magnetic induction of current
3. How does a generator work?
4. Building a simple electric motor
5. What is a transformer and why is it important?
6. Two-prong verses three-prong plugs
7. What is a fuse used for? And circuit breakers?

E. Technology – The Transportation Problem
1. What is the problem? pros and cons
2. Electric cars – pros and cons
3. Fuel cells, diesels, nuclear – solutions?
4. Discuss the possibility of a car that runs on water
5. Why is such a car not for sale today?
6. What is meant by machine efficiency?
7. Do we need other options to power our vehicles?

## III. Using the Labs and Fuel Cell Car Kit

A. Introduction
1. Show and explain the kit
2. If not using the Thames & Kosmos kit, at least perform labs 1-7
3. Show multimeters and solar cells to the students

B. Labs 1-7 (Rewritten from Thames & Kosmos lab manual, experiments 1-10)
1. Lab 1 – Using a Multimeter
2. Lab 2 – Current or Voltage?
3. Lab 3 – How Bright is Bright?
4. Lab 4 – Daily Cycle of Solar Radiation
5. Lab 5 – IV Graph of a Solar Panel
6. Lab 6 – Calculating Solar Cell Efficiency
7. Lab 7 – Electrolysis of Water

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C. Using a fuel cell to separate water into hydrogen and oxygen
1. Thames & Kosmos lab manual (experiments 11-22)
2. Worksheets available for experiments 11 and 15-22.

D. Using a fuel cell to power a car and a crane
1. Thames & Kosmos lab manual (experiments 23-34)
2. Worksheets available for experiments 27 and 30-33.

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## IV. Research Project and Presentations

A. Students work in groups and select a topic to research
1. Possible topics include:
    1. Electric cars
    2. Diesel engine vs. gasoline engine
    3. Production of solar cells
    4. Fuel cell cars
    5. Fuel cells – how they work
    6. Fuel cells – history and development
    7. Fuel cell generators
    8. Wind power generators
    9. Pros and cons of current gasoline transportation
    10. Photovoltaic effect
    11. High speed trains
    12. Steam engines
    13. Nuclear power plants
    14. Solar power plants
    15. Solar cells – history and development
    16. Wind power in America
    17. Batteries – How do they work and how are they made?
    18. Solar homes – Passive or active

B. Use periodicals, internet, and library books to gather information

C. Organize information into an outline for teacher approval

D. Prepare information to present to the class
1. Require some form of visual aid such as a poster, power point, video, hand-outs, brochures

E. Presentation of information to the class

# Labs 1-7

## Course Outline, Section III B

For these labs, each group of students will need a solar cell (about 2 V) and a digital multimeter.

*These labs can stand alone or be used with the Thames & Kosmos Fuel Cell Car & Experiment Kit.*

# Lab 1 – Using a Multimeter

*Based on the Introduction to Thames & Kosmos Fuel Cell Car & Experiment Kit Lab Manual*

The multimeter is a useful tool that is used to measure voltage, current, and resistance. In the following lab, you will use the multimeter to measure each of the items below. Read below to remind yourself what each of these mean:

**Voltage** is a measure of how strong the flow of electricity is. A high voltage shows that the "urge" to move is great and the electrons will try to move from the negative side to the positive side. Voltage is measured in volts. (It can be compared to "the size of the engine" in an automobile analogy)

**Current** is the rate of flow of electricity. A high current means that lots of electrons are flowing through the circuit each second. Current is measured in Amperes.

**Resistance** measures how difficult it is for the electricity to flow. As the electricity tries to overcome resistance, heat is produced. A high resistance means that the electricity has to work extra hard to get through the material. Resistance is measured in Ohms.

The **Purpose** of this lab is to familiarize you with the multimeter and to see how it works.

**Materials**:

Multimeter
Batteries (AA, 9V, C, D)
Resistors (variety of resistance) Wires and connectors
Small light bulb

**Preparation**:

1. Take a look at your multimeter and locate the following parts:
   - a. COM plug-in for the lead
   - b. V / Ω plug-in for the lead
   - c. A or mA plug in for the lead
   - d. Turning dial for selecting the different functions of the meter such as: V---, V~, Ω, A, mA.
   - e. Display (screen)
   - f. "Off"
   - g. 10 A plug (some models)

2. Using the box on the right, Draw and label the parts mentioned above to remind you of their location.

## Part I – Measuring Voltage

1. Make sure that the leads on the multimeter are connected to COM (black) and V (red). Secondly, be sure to turn the selector switch to DCV or V--- (NOT V~). DANGER: DO NOT MEASURE THE VOLTAGE OF A WALL OUTLET. THIS CAN LEAD TO SERIOUS INJURY.

2. Using the red probe for positive and the black probe for negative, measure the voltage of a variety of batteries and a solar cell. You can use the following table to record your data.

| Item | Measured Voltage | Voltage Written on the Battery or ? |
|---|---|---|
| AA Battery | | |
| C Battery | | |
| D Battery | | |
| Solar cell | | |
| Piece of metal | | |
| | | |
| | | |
| | | |

3. Notice how the measured voltage compares to the voltage written on the batteries and other devices. How does the measured voltage compare to the published voltage? Are they close?

4. What could account for the differences between the measured voltage and the published voltage?

5. When you are finished measuring voltage, turn off the multimeter and put all of the materials back in their proper places or move on to Part II.

## Part II – Measuring Resistance

1. For this part of the lab you will need five different resistors and a multimeter.

2. Notice that each of the resistors has four colored bands around them. These colors tell us what the resistance of each resistor is supposed to be. The last band is silver or gold and it tells us how accurate the resistor is. The silver or gold band is always the last color, it is not a part of the resistance value. (It shows the accuracy of the bands).

Use the table below to determine the NOMINAL values for each color.

| Color | Position 1 | Position 2 | Position 3 (Multiplier) |
|---|---|---|---|
| Black | 0 | 0 | 1 |
| Brown | 1 | 1 | 10 |
| Red | 2 | 2 | 100 |
| Orange | 3 | 3 | 1000 |
| Yellow | 4 | 4 | 10,000 |
| Green | 5 | 5 | 100,000 |
| Blue | 6 | 6 | 1,000,000 |
| Violet | 7 | 7 | 10,000,000 |
| Gray | 8 | 8 | 100,000,000 |
| White | 9 | 9 | (None) |

3. To read the chart above take a resistor and look at the color sequence. For instance, pretend the colors are red, red, brown, gold. Gold is always at the end and is not a part of the nominal value. Red stands for 2 and the brown represents a multiplier of 10. Red, red, brown means 22 × 10 (220 Ω). Orange, blue, yellow is 36 × 10,000 or 360,000 Ω (360,000 ohms or 360 kilo ohms). This is how to find the NOMINAL value for each resistor.

4. To find the MEASURED value for each resistor, switch the multimeter to Ohms (Ω) and move the red lead to the Ohms (Ω) plug-in (Black lead stays in the same place). To measure the resistance, just place the two probes on each end of the resistor.

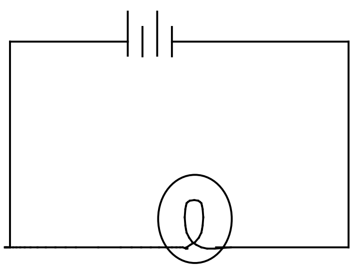
5. Fill in the table below.

| Resistor | Nominal value | Measured value | % error-optional |
|---|---|---|---|
| A | | | |
| B | | | |
| C | | | |
| D | | | |
| E | | | |

## Part III – Measuring Current

1. This part of the lab involves making a circuit and measuring current. It is helpful to have been introduced to electrical diagrams. Items needed include a small light bulb, a 9V battery (or 2 other batteries), wire, and the multimeter.

2.



Here is the electrical diagram of a circuit that includes a battery and a light bulb. They are connected to each other by wire. Build this circuit and get the light bulb to light up.

3. To measure current, the selector on the multimeter must be turned to DC current or DC Amps. The red lead must be in the 10 A socket. If the reading is too small, it will be necessary to move the selector and the red lead to milliamps (mA).

4. When measuring current, the circuit must be broken and the multimeter must be placed in line with the flow of current. For this to happen, one of the wires is removed and the red and black probes need to touch both ends of the break so that the current now has to flow through the multimeter. The light bulb should still light up while you are taking the reading. Do not leave the light bulb on for very long or you will burn it out.

5. What was the current reading for the light bulb circuit? ____________

6. If time allows, try to set up a different circuit with a resistor and measure the current in the new circuit. Fill in the table below.

| Battery voltage | Resistance | Voltage/Resistance<br>Divide V/R | Measured Current |
|---|---|---|---|
| | | | |
| | | | |
| | | | |

7. Is the value for voltage/resistance close to the measured current value?

8. Why might this be so?

# Lab 1 – Using a Multimeter

## Teacher Notes

Many of the following labs involve the use of a multimeter. This lab helps students to become familiar with this device. Students usually work in groups due to the limited number of multimeters. The time requirements will depend upon the student's pace.

**Preparation**
Since all multimeters are a little different, it is good to use the preparation to have students actually draw the location of the multimeter parts. Grading this will obviously depend upon the brand available.

Depending upon the amount of prep time, it is helpful to have a screwdriver and a few extra fuses around to fix the multimeters as students "forget" to move the probe leads.

**Part I-Voltage**
Whatever batteries are available will be suitable. If it hasn't been taught before, it is a good time to explain direct and alternating current. Also, remind students of the dangers of alternating current and wall sockets.

There is room on the table to add other voltage sources.

How good are your batteries? Students should see that batteries are not all identical. Most electrical devices are able to operate within a small range of battery voltages.

**Part II – Resistance**
Students like to use the chart to find the nominal values of the resistors. It is helpful to go through a few examples as a class before they struggle through it on their own.

To determine the percent error: take the difference between the nominal value and the measured value, divide that number by the nominal value, and multiply by 100 to get percent.

It is interesting to use the silver and gold bands to see if the resistors are within the published tolerance. Gold = +/- 5%, Silver = +/- 10%, no band = +/- 20%.

**Part III – Current**
This is also a good time to introduce students to electrical diagrams. This can be a whole lesson in itself and the lab makes for a good application of the skill. If able, have students draw the schematic with the ammeter in series with the light bulb and any other variations; multiple bulbs (or resistors) in series or parallel.

(Optional) The lab ends with a look at Ohms law ($V = IR$). Ohms law illustrates that current flow and current push are directly related to resistance. Lower resistance allows faster flow (more current) and/or less electron push (less voltage). Increasing resistance makes the voltage increase (push electrons harder to get through) and/or decreases current (electrons flow slower).

# Lab 2 – Current or Voltage?

*Based on Experiment 3 in Thames & Kosmos Fuel Cell Car & Experiment Kit Lab Manual*

As a solar cell is placed in the light, it is able to produce an electrical current. Brighter light should produce more electricity. This increase in the amount of electricity can be measured in either Volts or in Amps. In future labs, we will want to use this difference in electricity produced by the solar cell to measure the difference in brightness of a light.

Volts or Amps? Which one changes the most as brightness changes? Is it a consistent change? The **purpose** of this lab is to decide which is better at measuring a change in brightness? Or are they equally useful?

To conduct this lab, it is necessary to complete a table of measurements for both current and voltage as the solar cell is placed in different places. The resulting data is graphed and compared for usefulness.

**Materials**:

- Solar Cell
- Multimeter
- Light bulb in a dark room
- Sunny day
- Outdoor shadows or clouds
- Meter stick

**Predictions**:

1. If the light on a solar cell is brighter, do you expect the amount of voltage produced to increase? How about the current?

2. As the solar cell is moved away from a light bulb, what would you expect to happen to the voltage? How about the current?

3. Which of these, current or voltage, do you expect to change the most as a solar cell is moved to different brightnesses?

## Procedure- Part I – Practice Measuring Current and Voltage

1. Connect the multimeter to the solar cell with the (+) connected to red and the (–) connected to the black. Turn the dial to voltage. Using the solar cell and multimeter, measure voltage for each light source, and then write down the readings in Table A.

2. Turn the dial to 200 mA (or 400 mA, depending upon your multimeter) and write down the readings for current in Table A. Note: Change the multimeter cable plug-ins when switching between voltage and current!

3. The readings for Table A should be all completed.
   a. What produces the most current?
   b. What produces the least current?
   c. Can you graph these results? Why or why not?

### Table A

| Light Source | Current (mA) | Voltage (V) |
|---|---|---|
| Center of Classroom | | |
| Full Sun | | |
| Clouds or shadows | | |
| Fluorescent Light (2m) | | |
| Light Bulb (2m away) | | |
| | | |

## Part II – Graphing distance vs. current and voltage

1. Set up a meter stick and a lamp. Turn off the room lights so that the bulb is the brightest light in the room. Measure and record current and voltage as before. Complete Table B by moving the solar cell along a meter stick to get each of the distances on the table. Note: Be sure to change the cable plug-ins on the multimeter when

switching between current and voltage! **CAUTION: Do not let the solar cell get too hot or the current will shut down! Solar cells to not work well at high temps.**

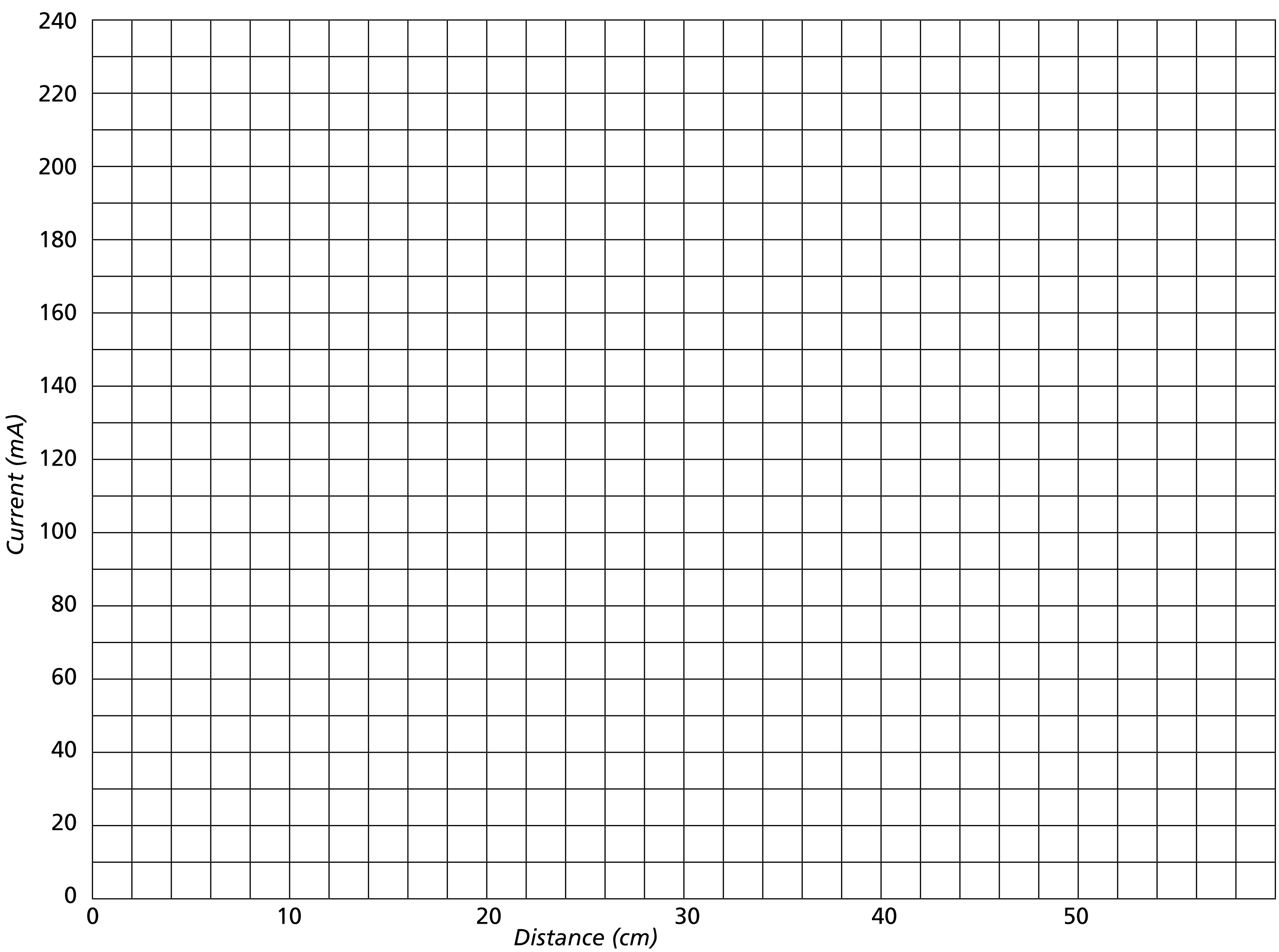
2. At a distance of 20 cm, try covering a small part of the solar cell while watching the multimeter. Which changes the most, current or voltage?

**Table B**

| Distance (cm) | Current (mA) | Voltage (V) |
|---|---|---|
| 5 | | |
| 10 | | |
| 15 | | |
| 20 | | |
| 25 | | |
| 30 | | |
| 35 | | |

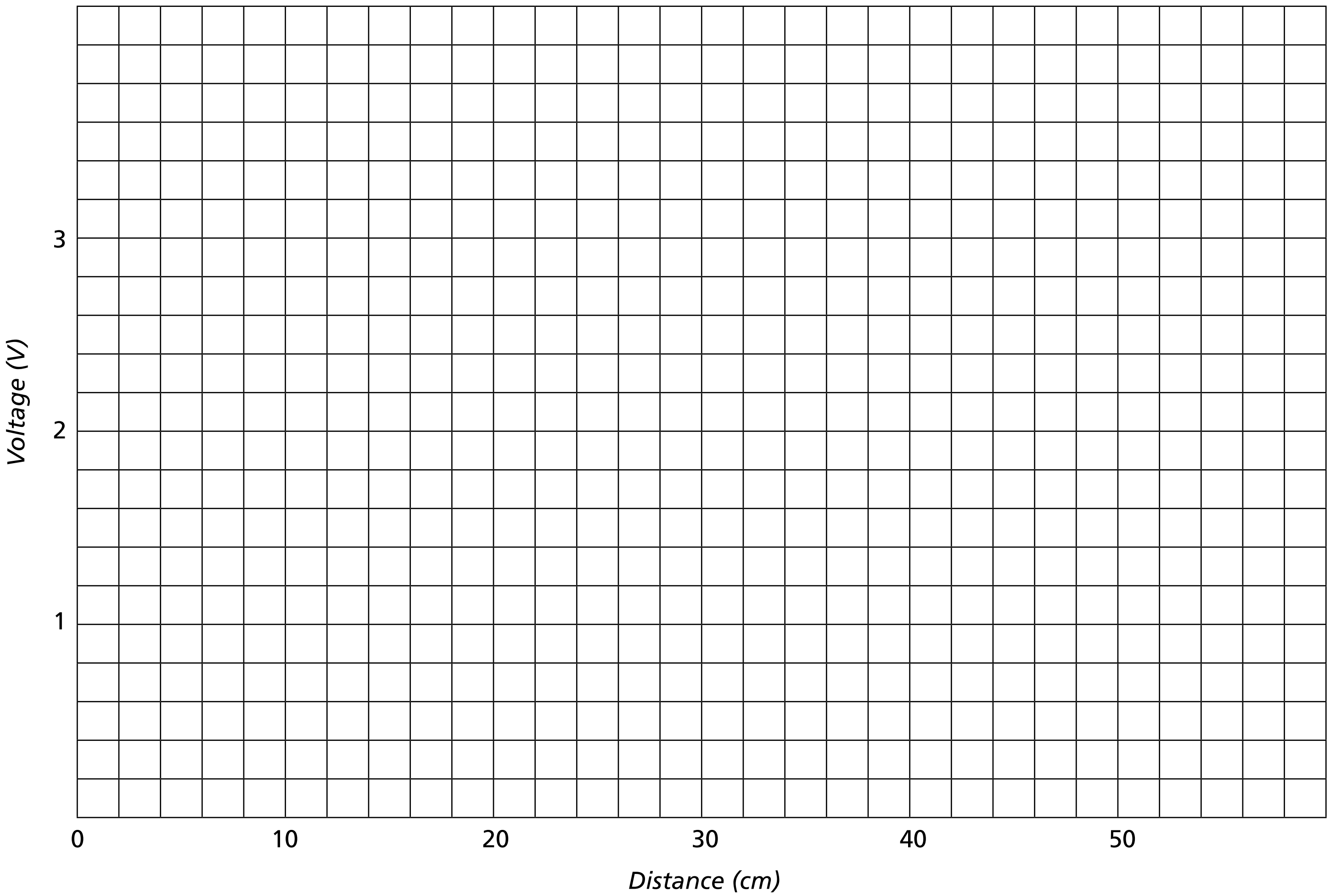
3. You have collected the data for Table B, now graph the Current vs. Distance on Graph A; and the Voltage vs. Distance on Graph B.

## Current vs. Distance Graph (Current Data from Table B)




4. Draw a line through the points on the graph and describe the relationship between current and the brightness of the light on the solar cell.

## Voltage vs. Distance Graph (Voltage Data from Table B)




5. Draw a line through the points on the graph and describe the relationship between voltage and the brightness of light on the panel.

6. Compare the two graphs. Which changes the most as the brightness of light on the solar panel changes?

7. To compare brightness with distance, should we use voltage or current as our measuring value? Why?

# Lab 2 – Current or Voltage?

## Teacher Notes and Answers to Questions

This lab is included so that students can see the difference between short-circuit current and no-load voltage. They will easily predict that more light should produce more electricity, but which measurement better indicates "more electricity": current or voltage?

Part I gives the students practice with using the solar panel to measure both current and voltage. Part II involves using a light bulb and measured distances to graph the changes of both current and voltage.

**Predictions**

1. Both current and voltage should be higher in brighter light.
2. Both current and voltage should decrease.
3. Either prediction is fine; the overall purpose of the lab is to answer this question.

### Part I

Be sure to draw their attention to Table A and make any changes you might need for your classroom situation. Allowing students to go outside to measure as they need to, or all at once, are matters of classroom management and teacher preference. Table A can be modified depending on what light sources are available to you, the teacher.

It may be worthwhile to review how to use the multimeter to measure both current and voltage. Depending upon the brightness outside, it may be necessary to change from mA to 10 A as the multimeters are brought out into the direct bright sunlight. This will not be intuitive to most students and will require some teacher explanation.

It is also helpful to direct students to either collect all the voltage readings first and then all the current readings (easier to remember to change the plugs). Or have them do the outside readings all at once (easier to keep an eye on all students).

3a. Full sun outside should give the highest readings for both current and voltage.
3b. Answers will vary; it depends upon light bulb size, distance, and ambient light.
3c. Difficult to graph; there are no comparable known values (what would be the independent, X-axis, variable? — which leads us to Part II

### Part II

A block schedule will allow this to fit into one period; otherwise start this part of the activity on a second day. This part of the lab requires the light bulb and meter stick set-up. Students can work in groups and share the data or set-ups. It may be helpful to review graphing techniques.

**Answers to questions in the lab (Part II)**

2. Current should change the most
5. Both graphs show a decrease as distance increases (voltage-linear, current-exponential)
6. Current changes the most
7. Answers will vary; the large range in current makes it a more accurate measure of brightness

## Lab 3 – How Bright is Bright?

*Based on Experiments 4 & 5 in Thames & Kosmos Fuel Cell Car & Experiment Kit Lab Manual*

A room can look bright when all of the lights are on. If one light is off, is the room less bright? Is a bright room brighter than an overcast sky outside? In this lab, you will measure the difference in brightness using a solar cell and a multimeter.

If you did lab 2, you realize that measuring the current change in a solar cell is a good way to compare the difference between brightness. (If you didn't do lab 2, this will have to be presented as a given fact.) Basically, the current changes more dramatically in a solar cell as the intensity of light hitting the cell changes. Using this change in current, you can get numbers that directly relate to brightness. Instead of saying "That's really bright," you can say that "This light has a brightness of 2.4 which is much brighter than another light with only a brightness of 0.32." Using numbers (quantitative) makes comparisons much more scientific.

The **purpose** of this lab is to compare the brightness of different sources of light. You will also compare direct and diffuse light.

**Materials**:

| | |
|---|---|
| Solar cell | Cardboard (about the size of the solar cell) |
| Multimeter | Sheet of paper to roll into a tube |
| Sunny day | Lamp with a 60 W bulb |
| Fluorescent lights | |

**Predictions:**

1. Which is brighter, the 60 W lamp at 10 cm or the sun?
2. If you hold your hand in front of the sun, how can you still see the back of your hand? Explain.
3. Which are brighter: fluorescent lamps or incandescent bulbs?
4. Do different surfaces reflect different brightness? For example, concrete versus grass?

### Procedure – Part I Calibration

1. To do Part II of the lab, you need to calibrate your brightness-measuring device. The multimeter will give values in amperes, but that is not a unit for brightness. For this lab, you will use irradiation (this is another name for brightness), which is measured in Watts/square meter. To calibrate, you need to measure and graph the current for three known levels of brightness — the sun, a 60W bulb, and darkness (no light).

2. Connect the cell to the multimeter and see that it is reading current in mA. Note: Make certain the red lead is plugged into the mA spot. In the direct sunlight, turn the cell slowly back and forth until you have the highest reading for the direct sun.

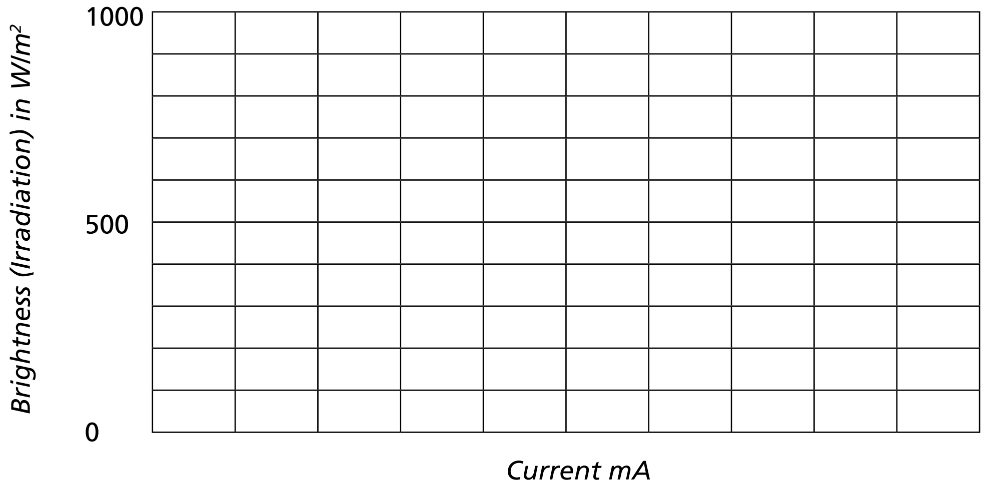
3. Direct sun = ________ mA. The direct sun has an intensity of about 1000 $W/m^2$ in the summer and 800 $W/m^2$ in the winter. Now you know that whenever the current reads you value above, the intensity is about 1000 $W/m^2$ (or 800 $W/m^2$).

4. Now do the same as above for the 60 W bulb. A normal 60 W bulb has a radiation of 300 $W/m^2$ at a distance of 10 cm. So now take the cell and find the current produced by the solar cell at 10 cm away from a 60 W bulb. 60 W bulb = _________ mA. Again, tilt the cell back and forth to get the highest reading.

5. If no light is on the cell, the current reading is 0 mA. Also, if no light is hitting the cell, the irradiation must be 0. Cover the cell completely and see if the current drops to 0.

6. Graph the three points on the graph below.

7. Drawing a line through your three points should yield a line that is very close to straight. The graph is now a tool that will take any current reading and convert it to an irradiation reading.




8. Scientists like to turn graphs into equations. You can turn the graph above into an equation by finding the slope of the line and using the equation y = m x + b.

x = the current reading (from the multimeter)

b = the y intersect point, this should be 0 as you used 0,0 as the "no light" point

m = the slope of the line (rise/run) Note: Be sure to use the units of the x and y axis when calculating the slope. The slope of your graph is _______W/m$^2$ / ______ mA = ________.

9. Now, finalize your equation. If the slope ended up to be 1.5, then the equation would be y = 1.5x + b

"y" irradiation (in W/m2) = "1.5" slope times "x" current (in mA).

The b is zero and can be dropped.

The equation for your graph is:

Brightness = ______ (your slope) times current

Congratulations! You have calibrated your brightness meter!

## Part II – Comparing Brightness Questions

Now that you have a way to turn current into brightness, you can convert mA to brightness and then compare the brightness to answer the following questions:

1. Which is brighter, the sun on a bright day, or the light in a classroom?

   Sun = _______mA which is ________ (W/m$^2$) Brightness

   Classroom = _____mA which is ______ (W/m$^2$) Brightness

2. How much brightness is lost when the sun goes behind a cloud? Or in a shadow?

3. How does the brightness of light reflected from the concrete compare to the light reflected off of grass?

4. Pick two objects of different color. Compare the brightness of light reflected off the two objects. Which color is brightest?

5. Compare the brightness of an incandescent and a fluorescent bulb at 20 cm away.

## Part III – Direct and Diffuse Radiation

1. Direct light is light that hits the solar cell in straight lines directly from the source. When you hold up your hand to cover the sun, light is still hitting your eyes. Some of this is diffuse light.

2. Take a piece of cardboard that is about the same size or larger than the solar cell. In the sunlight, hold the cardboard as far away from the solar cell as possible so that it still shades the entire solar cell. This allows as much diffuse light as possible to hit the cell. Calculate the brightness. Do it three times and take an average of the three.

_____ mA→ _____ ($W/m^2$) Diffuse
_____ mA→ _____ ($W/m^2$) Average brightness = _____
_____ mA→ _____ ($W/m^2$)

3. Now to get a reading of the direct light and not the diffuse, you need to take a sheet of paper and make a tube with a diameter a little large than the solar cell. Hold the tube and the cell towards the sun and try to get a reading of the current with only direct sunlight on the cell. Again, try for three readings and find an average.

_____ mA→ _____ ($W/m^2$) Direct
_____ mA→ _____ ($W/m^2$) Average brightness = _____
_____ mA→ _____ ($W/m^2$)

4. Since you have this method of measuring down by now, it would be good to take one more measurement. This is called the albedo radiation. Here you need to get a measurement of the reflected light off of the ground. Turn the solar cell upside down and measure the brightness of the light reflected back up onto the cell. Again, take three readings and find an average.

_____ mA→ _____ ($W/m^2$) Albedo radiation
_____ mA→ _____ ($W/m^2$) Average brightness = _____
_____ mA→ _____ ($W/m^2$)

5. Write a paragraph explaining what factors you need to take into consideration when deciding where to place a solar panel for a house. What should you look out for to get maximum power output? Be sure to use the data above in your explanation.

## Lab 3 – How Bright is Bright?

## Teacher Notes and Answers to Questions

This lab takes a solar cell and a multimeter and turns them into a meter for measuring brightness. Part I is necessary to calibrate the brightness meter. Part II uses this new meter to compare a variety of brightness. Part III uses the meter to compare direct and diffuse radiation. Each of the parts of the lab can be done on different days unless students have a longer class period (block schedule).

**Predictions**

1. Answers may vary, but the sun is brighter.
2. Diffuse light is the result of light reflecting off of surfaces all around us and onto the back of our hand and into our eyes.
3. It certainly depends on the bulb and the distance to the bulb.
4. This one is pretty obvious, but it starts the thought process for later in the lab.

### Part I – Calibration

It is essential that students take this part slowly and carefully. The rest of the lab relies upon the slope determined from this calibration.

Students will plot three points on a graph, determine the slope of the line made from the three points and then use that slope to convert all measurements in milliamps into irradiation units of W/m$^2$. Remind students that brightness and irradiation are two words meaning the same thing.

The three points to be plotted are three items of known brightness; darkness (0 W/m$^2$), 60 W bulb (300 W/m$^2$), and the sun on a bright day (800-1000 W/m$^2$, 800 in winter and 1000 in summer).

Values for current will depend upon solar cell range and size. The application of mathematics to determine slope of a line is intentional as reinforcement for the grade level.

### Part II – Comparing brightness

Now that the conversion factor is determined, students can compare brightness quantitatively (using numbers). Students can use the meter to answer the questions. It will involve setting up and collecting data both inside and outside (on a sunny day).

**Answers to Questions**

1. The sun should always be brighter.
2. Answers will vary. A percent drop would be interesting.
3. White car should be brighter.
4. Answers will vary.
5. Again, answers will vary.

### Part III – Diffuse and Direct

Answers will vary for all.

5. Paragraph should include factors such as shadows and obstructions of light. Buildings, trees, cloud cover, light reflectors, and other items could affect the amount of light hitting a solar panel.

# Lab 4 – Daily Cycle of Solar Radiation

*Based on Experiment 6 in Thames & Kosmos Fuel Cell Car & Experiment Kit Lab Manual*

As the sun moves across the sky, it changes its position with respect to a stationary solar panel. As you can imagine, a solar panel in Australia will be oriented a bit differently than a panel in Spain, or in Alaska. In this lab, we will try to determine the best position for a solar panel at your location so that it will receive the maximum amount of radiation throughout the day.

Some research facilities have electrical powered "sun trackers" that keep their solar panels facing the most direct sun at all times. These trackers are an added expense and also use up much of the electricity that the panels are producing. For these reasons, most solar panels are oriented for the location in which they are installed and then fixed into position to receive the maximum solar radiation during most of the daylight hours.

The **purpose** of this lab is to determine the best position for a solar panel. You will determine this by measuring and graphing the solar radiation throughout the day. We will find three different values each hour: global, vertical, and horizontal irradiation. It would be interesting to do this at different times of the year as well, but using a whole day will require enough time as it is.

**Materials:**

- Solar Cell
- Multimeter
- Masking Tape
- Sunny day
- Compass

**Predictions:**

1. Will the brightness of the sun change as it moves across the sky? How much? (Twice as bright at noon?)
2. Why do solar panels face south?
3. Which will get more light, a vertical solar panel or a horizontal? Why?

**Procedure:**

1. Connect the multimeter to the solar cell with the + (positive) connected to the red and the – (negative) connected to the black. Turn the dial to 200 mA (or 400 mA) and make sure you get a reading on the meter. Now turn it back to off to save the batteries.

2. Find a location that will work for the entire day to take readings in the sunlight.

3. Using the compass, place the solar cell facing exactly south and put a piece of tape in front of the solar cell so that you won't need the compass every time.

4. Look at the data table. You will need three measurements every hour throughout the day, starting at sunup. You will need to work out the logistics of getting a reading every hour.

5. Collect the data in the table. Be sure that you get the readings in mA and then you can convert them to brightness later.
   a. Global reading involves moving the panel around slowly directly at the sun to get the highest reading you can.
   b. Horizontal reading is taken with the panel perfectly flat
   c. Vertical reading has the panel straight up and down facing exactly south.

| Date: | | Weather: | | | | |
|---|---|---|---|---|---|---|
| **Time of Day** | **Global** | | **South Vertical** | | **Horizontal** | |
| | Current | Radiation | Current | Radiation | Current | Radiation |
| | | | | | | |
| | | | | | | |
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6. Using the table alone, it is difficult to see patterns and to get an overall picture for the irradiation of the whole day. To better see the overall picture, you will need to graph your data on a Irradiation vs. Time of Day graph. Time of Day will be on the X axis and Irradiation in $W/m^2$ on the Y axis. Start the day at 0 hours and continue to 24 hours (Enter zero solar irradiation during the night hours).

7. Use a different color for each of the global, vertical, and horizontal data. Label both axis and show the units. Give the graph a title.

**Questions:**

1. Which of the readings gives the most light on the solar panel?

2. For an average day, 7 AM - 7 PM, what is the average output for

   Global? ____________

   Horizontal? ____________

   Vertical? ____________

3. Using global as 100%, what percentages do the other two have for output throughout the day?

4. At a particular time of day – e.g. 2:00 PM – and again using global as 100%, what is the percent of output for vertical and horizontal?

5. Throughout the day, which gives more light to the panel, horizontal or vertical? Why might this be so?

6. Using the information you learned in this lab, what angle would you place a south facing solar panel to get the maximum power output each day? Explain why this is your answer.

# Lab 4 – Daily Cycle of Solar Radiation

## Teacher Notes

This lab takes the measurements of light intensity throughout the day for maximum output, vertical output and horizontal output. The results are graphed and compared to see how much the tilt of a south facing solar panel relates to the power output of the panel.

The first thing to note here is collecting solar radiation for a 24 hour period will require some out of classroom time. It will be best to spend one day to explain the lab and to practice collecting global, vertical, and horizontal irradiation. On the second day, try to be creative so students can get readings throughout the day. Another possibility is to send the multimeters home and give extra credit to the students that actually get data on a Saturday every hour. Then, their data can be used by the rest of the class.

A supplementary item for lab 4 would be to purchase a Hubbard Suntracker. It uses a transparent hemisphere and a mirror that allows students to track the path of the sun. Then students can see and measure the best angle for an immobile solar panel. The Hubbard Suntracker is available through a number of science supply vendors. It would be ideal to get a best angle from the Suntracker and then set up a panel at that angle and add it to the data collection. This would allow students to see how much the angle of tilt can maximize the panel's power output.

**Predictions**

1. Yes, brighter at noon
2. In the northern hemisphere, the direct rays of the sun are usually towards the equator which is located to the south
3. Horizontal, unless at high latitude

**Answers to Questions**

1. Global
2. Answers will vary according to students' data
3. Answers will vary according to students' data
4. Answers will vary according to students' data
5. Horizontal, unless at high latitude
6. Discuss with students

# Lab 5 – IV Graph of a Solar Panel

*Based on Experiment 7 in Thames & Kosmos Fuel Cell Car & Experiment Kit Lab Manual*

All electrical devices have electrical characteristics that make them work best in certain situations. For instance, all electrical batteries are not the same. Sometimes a 1.5 V AA battery is best (e.g. in a Walkman) and other times a 9V battery works better (e.g. in a multimeter). Each battery is used according to the electrical requirements of the device it is used in. The same is true with solar panels. Notice that the solar panel on a calculator is very different from the solar panel on a house.

The **purpose** of this lab is to learn how to construct an IV graph for a solar panel, to determine the maximum power of the panel and to compare the properties of our panel to the uses it might be good for.

An IV graph compares the changes in the power of a circuit as resistance is changed. It includes both current (I) and voltage (V) readings. They are related to resistance as shown through Ohm's Law of electricity. Ohms law can be summarized in the following equation: $V = I \times R$ (voltage equals the current times the resistance). What this means is that the current, voltage, and resistance are interrelated within an electrical circuit. (Ohms law was explained in lab 1.)

**Materials:**

| | |
|---|---|
| Solar Panel | Multimeter |
| 3 resistors ~5, 10, 20 Ohms | Breadboard (or connectors) |
| wires for connections | Light source |

**Predictions:**

1. Does resistance always increase with multiple resistors? How so?

2. What is power? How is it calculated?

3. At what voltage will the solar cell produce maximum power? At the highest voltage, the lowest voltage, or somewhere in between?

## Procedure: Part I

1. You will need to calculate the different resistance values that can be achieved with the three resistors. To begin with, each resistor can be used by itself. Enter the resistance of each resistor as the nominal value in Table A
Your teacher may tell you the resistance or you may use the color band table from lab 1.

### Table A – single resistors

| Resistors | Nominal value – Ohms | Measured value -Ohms |
|---|---|---|
| R1 | | |
| R2 | | |
| R3 | | |

2. To measure the actual resistance, use the multimeter. Turn the dial to resistance or Ohms Ω and connect the leads to the ends of the resistors. Enter the values in Table A as measured values.

3. For Table B, you will combine the values of the resistors. They can be connected in series and parallel. In series, the resistors are connected end to end and the overall resistance is from the front of the first resistor to the back of the last resistor. These values can be calculated by adding each of the individual resistor's values. First, figure the nominal values and then measure the values. Your teacher may have breadboards to make this easier.

### Table B – resistors in series

| Resistors | Calculated value - Ω | Measured value - Ω |
|---|---|---|
| R1 + R2 | | |
| R2 + R3 | | |
| R1 + R3 | | |
| R1 + R2 + R3 | | |

4. In a parallel circuit, all the resistors are connected at each end. In other words, the left sides of both (or all) the resistors are connected and the right sides of both (or all) the resistors are connected and the meter is connected to these ends. Calculating the total resistance is a bit more difficult. In a parallel circuit, the total resistance = 1/R1 + 1/R2. In Table C, try to figure the total resistance for each combo and then measure them.

## Table C – resistors in parallel

| Resistors | Calculated value - Ω | Measured value - Ω |
|---|---|---|
| R1 + R2 | | |
| R2 + R3 | | |
| R1 + R3 | | |
| R1 + R2 + R3 | | |

5. You can see that the three resistors allow us to measure 11 different resistance values as we prepare to make an IV graph. To make the IV graph we need more data. Specifically, we need voltage and current data for each different resistance.

## Procedure: Part II

1. Setting up the lab. On one end of a table, put a lamp with a 40 or 60 W bulb. Set up the solar cell and multimeter(s) so that the circuit is a no-load current (without any resistors). Move the solar cell closer or farther from the light bulb (in a darkened room) until the current reading is about 160 mA. Tape the solar cell to the table so it will not move around.

2. To collect the following data, you will need to make sure the light and solar panel will not be disturbed. Changing the resistors will need to take place without bumping the light setup. For each different resistance, the current and voltage must be measured. This can be done with two multimeters or by switching one multimeter back and forth. Remember to measure voltage across (in parallel with) the resistors (with the cords in the voltage sockets) and to measure current in-line (in series) with the resistors (with the cords in the mA sockets).

3. Now fill in data Table D

| Resistance | Voltage | Current | Resistance | Voltage | Current |
|---|---|---|---|---|---|
| A. | | | H. | | |
| B. | | | I. | | |
| C. | | | J. | | |
| D. | | | K. | | |
| E. | | | | | |
| F. | | | ∞ Ω | | 0 A |
| G. | | | 0 Ω | 0 V | |

4. If the circuit is left open, the resistance approaches infinity ∞, the voltage is at max (measure with the multimeter), and there is zero 0 current (electrons cannot flow through an open circuit). Add this info to Table D as one of the points.

5. If you connect the circuit with no resistors, the voltage drops to zero 0 and the current is maxed out (measure with the meter). Add this info to Table D.

6. Now that you have data points, it Is time to plot them on a graph. The x axis will be voltage and the y axis will be current. Give the graph a title and label the axis. Determine the best range and label the values for each axis and show units for each axis.

7. Plot the points and draw a smooth curved (no wriggles) line through the points to produce the IV curve for your solar panel.

8. There are a couple of ways to determine the power for each voltage on the graph. You can use calculus to determine the area under each segment of the graph or you can make a new graph with new data using the fact that power (watts) equals current (amps) times voltage (volts).

9. Use data from table D on the last page to complete this table.

| Point | Voltage | Power(I*V) | Point | Voltage | Power(I*V) |
|---|---|---|---|---|---|
| A | | | G | | |
| B | | | H | | |
| C | | | I | | |
| D | | | J | | |
| E | | | K | | |
| F | | | Calculate Power for each | | |

10. Now, use this data to fill in the graph on the next page. Power is in watts on the Y-axis and volts on the X-axis. Draw a smooth line through the points, the top of the curve is the MPP. The MPP is the Maximum Power Point.

11. What is the Maximum Power Point for your graph? _____ Watts

This is the max power that the solar panel will produce at that particular brightness. If you change the distance between the solar panel and your light, you will get a new MPP for the different brightness.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
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## Questions

1. Why are some points off the line on the first graph? (Give more than one possible reason.)

2. If I were to go out to buy a motor to run off this solar panel, which motor should I buy for the best use of the panel; 0.5 V, 1.0 V, 1.5 V, 2.0 V

3. Compare the two graphs you made. Could you predict the MPP point on the first graph? Explain.

4. If time allows and your teacher requests it, move the light or the solar cell to a different distance (to get a different brightness) and find the new MPP (Maximum Power Point). Graph the data on the same graphs using a different color. Are the MPP's the same?

# Lab 5 – IV Graph of a Solar Panel

## Teacher Notes and Answers to Questions

This lab shows students how to construct a current voltage graph which can give the maximum power output for a solar panel. The lab has two parts and will take about two days. Part I looks at resistors and how the resistance changes as they are arranged in series and parallel. This is an excellent way to reinforce the concept of adding resistors in both series and parallel. Part 2 takes the resistors and sets up a circuit to measure both the voltage and the current as each of the different resistances are exchanged. Again, the results are graphed and analyzed.

It is important to introduce students to series and parallel before handing out the resistors. These combinations are used in many real circuits and it is great practical application for calculating total resistance. Three resistors can be set up to give 11 different total resistances.

**Predictions**

1. Most students will answer yes, but some may know that resistors in parallel will actually have less total resistance.

2. Power is the rate at which energy is used or produced. It is measured in watts.
Power = IV (current × voltage)

3. Predictions will vary; the lab results should make it clear.

## Part I – Resistors

Give each group of students three resistors. Due to the low output of these little solar panels, it is best to use resistors less than 100 Ohms (less than 1000 Ω is okay).

It is best to go through the calculating of parallel resistors before handing out resistors. $1/R_{total} = 1/R1 + 1/R2$ + etc. Work through a few of these so that students have success with the mathematical concepts. Measuring the value will give them immediate feedback to see if their answer was correct (within a few ohms).

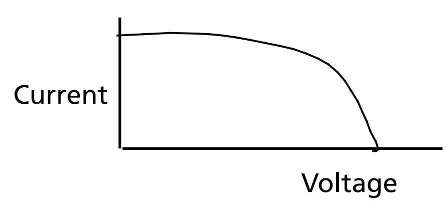
Depending upon the depth of coverage, this is also a good time to see if the resistors are within the published range. Gold +/- 5%, Silver +/- 10%, No band +/- 20%

With three resistors, students should end up with 13 resistance values. No resistor (0 ohms) should equal max current (measure with meter) and 0 volts. Infinite resistance (open circuit) will give 0 Amps and max voltage (measure with meter).

## Part II – Measure IV and graph

Once the apparatus is setup, everything except the changing of the resistors must stay exactly the same. (light, solar panel, and distance between them).

The curve of the IV graph should look a bit like this:




**Answers to Questions**

MPP for the student's graph will vary according to solar panel, brightness of light, quality of panel components, and accuracy of students' measurements.

1. Resistors have bad connection, meters have bad connection, misread the x or y axis, used the wrong resistor combo

2. This will depend upon students' results.

3. Depending upon geometry skills, only some students will see and explain the connection here. The area of the rectangle formed by any point on the graph gives the power at that point. The point on the curve with the largest rectangle (IV graph) is also the MPP on the voltage-power graph.

4. This is up to the teacher and the amount of time remaining for lab time. It would be useful for the group that gets done early to work toward a second or even a third MPP value. Comparing the values shows how each MPP is unique to the panel and the brightness. They could then share results with the rest of the class.

# Lab 6 – Calculating Solar Cell Efficiency

*Based on Experiment 8 in Thames & Kosmos Fuel Cell Car & Experiment Kit Lab Manual*

Solar cells do not turn all the light from the sun into electricity. In fact, only the light that hits the solar panel is used in creating electricity. The light from the sun has power in it. When that light hits the solar cell, how much of that power is actually turned into electricity? This amount can be called the solar cell's "efficiency."

The **purpose** of this lab is to find the power efficiency of our solar cells. It is written as a percent and can vary with different types of cells and even amongst the same types of cells. Early solar cells had very small efficiencies and now solar cells are made that have efficiencies up to 25%. That means that 25% of the power in the sunlight hitting the solar cell is converted into electrical power.

In lab 3, the solar cell was used as a brightness meter. It used two known measures of brightness (irradiation) to calibrate the meter; the sun on a bright day and a 60 W bulb. It was stated that on a bright day in the summer, the irradiation from the sun was 1000 W/$m^2$ and on a clear winter day it was about 800 W/$m^2$.

## Calculating Efficiency

1. To find the power of light hitting the solar cell, you will need to measure exactly how large the surface area of the cell is. Using a ruler, measure the solar cell parts, not the spaces, and figure how many square meters the cell is. Area is length × width. It might be easier to measure length and width in mm and then convert them to meters before multiplying.

2. The solar cell has an area of _____________$m^2$.

3. Using 1000 W/$m^2$ for summer or 800 W/$m^2$ for winter, calculate the watts of power hitting the solar cell. (Irradiation × Area)

Light (irradiated power) = ____________ Watts

4. For the power output of the solar cell, it is necessary to find the MPP Maximum Power Point. This was done in Lab 5 and you can use the value found there. (otherwise read through Lab5 and find the MPP).

Generated Power (MPP) = ____________ Watts

5. Calculate the solar cell's efficiency:

Efficiency = output power (electrical) / input power (light)

6. Multiply the efficiency from step 5 above by 100 to get the percent efficiency of the solar cell

The efficiency of this solar panel is ____________.

# Lab 6 – Calculating Solar Cell Efficiency

## Teacher Notes

This is the final lab on understanding the solar cell. The issue of solar cell efficiency is of great interest to anyone concerned about clean energy. The more efficient solar cells become, the more they will be used as a source of electricity. The best solar cells operate at about 25%. In some places, there is almost unlimited sunlight available, higher efficiency means that more of the sunlight is converted to electricity.

This lab requires students to have done lab 3 and lab 5. The results from those labs are required to determine the solar cells efficiency.

Answers should be somewhere between 8% - 16% efficiency.

Now is a good time for students to do some research into how solar cells and panels are manufactured. The lab manual by Thames & Kosmos that accompanies the Fuel Cell Car & Experiment Kit has good pictures and details of the manufacturing process.

# Lab 7 – Electrolysis of Water

*Based on Experiment 9 & 10 in Thames & Kosmos Fuel Cell Car & Experiment Kit Lab Manual*

Water is a wonderful substance. All of life, as we know it, relies on and is made up of mostly water. As a chemical, it is simple, orderly, and stable. It can be referred to in its chemical formula as $H_2O$, which identifies its components: hydrogen and oxygen.

The **purpose** of this lab is to use an electrical current to separate water into these two components, hydrogen and oxygen. Secondly, you will administer a flame test to see which is the hydrogen and which is the oxygen.

To separate water, an electrical current is used. Usually, we are warned against the dangers of electricity in water, like the warning label on a hair dryer. In this lab, we will use a small current (from the solar cell) so that it will be safe for use in the classroom. **Do not try this with electricity from a wall outlet!** The current there is enough to cause real damage.

**Materials:**

| | |
|---|---|
| Safety glasses | Plastic tub of water (about 10 cm deep) |
| Salt water | Aluminum foil (copper electrodes are better) |
| Solar cell | Wires |
| 2 Test tubes | Wooden splint or long match, and a candle |

Light source (75 W bulb or the sun through a window)

**Predictions**

1. Which electrode (positive or negative) will produce hydrogen?

2. Which electrode will produce oxygen?

3. How could you test a gas to see if it is oxygen?

4. How could you test a gas to see if it is hydrogen?

## Procedure – Part I Electrolysis

1. Begin by making a tub of salt water. You can use a plastic container (even a plastic cup works fine) that is around 10 cm deep. Pour water to three quarters full and add some salt (at least 3 or 4 teaspoons). Stir the water until the salt dissolves. This can take a little time. Be patient.

2. Make 2 electrodes (if your teacher doesn't have some metal ones already). Cut two identical pieces of aluminum foil 10 cm X 10 cm. Fold each of the sheets back and forth like a fan /\/\/\/\. Each bend should be 1 cm. Now you have two thicker pieces of foil that are 1 cm x 10 cm. At 1 cm from one end, fold the top over. These are your electrodes.

3. Connect wires from the solar cell (+ and -) to the electrodes. Be resourceful here, a paper clip might be helpful. Place the electrodes in the water and use the folded top to hang them on the edge of the tub. Set the electrodes about 4-10 cm apart from each other in the water.

4. Now the apparatus is ready to split the water. Follow the electrical charge with your finger. It should go from the solar cell (+) through the wire to the (+) electrode, then through the water to the (-) electrode and then back up the wire to the solar cell (-).

5. If all looks good, set up the 75 W light bulb or the sun through the window onto the solar cell to start the splitting of the water into hydrogen and oxygen.

### Questions

1. Why do you think the salt is added to the water?

2. Why do you think electrodes are used instead of just hanging the wires in the water?

3. How can you tell that the water is being split into hydrogen and oxygen gas?

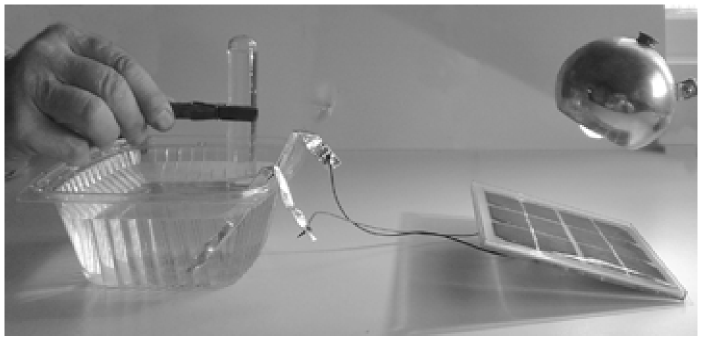


*Figure 7.1: Collecting hydrogen gas*

## Part II – Testing Hydrogen

1. To test a gas, you need to collect a gas. A test tube provides a good method to collect gas. Since gas is less dense than water, it is obvious that the bubbles will rise in the water. Fill a test tube with water in the tub by immersing it and then turn it upside down (with the water still inside it) and move it above the bubbles at one of the electrodes. Make sure the test tube stays full of water, even while it is upside down and sticking out of the water. As the bubbles rise into the test tube, they will push out the water and make a big bubble of gas inside the test tube. See figure 7.1 above.

2. Wait for the test tube to fill with gas.

3. If this is the heavy bubbling electrode (-), it is likely to be hydrogen inside the test tube. To test for hydrogen: a) Put on safety goggles b) light the candle and move it near the water tub c) remove the test tube of gas and bring the opening to the candle's flame while tilting it slightly to the side.

4. If the gas is hydrogen, you will hear a small pop or a puff as the hydrogen burns up. To try the test again, you will need to go back to step 1 and reload the test tube with water and then with gas bubbles.

5. Did you hear a small pop? If not, try it again and move the test tube to the flame a little faster this time. Hydrogen is lighter than air and will stay inside the test tube for a little while as long as it is kept upside down.

## Part III – Testing Oxygen

1. The oxygen electrode seems to produce bubbles much slower and if you look at the aluminum after a while, it is all corroded and broken into pieces. This is due to oxidation or the "rusting" of the aluminum in the presence of oxygen. If you teacher has some copper electrodes, it should work easier to get the bubbles flowing.

2. Using a test tube again, collect the gas from the electrode as you did with the hydrogen above. When you have a full test tube of gas (this may take a while), you are ready to test for oxygen.

3. The oxygen test is called the glowing splint test. To perform it, you will need safety glasses and a small stick of wood or a long wooden match. To test for oxygen: a) light the wood or match and get a good flame b) blow out the flame and see that the stick is still glowing a bit c) insert the glowing stick into the mouth of the test tube – all the way inside.

4. If the test tube is full of oxygen, the stick should start burning again.

5. Everything needs oxygen to burn. Our air is about 23% oxygen. When the glowing stick is immersed into 100% oxygen, it is so good for burning that it starts burning right up again.

6. Perform the hydrogen tests two or three times. It takes so long to collect the oxygen that one test should be enough.

## Questions

1. In your own words, write step-by-step directions for testing a gas to see if it is hydrogen.

2. In your own words, write step-by-step directions for testing a gas to see if it is oxygen.

3. What are some uses of hydrogen?

4. What are some uses of oxygen?

5. Hydrogen can be burned as a fuel and can be used to run a fuel cell. What is a major concern with running cars on hydrogen?

6. What is the chemical formula for water? __________

# Lab 7 – Electrolysis of Water

## Teacher Notes and Answers to Questions

**It is important to stress some safety for this lab. Require students to wear safety goggles when using open flames. It is also good to discuss the safety issue with electricity and water. The current from the solar cell is safe, but the current from a wall outlet could be fatal. Matches and candles need to be monitored to reduce "playing with fire." There should be no second chances for playing with fire. The student is removed from the lab and sits alone for the rest of the class time.**

This is a classic science lab: the electrolysis of water. You can buy an expensive, big glass apparatus to use for a classroom demonstration. It seems that students prefer this lab's hands-on option using the solar cell. Students are right there watching and touching and very interested in the whole process. Allowing the students to actually do the tests for the gases greatly increases their interest in this lab.

Depending upon what is available in your classroom, the material can be upgraded to get better results, especially the electrodes. Longer electrodes that will bend up into the test tubes will increase the speed of gas collection. While students are waiting, they can answer the questions on the lab.

### Predictions (accept student's guesses at this point)

1. Negative electrode
2. Positive electrode
3. Glowing splint test
4. Flame test will pop

### Electrolysis

Salt water is safer than acid water, but the salt must be dissolved to produce any ions. It would be good to mention to the students that the moving of electrons allows current to flow through the metal wires, but the moving of ions (Na+ and Cl-) in the water allow the current to flow there.

This might be a good time to talk about electrolytes (liquids that will conduct an electrical current). Set up a circuit with a bulb to test different substances. Pure distilled water will not conduct electricity due to a lack of ions.

### Answers to Questions

1. The salt releases two ions Na+ and Cl-. These ions are essential for current to flow.
2. The electrodes have more surface area to contact more water molecules at a time.
3. The formation of bubbles around the electrodes indicates gas production.

### Testing gases

It can be difficult to let middle school students test these gases on their own. **Share the safety concerns with the students and really expect them to take it seriously, they will usually do okay. Do not tolerate playing around with fire and immediately have them sit out the lab if they are seen playing with fire.**

Another option is to hold the matches and candle so that students need to call the teacher over to observe as they perform their gas tests.

If there is not enough oxygen produced, either run the electrodes for half the day or wait until the hydrogen fuel cell is operating in later experiments. The fuel cell will produce great quantities of both gases very quickly.

### Answers to Questions

1. Answers will vary, but should be close to instructions
2. Same as above
3. Rocket fuel, fuel cells, fusion, blimps before the Hindenburg exploded in New Jersey in 1937 (See page 76 in the Thames & Kosmos lab manual)
4. Respiration, burning anything (combustion), rocket fuel
5. Storage-cars with tank of hydrogen could explode on impact
6. $H_2O$

# Supplemental Worksheets

## for Students to Use with Experiments 11-33 from the Thames & Kosmos Fuel Cell Car & Experiment Kit Lab Manual

### Course Outline, Section III (C & D)

*These experiments require the car, fuel cell, solar cell, and lab manual from the Thames & Kosmos Fuel Cell Car & Experiment Kit. Using the instructions from the lab manual, these worksheets are to help students collect data and make the calculations.*

*(See Student Objectives, Instructional Strategies, and the Course Outline in this document for further clarification)*

## Supplemental Worksheet for Experiment 11

*Thames & Kosmos Fuel Cell Car & Experiment Kit Lab Manual - Page 54*

### Calibration of the Gas Tanks

*(Results to be used later with experiment 15)*

The kit comes with a double gas tank, one for hydrogen and one for oxygen. The stickers for the gas tanks are not accurate. The purpose of this experiment is to make a table that can be used to adjust the sticker reading to the actual gas volume.

First of all, follow the directions in experiment 11 (T&K lab manual, pg. 55) on the cutting of the hose and how to use a syringe.

Then:

1. Fill the syringe with water and remove the bubble at the end. Push the plunger so that it is exactly on one of the ml marks.

2. Be sure the stickers are on the gas tanks. The big tank should read "hydrogen" and the small tank, "oxygen." Each tank should also have a grid on the side with the 0 on the small end of the tank. Turn the tanks small side down and put some tape over the small end of the tank. (For better accuracy, put a piece of hose in the tank and press it down into the hole to simulate the tube that will be there when collecting gas later). See T&K lab manual pg. 56 for pictures.

3. Using the ml reading on the syringe, squirt exactly 3 ml of water into each of the tanks. Look at the tanks and read what the gridlines on the tanks show for the ml of water in the tanks. Fill out the table on the next page for 3 ml of hydrogen and for 3 ml of oxygen. Now, add another 3 ml (exactly) from the syringe. Enter the tank readings from the sides of the hydrogen and oxygen tanks. Continue to add water until the tank is full or the table is filled.

| Amount of water added | Hydrogen tank reading | Oxygen tank reading |
|---|---|---|
| 3 ml | | |
| 6 ml | | |
| 9 ml | | |
| 12 ml | | |
| 15 ml | | |
| 18 ml | | |
| 21 ml | | |
| 24 ml | | |

4. You must keep the table above so that you can look at it later to find out how much gas is in the gas tanks. If the oxygen tank reads 18, then look at the table under oxygen tank reading until you are closest to 18, then look way to the left and see how many ml equates with an oxygen tank reading of 18.

If the amounts of water are within 1 ml of the tank readings, there is no need for this chart. In that case, go ahead and use the sticker readings on the tanks.

## Supplemental Worksheet for Experiment 15

*Thames & Kosmos Fuel Cell Car & Experiment Kit Lab Manual - Page 61*

### Quantitative Measurement of Gas Generation Rates

*(For more accurate results, do experiment 11 first)*
*Experiment 11 - explained how to adjust the tank readings*
*Experiment 12 - explained how to fill the fuel cell with water*
*Experiment 13 - explained how to use the fuel cell to split water into $H_2$ and $O_2$*
*Experiment 14 - explained how to test for hydrogen and oxygen*

The **purpose** of this experiment is to measure the rate that hydrogen and oxygen gas are produced by the fuel cell.

1. Follow the assembly procedures as explained and illustrated in the T&K lab manual for experiment 15 (pgs. 61 & 62). To collect the following data you must have the gas tanks in the car with the tubes pressed in and connected to the fuel cell. The fuel cell is filled with distilled water. Make sure you have double checked all wires and connections as shown in Fig. 95 (pg. 62) in the lab manual.

2. In this experiment, you will need a timer and someone to watch the oxygen tank and someone to watch the hydrogen tank. The tank watchers can also write down their data or have someone else record the results in the data table below. If you don't have enough people, just do the hydrogen tank first and then refill everything and then do the oxygen tank second.

3. The timer starts timing when the first bubbles enter the tanks. The recorders enter the data under the tank reading column for either hydrogen or oxygen. Be ready as soon as the light shines on the solar panel.

**Hydrogen Data Table**

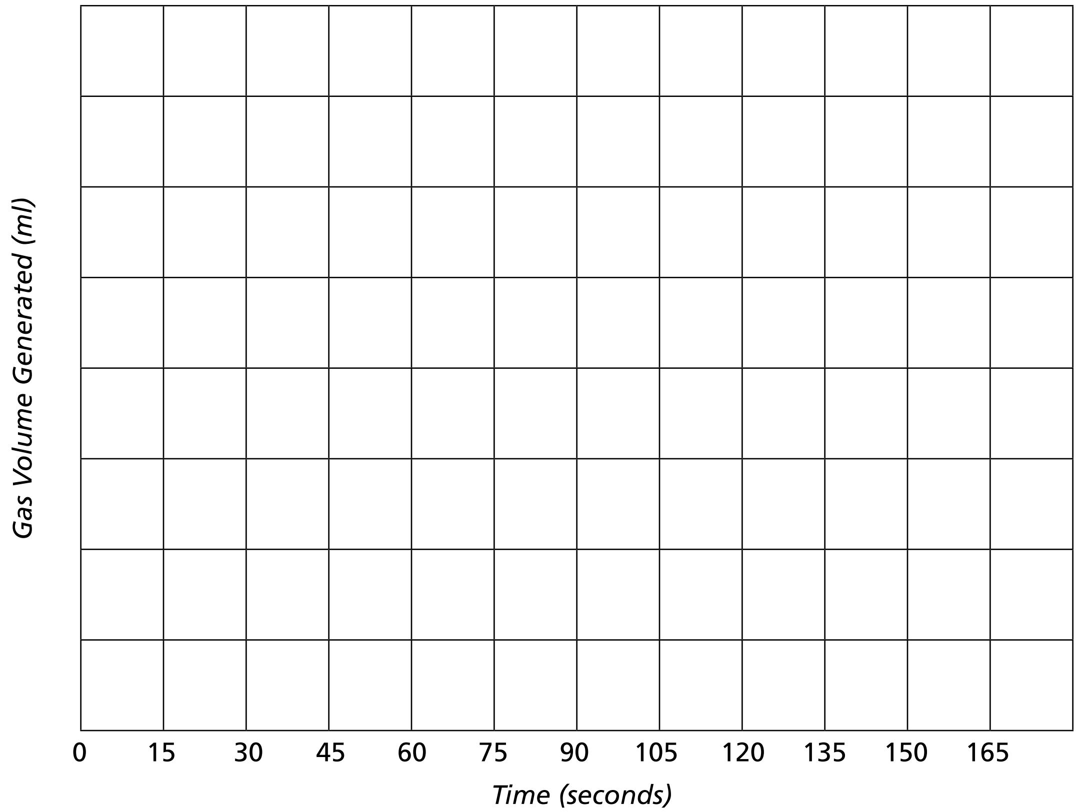
| Time (sec.) | Hydrogen Tank reading | Corrected value (ml) | Time (sec.) | Hydrogen Tank reading | Corrected value (ml) |
|---|---|---|---|---|---|
| 15 | | | 105 | | |
| 30 | | | 120 | | |
| 45 | | | 135 | | |
| 60 | | | 150 | | |
| 75 | | | 165 | | |
| 90 | | | 180 | | |

**Oxygen Data Table**

| Time (sec) | Oxygen Tank reading | Corrected value (ml) | Time (sec) | Oxygen Tank reading | Corrected value (ml) |
|---|---|---|---|---|---|
| 15 | | | 105 | | |
| 30 | | | 120 | | |
| 45 | | | 135 | | |
| 60 | | | 150 | | |
| 75 | | | 165 | | |
| 90 | | | 180 | | |

4. After all of the tank readings have been recorded, take out the calibration table from experiment 11 and convert each of the tank readings to milliliters (ml). Enter the ml values into the tables above.

5. Now graph the data on the next page. Use two colors: one color for hydrogen and a different color for oxygen. Time in seconds is on the x-axis and gas volume in milliliters (ml) is on the y-axis.




6. After all of the data points have been placed on the graph, draw a straight line through the points of each color. (a best fit line)

7. The slope of each line will represent the rate of gas production. Remember that the slope of a line is the rise divided by the run. Using the values on the x and y axis, calculate the slope of the line for hydrogen and oxygen.

Slope for Hydrogen = ______ ml/sec.  Slope for Oxygen = ______ ml/sec.

(Save this value for experiment 17)

8. Check to see if the rate for hydrogen is about double that of oxygen.
Explain why this might be so.

# Supplemental Worksheet for Experiment 16

*Thames & Kosmos Fuel Cell Car & Experiment Kit Lab Manual-Page 65*

## Measuring Current and Voltage during Fuel Cell Electrolysis

Experiment 16 shows you how to connect the multimeter to measure voltage (T&K fig. 100, page 64) and to measure current (T&K fig. 101, pg 65).

Follow the directions carefully and take readings for voltage and current while the fuel cell is producing hydrogen and oxygen. Remember to turn off the light to the solar cell (or cover it with a piece of cardboard) to stop the electrolysis when you switch from measuring voltage to measuring current.

Voltage reading for fuel cell electrolysis = _______Volts

Current reading for fuel cell electrolysis = _______ Amps (not mA)

How do these readings compare to the no-load voltage and current that was measured for the solar cell back in T&K experiment 3 (Lab 2)? Are they higher or lower? Why?

# Supplemental Worksheet for Experiment 17

*Thames & Kosmos Fuel Cell Car & Experiment Kit Lab Manual - Page 66*

## Efficiency of Water Electrolysis

Experiment 17 determines the efficiency of the water electrolysis using the fuel cell. It requires data from experiments 15 and 16.

Efficiency is a measure of how good a fuel cell is at storing energy (from the solar cell) as hydrogen gas. 100% would mean that all of the electrical energy from the solar cell produces a chemical change resulting in hydrogen gas. That would be impossible.

To determine efficiency, you need the power produced by the fuel cell divided by the power put into the fuel cell (times 100). This is all explained in detail in the green section of T&K lab manual experiment 17.

**In short:**
The chemical equation for electrolysis is $2H_2 + O_2 \rightarrow 2\ H_2O$

To use this chemical equation, the rate of hydrogen production must be converted from ml/sec to moles/sec.

The energy in a mole of hydrogen gas is about 237,000 joules.

**Output power** = rate of hydrogen production (from experiment 15) ______ml/sec X

0.00004166 mol/ml $H_2$ X 237,000 J/ mol =_______J/sec or Watts

**Input power** = _____ Volts X _____ Amps (from experiment 16) = ______ Watts

**Efficiency**

Output power / Input power = _______ X 100 = ______ % Efficiency

This tells you how good the fuel cell is at storing electricity as hydrogen gas.

# Supplemental Worksheet for Experiment 18

*Thames & Kosmos Fuel Cell Car & Experiment Kit Lab Manual - Page 68*

## Influence of Light and Shade on Water Splitting

*(Difficult and time consuming; advanced level experiment)*

The purpose of experiment 18 is to measure how changing the light on the panel affects the rate of gas production. Using the fuel cell and the solar cell, this experiment tests to see how the rate of hydrogen gas production changes with a change in light intensity. Changing light intensity can be done approximately by changing the distance between the light source and solar cell. For more accuracy, you can use some data calculated earlier. (See box, or skip to step 1 below)

> Back in lab 3 (T&K lab manual experiment 4), you determined a calibration value to convert the current produced by the solar cell into a value for brightness ($W/m^2$). It would be most accurate to set up the soar panel and, using the methods learned in lab 3 (T&K lab manual experiment 4), measure the current and calculate the intensity of light for the panel at 15 cm, 20 cm, 30 cm, 40 cm from the light source (this should be done in a darkened room). Ask your teacher if you have time to measure intensity, otherwise just use the distance as a measure of changing brightness.

`

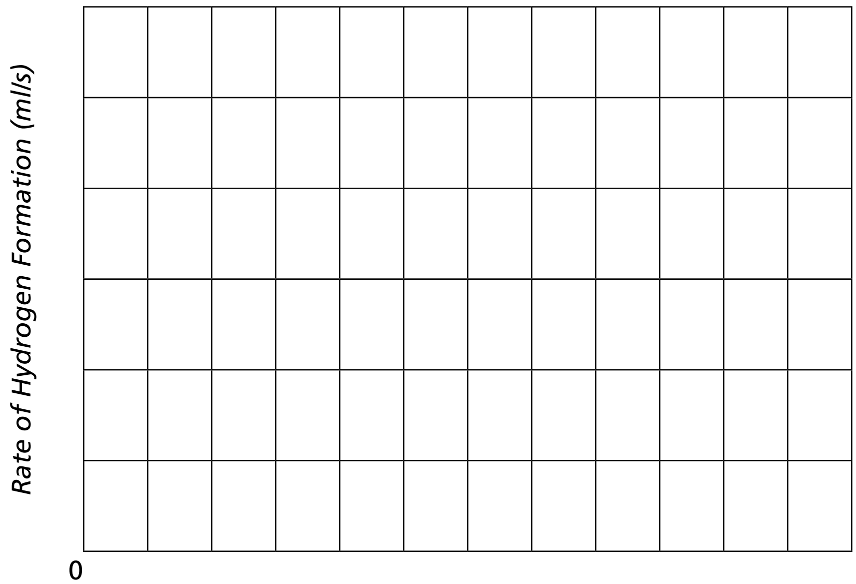
1. Enter the data for distance (and intensity, if you have it) in the data table below and set up the solar cell and fuel cell to generate hydrogen gas again. Read through the directions in experiment 15 and be sure to use distilled water in the fuel cell. (Diagram on T&K lab manual page 62).

2. To determine the rate of hydrogen production, you will first need to set up the light at 20 cm from the solar cell in the darkened room. Have a timer ready and time how many seconds it takes to produce 6 ml of hydrogen gas. (If it works to collect 3 ml of hydrogen at a time, check with your teacher and change column 3 below).

| Distance | Light Intensity | ml of Hydrogen | Time (sec) | Rate (ml/sec) |
|---|---|---|---|---|
| 15 cm | $W/m^2$ | 6 ml | | |
| 20 cm | $W/m^2$ | 6 ml | | |
| 30 cm | $W/m^2$ | 6 ml | | |
| 40 cm | $W/m^2$ | 6 ml | | |

3. Measure the times for the rest of the distances. Calculate the rate by dividing ml of hydrogen by time for each of the distances.

4. Using the graph on the next page, determine the range for the x-axis (distance or intensity), label the axis, plot the four points from the graph, and draw a best fit line for the data.




**Questions**

1. Looking at the graph above, how does light intensity (or distance to the lamp) relate to the rate of hydrogen formation? Explain as best you can.

2. While the solar cell / fuel cell is producing hydrogen, cover a part (about ¼) of the solar panel. What happens to the bubbles? Do they slow down or stop completely? What could be a reason for this?

3. If your solar panel is actually an assembly of more than one solar cell (as the one provided in the kit), answer the following two questions.

   a. Do you think the individual cells are in series or parallel? Explain.

   b. If the fuel cell only needs about ½ of the voltage that the solar panel can produce, draw an electrical diagram for two possible panel arrangements that would allow the fuel cell to continue to work with part of it covered.

# Supplemental Worksheet for Experiment 19

*Thames & Kosmos Fuel Cell Car & Experiment Kit Lab Manual - Page 70*

## Splitting All of the Water in the Fuel Cell

This experiment will take a long time (6 - 8 hours), but the results are needed for experiment 20. The purpose of this experiment is to again determine the rate of hydrogen formation and to record how long it takes to use up all of the water in the fuel cell.

1. Set up the solar panel-fuel cell apparatus to split water again, complete with a multimeter to measure voltage. (See experiment 15 for cell set-up and fig. 100 on pg. 64 for voltage measuring diagram).

2. Get ready with a stop watch to start the timer as soon as bubbles are forming. Turn on the lamp to start the formation of hydrogen and record the time it takes to produce 6 ml, 12 ml, 18 ml, & 24 ml of hydrogen. When the voltage is stable (not changing), record that too. Do not stop the fuel cell!

Stable Voltage = _______ Volts

| Amount of hydrogen | Time (sec.) | Rate of production |
|---|---|---|
| 6 ml | | 6 ml / time = |
| 12 ml | | 12 ml / time = |
| 18 ml | | 18 ml / time = |
| 24 ml | | 24 ml / time = |
| Find the average rate of production; add together and divide by 4 = | | |

3. Let the gas just bubble out of the tanks and keep the fuel cell going for a long while. Check on it every 20 minutes or so to see if either the bubbles slow down or the voltage increases.

4. As soon as the bubbles slow down or the voltage increases significantly, stop the timer and write down the total time to empty the fuel cell of water.

Total time to empty fuel cell = _______ sec.

5. Calculate the amount of gas produced from the fuel cell. To do this, take the average rate from the table above (ml/sec) times the total time (sec) = ml.

# Supplemental Worksheet for Experiment 20

*Thames & Kosmos Fuel Cell Car & Experiment Kit Lab Manual - Page 71*

## How Much Water Was There in the Fuel Cell?

This experiment is a continuation of experiment 19 and relies upon the data collected there. You will be working out some calculations, but not collecting any new data. The purpose of this experiment is to determine the amount of water in the fuel cell.

1. Look at the results from experiment 19 and enter the total amount of gas produced for the fuel cell in the space below.

Total amount of gas produced by the fuel cell = _______ ml.

2. Chemistry tells us that 1 ml of hydrogen = 1/24,000 moles of hydrogen gas ($H_2$). 1/24,000 = 0.000041667. Calculate the number of moles of gas that were produced by the fuel cell. Total gas (ml) X 0.000041667 =

______ moles of hydrogen gas ($H_2$).

3. The chemical equation for the formation of hydrogen is:

$H_2O \rightarrow H_2 + O_2$ (unbalanced equation)

Balance the equation above.

4. For 1 mole of water, how many moles of hydrogen are formed? ____

5. In question 2, we determined the number of moles of hydrogen gas formed. Using the information above, how many moles of water were used to produce that hydrogen?

6. 1 mole of water is the same as 18 ml of water. Convert the number of moles of water into ml of water by multiplying the moles of water by 18 ml/mole. What do you get?

_____ ml of water in a full fuel cell

# Supplemental Worksheet for Experiment 21

*Thames & Kosmos Fuel Cell Car & Experiment Kit Lab Manual - Page 72*

## Solar Splitting of Water

**Is it better than with the lamp?**

So far, you have been using a light bulb to provide the light for the production of hydrogen. Will the sun provide a better source of energy? Back in lab 3 (experiments 3 & 4), the solar panel was used to compare the brightness between the sun and a lamp. Which is brighter?

The purpose of this experiment is to use data collected in previous experiments to determine if the sun is more efficient than a lamp at producing hydrogen gas

1. This experiment will require a nice, sunny day. Cut a piece of cardboard to cover the solar cell that can be used as an on/off switch for the solar cell.

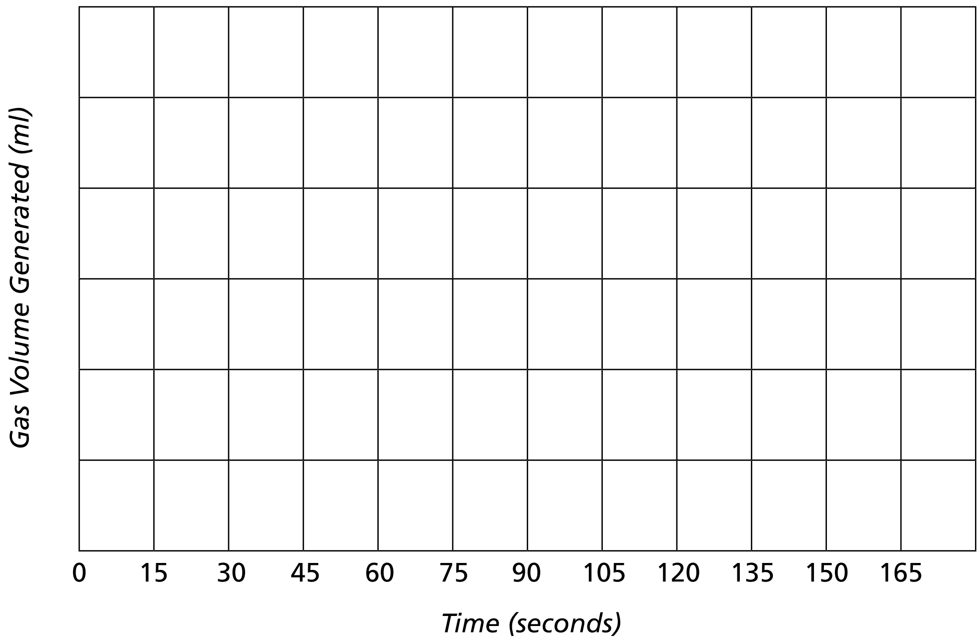
2. Look back at experiment 15. Configure the solar cell-fuel cell apparatus so that it will produce the gasses. Use the table below and graph (next page) to collect the data necessary to determine the rate of hydrogen gas production with the sun as the source of light. Use cardboard as an on-off switch.

## Hydrogen Data Table

| Time (sec.) | Hydrogen Tank reading | Corrected value (ml) | Time (sec.) | Hydrogen Tank reading | Corrected value (ml) |
|---|---|---|---|---|---|
| 15 | | | 105 | | |
| 30 | | | 120 | | |
| 45 | | | 135 | | |
| 60 | | | 150 | | |
| 75 | | | 165 | | |
| 90 | | | 180 | | |

3. Look back at experiment 16. Configure the solar cell, fuel cell apparatus with a multimeter to measure the current and voltage while gas is being produced. Look carefully at the diagrams on pgs. 64 and 65 to see how the multimeter is connected for each of the measurements. Voltage is measured in parallel and current is measured in series.

_____ Watts = volts × amps = fuel cell power used during electrolysis




_____ ml/sec = the rate of hydrogen gas production with the sun

4. Using the worksheets for experiments 16 & 17, you can find the power output in the formation of hydrogen gas, the power input from above, and the efficiency of the electrolysis using the sun instead of a light bulb.

Efficiency of the fuel cell using the sun = _____ %

5. Finally, compare the differences of brightness between the bulb and the sun as measured back in lab 3 (experiments 3 & 4). Compare the rates of hydrogen production (experiment 15) between the light bulb and the sun. Compare the efficiency of the fuel cell between the light bulb and the sun. Write a paragraph about your findings below.

# Supplemental Worksheet for Experiment 22

*Thames & Kosmos Fuel Cell Car & Experiment Kit Lab Manual - Page 72*

## How Long Does the Gas Remain in the Tank?

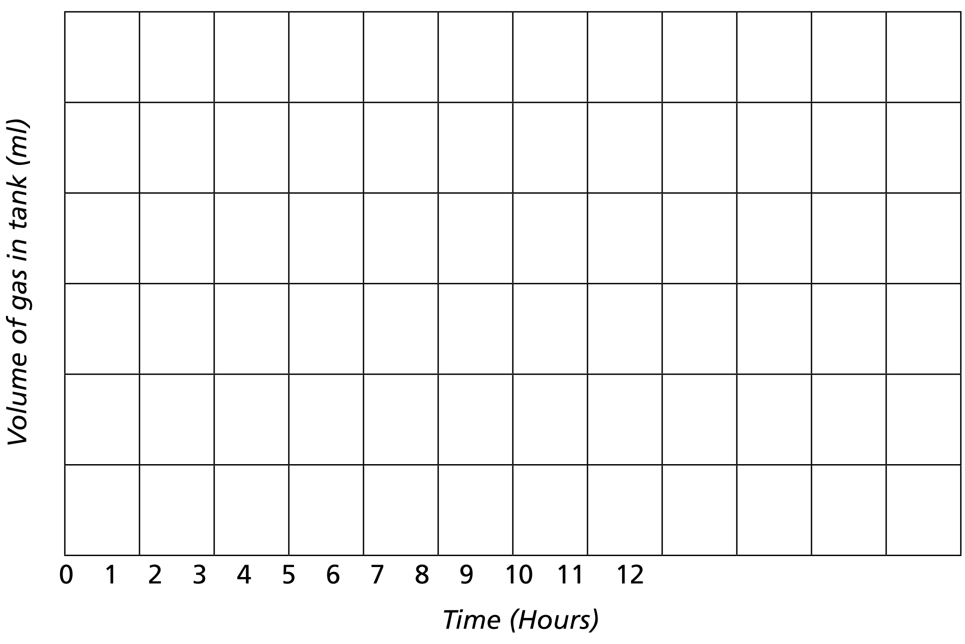
The purpose of this experiment is to measure the rate at which the gases leave the storage containers. If this were a real car, it would be essential to know how long you could store gas in the vehicle once the tanks were full.

1. Fill the fuel cell with distilled water and connect the solar panel to produce hydrogen gas. Run the fuel cell until the gas tanks are completely full and bubbles are starting to go up the outsides (explained in experiment 15).

2. Disconnect the solar panel so that no more gas is being produced. At the same time, note the time and enter it in the table below at 0 hours elapsed.

3. Continue to check the tanks every two hours. Enter the amount of gas in the tanks (convert to ml using the table from experiment 11) in the table. Leave the tanks overnight and record the time and amount in each tank the next morning.

| Time | Hours elapsed | Amount of Hydrogen | Amount of Oxygen |
|---|---|---|---|
| | 0 hours | Full Tank | Full Tank |
| | 2 hours | | |
| | 4 hours | | |
| | 6 hours | | |
| | | | |




4. Record the data points above, using different colors for each gas. Where does the gas go? How could you reduce this loss?

## Supplemental Worksheet for Experiment 27

*Thames & Kosmos Fuel Cell Car & Experiment Kit Lab Manual - Page 83*

### Range of the Car (and Average Speed)

*Experiment 23 – showed how to get the car to move forward*
*Experiment 24 – showed how to use the motor as a generator*
*Experiment 25 – showed how the motor could store energy in the fuel cell*
*Experiment 26 – used the motor to generate voltage*

Now that you have the car working, the purpose of this experiment is to see how far and how fast it will go. It will be difficult to measure a straight line to see how far it goes. Instead, you can have it run around in laps.

1. Turn the wheels so that the car will go in a circle (it may be helpful to tighten the set screw). Do not make the circle too small, but make sure it won't run into things. Fill the gas tanks and reconnect the motor. Start timing the car and counting the laps.

How many laps did the car run? _______ laps

How long did it take? _______ seconds

2. While the car is running around in circles, put some tape on the ground right under where the car runs to record the size of the circle. When the car has stopped, use a meter stick to measure the diameter of the circle.

Diameter of the circle = _______ cm / 100 = _____ meters

3. The circumference of the circle will equal 1 lap.

Circumference = $\pi$ (3.14) × diameter = _____ meters/ lap

4. Now multiply the distance for one lap times the total number of laps the car traveled. This is the range of the car; how far the car can go on a full tank of gas.

Range = _____ meters

5. The average speed of the car can be calculated in meters/second. Take the range (meters) and divide by the total time (seconds).

Average speed = ______ m/s

## Supplemental Worksheet for Experiment 30

*Thames & Kosmos Fuel Cell Car & Experiment Kit Lab Manual - Page 86*

### What is the Power of the Crane?

*Experiment 28 – determined if the fuel cell can run on oxygen from the air*
*Experiment 29 – set up the crane*

Using the crane assembly from experiment 29, the purpose of this experiment is to calculate the power of the crane. Remember that power is a measure of how quickly energy is used or produced and it is measured in Watts.

Power = Energy/Time

To calculate the power of the crane, you will need to measure how much potential energy the crane gives to a mass, and then time how long it takes to lift the mass to that height.

1. Remember that potential energy of an object on the ground is 0 joules. An object at any height has a potential energy equal to the mass × gravity (standard gravity, 9.81 $m/s^2$) × height (meters).
Or potential energy = mgh.

    Connect a 100 g mass to the crane.

2. Set up the crane to pull the mass up to a height of 2 meters. Get your timer ready and start the motor. Time how long it takes for the crane to pull up the mass and record the values below:

    Height = _____ meters Time = _____ seconds

3. Potential energy = mgh = mass × gravity × height = grams × 9.81 × meters

    Calculate the potential energy given to the mass by the crane.

4. Power of the crane = Potential energy / Time for mass to go up. Find the power of the crane.

    Power of the crane = _____ watts

# Supplemental Worksheet for Experiment 31

*Thames and Kosmos Fuel Cell Car & Experiment Kit Lab Manual - Page 87*

## Total Energy Delivered by the Crane

The purpose of this experiment is to measure how much work the crane can do on one tank of hydrogen.

1. Starting with full gas tanks, count how many times the crane can lift the mass to the same height as above.
2. Once the mass is at the height, turn off the motor and slowly pull the string back down.
3. How many times did the mass go up the height? _______ Times
4. The total work equals the energy (potential energy from experiment 30) × (number of times) = _____ Joules

# Supplemental Worksheet for Experiment 32

*Thames & Kosmos Fuel Cell Car & Experiment Kit Lab Manual - Page 88*

## Measuring Voltage and Current of the Fuel Cell

Our final goal (experiment 33) is to find the efficiency of the fuel cell as it is used to produce mechanical energy. The purpose of experiment 32 is to measure the current and voltage while the fuel cell is “working” and while it is not (no-load).

1. Read the directions for experiment 32 in the T&K lab manual and refer to fig. 144 on T&K lab manual pg. 88 to set up the fuel cell and multimeter. This is so you can collect the no-load voltage.

Measured no-load voltage = _____ mV

2. Do the same for the operating voltage with the motor running as shown in fig. 145 on page 89. Wait until the voltage settles down to a steady reading.

Measured operating voltage = _____ mV

3. Change the wiring so that you can measure the short circuit current. Read the directions and follow the diagram on fig. 147 on pg. 89.

Measured short circuit current = _____ A

# Supplemental Worksheet for Experiment 33

*Thames & Kosmos Fuel Cell Car & Experiment Kit Lab Manual - Page 90*

## Efficiency of the Fuel Cell

The purpose of this experiment is to determine the efficiency of the fuel cell and to compare that efficiency to other power generating devices.

Remember that efficiency shows how much power comes out of a device compared to how much power goes into the device. You will use the equation "power out / power in."

With the fuel cell there are two conversions that take place: 1) changing the electricity from the solar cell into stored hydrogen, and 2) changing the stored hydrogen into electrical energy.

The overall efficiency of the fuel cell will combine both steps and will use a unique formula to show the efficiency. The result will not be exact, but it will be close enough for science class.

Efficiency = operating voltage / electrolysis voltage × 100.

Use the operating voltage from experiment 32 and the electrolysis voltage from experiment 16 to calculate the total efficiency of your fuel cell.

Operating voltage (experiment 32) = ______ volts

Electrolysis voltage (experiment 16) = ______ volts

Determine the efficiency of your fuel cell.

Take a look at the efficiencies of other motors on the graph in the T&K lab manual on pg. 91. Do you see why scientists are so interested in fuel cells? Explain.

## Assessment Strategies

Section one is mostly vocabulary and concepts of electricity. It will be helpful to give quizzes after each topic or to cover the whole section and then give a section test on the topic. Most textbooks will have a sample test, assignments, and quizzes to assist in the assessment of this section. In the research classroom for this project, a modified test from a textbook publisher was used. Modifications included drawing and interpreting electrical schematic drawings.

Section two involves mostly vocabulary and concepts as well. It will require many of the same types of assessment as section one; quizzes, worksheets, test.

Assessment of the labs can be done by checking through the lab and assigning points for the completion of the questions, tables, and graphs. For instance, completing labs one through seven could have a value of 20 points. Each completed worksheet could have a value of 10 points. Lab groups of students can present the previous day's lab results and answers for the questions. Each group can take a turn at presenting what they have learned. These "lab recaps" will help to prepare students for the presentations at the end of the course.

The research and presentation section of the course will require a rubric for the time spent researching, outlining, preparing a visual aid and presenting the information. A possible rubric is on the following page. As the final project, this could also represent the final exam grade for the course.

**8th Grade Physical Science – Research and Speech Rubric for ______________________**

Topic ________________________________

Preparation – 20 pts __________

-use of class time
-writing notes from computer
-staying on task
-turned in on time

Organization – 20 pts __________

-outline of information
-clear and complete
-detailed enough to follow

Content – 20 pts __________

-stay on topic
-enough material to explain topic
-good information

Visual Aid – 20 pts __________

-construction and quality
-useful in the presentation

Speech – 20 pts __________

-voice (loud enough, clear)
-posture
-interesting and enthusiasm
-involvement of each student (if working in groups)

Listening (points deducted) – ________

-pay attention to others' presentations

Total points __________ /100

## ITEA Standards Incorporated into the Course

Although this course is designed to be used in a physical science classroom, it could easily be adapted for use in a technology classroom as well. As this field project is under the advisement of technology education, it seems prudent to apply the content to the ITEA (International Technology Education Association) Standards for Technological Literacy: Content for the study of Technology as well as NSTA Standards (following).

The applied content standards are as follows:

1. Standard 1 – The Scope of Technology
   a. Students should learn that "new products and systems can be developed to solve problems." (International Technology Education Association [ITEA], 2000, p. 27)
      i. Students will discuss the issues and problems of transportation and possible solutions. They will see that new technologies, such as fuel cells, give possible solutions to present day energy problems.

2. Standard 3 – Relationships Among Technology and Other Fields
   a. Students should learn that "technological systems often interact with one another." (ITEA 2000)
      i. In the labs and experiments, students will see the interaction between the solar cell and the fuel cell. The fuel cell could run on a battery or another power source, but it does rely upon some other technological system for its operation.
      ii. As students discuss the variety of energy transfers, they will see the importance of different technological systems working together in providing energy for today's society.
   b. "A product, system, or environment developed for one setting may be applied to another setting." (ITEA 2000)
      i. Students will see that solar cells developed by the space industry can now be used in energy for the grid, individual homes, and possibly even cars in the future.
      ii. Students will see that fuel cells developed in science labs years ago are now considered for use in generators and vehicles.
   c. "Knowledge gained from other fields of study has a direct effect on the development of technological products and systems." (ITEA 2000)
      i. The whole focus here is to incorporate both science and technology. With the calculations involved, there is also the mathematic component. Ending the course with the research and presentation will include communication and speech. All of the fields together combine to give the students a depth of understanding often lacking in a typical science course.

3. Standard 6 – Impact of Society on Technology
   a. Students will learn about the dynamics between "society and the acceptance and use of products and s ystems." (ITEA 2000)
      i. The idea of a hydrogen fuel car ever making it to production depends upon whether or not such a technology can work. And secondly, how does it "accord with economic, political, environmental and cultural concerns". Students need to see that a working product is only half of the success of a new product.

4. Standard 8 – Attributes of Design
   a. Students will learn that there is "no perfect design and every technology has both criteria and constraints." (ITEA 2000)
      i. The class discussion and the final papers will spend time looking at the pros and cons of fuel cell technologies.
      ii. Many of the experiments are using quantitative research to show the abilities and limitations of both the fuel cell and the solar cell.

5. Standard 12 – Use and Maintain Products and Systems
   a. Students will be able to "use information provided in manuals to see and understand how things work." (ITEA 2000)
      i. Working with the fuel cells, students will be using the Thames & Kosmos Lab Manual with its information as they explore the workings of the fuel cell.
   b. Students will learn to "use calculators in various applications" (and other tools as well). (ITEA 2000)
      i. Students will be using calculators as well as multimeters, tables, and graphs to learn more about solar cells and fuel cells.

6. Standard 13 – Assess the Impact of Products and Systems
   a. Students will be able to "use instruments to gather data." (ITEA 2000)
      i. This is done with the multimeter.
   b. Students will learn to "use data collected to analyze and identify the positive and negative effects of a technology." (ITEA 2000)
      i. The use of tables and graphs to determine slopes as rates of change all contribute to the understanding and analysis of the fuel cell and its feasibility as a vehicle energy source.

7. Standard 16 – Energy and Power Technologies
   a. Students will learn that "energy is the capacity to do work." (ITEA 2000)
      i. This will be discussed in the initial part of the course.
   b. Students will learn that "energy can be used to do work, using many processes." (ITEA 2000)
      i. Looking at the notes in the course outline, it is clear that the definitions of both work and energy are discussed.
   c. Students will learn about power and the "efficiencies of energy use in our environment." (ITEA 2000)
      i. Students will be calculating the power of both the solar cell and the fuel cells.
      ii. Students will be calculating the efficiencies of both the solar cell and the fuel cell (lab 6 & experiment 33).

8. Standard 18 – Transportation Technologies
   a. Students will be better equipped to "select, use, and understand transportation technologies." (ITEA 2000)
      i. The kit from Thames & Kosmos is a fuel cell vehicle kit. The whole focus of the experiments is for students to better understand the idea of using a fuel cell to power a car with only water and sunlight as the energy sources. Can this be done? Transportation and the feasibility of fuel cell cars is the application of this course on electricity and energy transfer.

*Standards taken from Standards for Technological Literacy: Content for the Study of Technology (2000) written and published by the International Technology Education Association (ITEA).*

## NSTA Standards Incorporated into the Course

This course is designed to be used in a middle school physical science classroom. The NSTA (National Science Teachers Association) has published the Science Content Standards to change the emphasis of teaching science in America. This course tries to incorporate some of those changes. One change mentioned is to reduce the "studying of subject matter for its own sake" and instead to "learn the subject in the context of inquiry and technology". In accordance with the desires of NSTA, this course will also focus students into "analyzing science questions rather than trying to verify science content". The labs and experiments will require "extended periods of time instead of confining the activities to one class period". It is also expected that students will be applying the content "within a realistic context" and will require students to "develop manipulation, cognitive, and procedural skills" (National Committee on Science Education Standards and Assessment [NCSESA], 1996, p. 113). The direct application of the NSTA content standards for middle school (grades 5-8) are described below:

I. Content Standard A - Science as Inquiry
   a. Developing students' ability to do and understanding about science inquiry
      i. Students will be learning data collection procedures while using the multimeter to gather data and tables to organize data
      ii. Students will be learning the language of science as they develop spreadsheets and graph results for analysis and interpretation of data.
      iii. By requiring groups to present lab findings the day after completion, students will receive practice in communicating scientific procedures and explanations.
      iv. Many of the experiments will require mathematical applications.
      v. The multimeters provide a unique use of technology to collect data for analysis.

II. Content Standard B – Physical Science
   a. Developing students' understanding of transfer of energy
      i. The course content will include an overview of many kinds of energy transfer, but the labs will

allow students to experience and explore energy transfers between light and electricity, electricity and chemical, chemical and electrical, electrical and mechanical.

ii. Students will build electrical circuits and show energy as it relates to light, chemical changes, and electricity.

iii. Students will clearly experience the influence of the sun's energy and the potential it provides in the transfer to electricity.

III. Content Standard E – Science and Technology

a. Developing students' abilities and understandings about science and technology.

i. Class discussion and introduction to the kit will involve looking at the human needs connected with energy and transportation. Students will look at possible solutions to the problem and develop a better understanding of one possible solution; a hydrogen fuel cell vehicle.

ii. The kit provides an easy to assemble project that will give students the thrill of accomplishment without the lengthy learning of new skills.

iii. The research project at the end will provide reinforcement and connection to their world as they study technology that relates to their everyday world.

iv. By completing the labs, students will experience the interrelationship between science and technology. They will use technologies such as the multimeter, solar cell, and fuel cell as "tools for their investigations, inquiry, and analysis".

IV. Content Standard F – Science in Personal and Social Perspectives

a. Developing students' understanding of science and technology in society.

i. As students discuss and research the pros and cons of various energy sources for transportation, they will see that each possible solution is not "entirely beneficial nor entirely detrimental".

ii. Students will research and present their findings. This will allow them to see the variety of energy choices available to society and that each has its own impact on the students' worldview.

*Standards taken from the National Science Education Standards written and published by the National Committee on Science Education Standards and National Academy Press.*

## Conclusion

What can be done to bridge the separation between science and technology? Science sometimes uses technological gadgets but the design process and the fixing of things has been shifted over to engineering and technology. Science teachers have learned to teach concepts to students, but often miss the opportunity to apply that science. Today's young people spend little time taking things apart and learning to work with tools. With public school curriculum skewed in favor of science, students need a more hands-on approach within the science classroom.

This project is an attempt to bring more applied science to a middle school physical science classroom. Middle school is not college prep. There should be no pressure to cover the extensive material of an Advanced Placement course. Students can use this time in middle school to search and explore. This project gives students the opportunity to discover more about solar panels and hydrogen fuel cells. Most teachers do not have time to rewrite and revise and develop handouts and worksheet for a new science kit. Therefore, the foundation of this entire project was to make the Thames & Kosmos Lab Manual, which comes with the Fuel Cell Car & Experiment Kit, usable for any middle school science teacher.

Teachers want students to obtain useful knowledge in the classroom. So often, classroom learning is filled with lectures, reading and answering questions. There is a lot of material to cover and so little time. Many science teachers would do well to incorporate more technology, more projects, more useful knowledge in the classroom. This project is an attempt to do just that.

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## Additional Resources

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