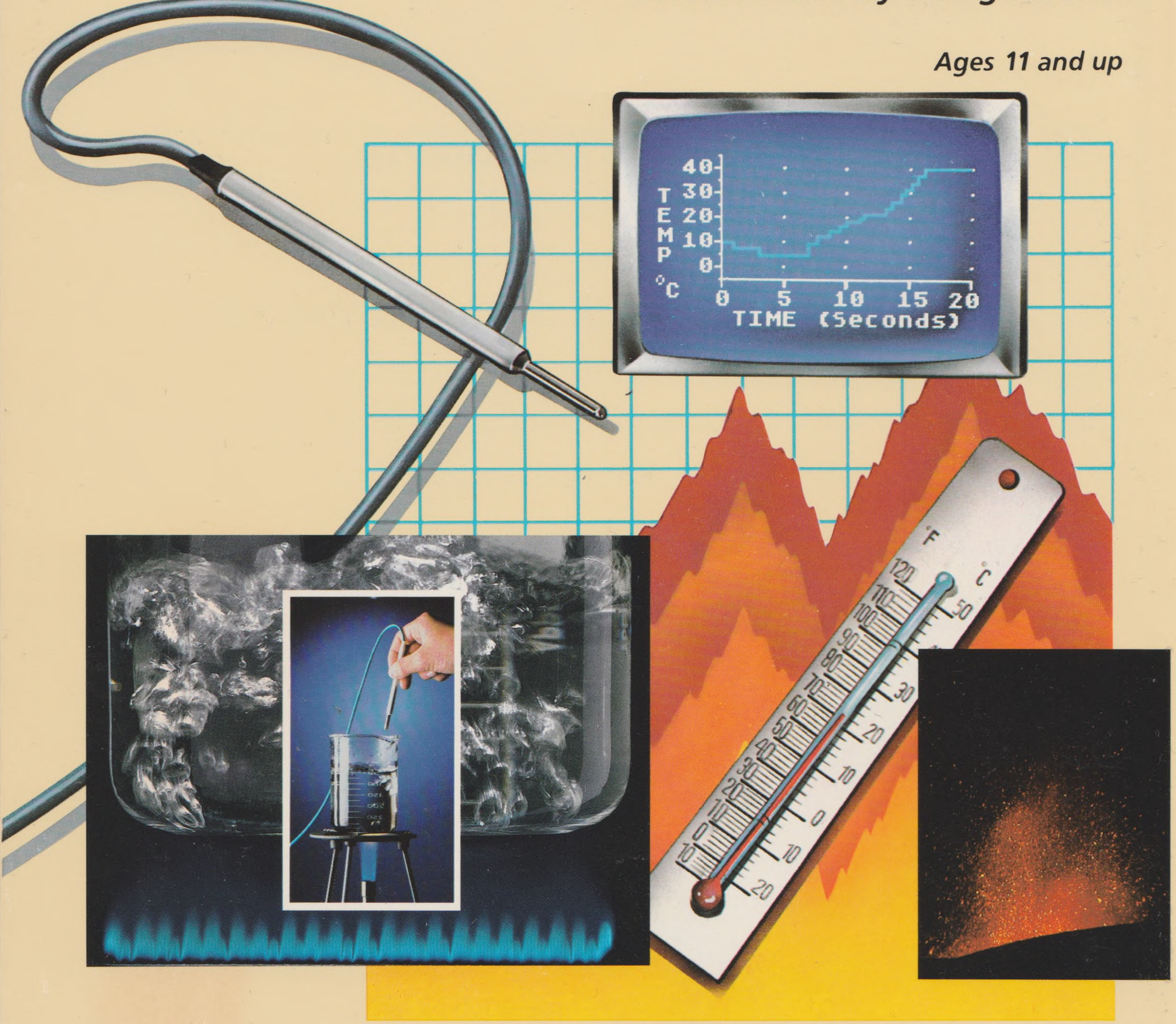
Temperature Lab

Learn science by doing science

Ages 11 and up



Developed by Creative Technology at Dickinson College

SCIENCE DISCOVERY SERIES™

HAYDEN SOFTWARE

Commodore 64

SCIENCE DISCOVERY SERIES™

Introduction
and
Temperature Lab Experimenter's Guide

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1541 BACKUP Program courtesy of Commodore Business Machines, Inc.

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PREFACE

I hear, I forget.
I see, I remember.
I do, I understand.
Chinese Proverb

Science is at heart a human creation. It is one of the ways that human beings try to make sense of the world around them. It is a way of looking for patterns in nature. These patterns are discovered by making observations, taking measurements, and then developing methods for organizing and analyzing this information. The ideas developed in the process of doing science help shape our view of the world.

The Science Discovery Series™ is fundamentally different from most educational computer products currently available. Rather than providing programmed instruction, or simulating scientific phenomena, the Science Discovery Series is intended to enable users to learn science by doing science. The elements of the series are tools for discovery. By using a computer to measure, organize, and analyze real physical quantities quickly and easily, the computer becomes an instrument in the scientific process. We use technology rather than technology leading and using us. In the Science Discovery Series, the computer becomes a working companion. Each Lab in the series is a creative tool for discovery in an intriguing universe. Its purpose is to help us expand our own understanding of the natural world.

THE DRAGON SYMBOL

About the Science Discovery Series dragon —The dragon, like science, is a creation of human imagination shared by many cultures. The word 'dragon' comes from the Greek to 'see' and means 'sharpsighted.' Like the dragon in Chinese culture, our Science Discovery Series dragon is a friendly, benevolent creature. It embodies the spirit of creativity, curiosity, and keen observation needed to contribute to modern science.

CHAPTER 1
Introduction to the Science Discovery Series

The great intellectual division of mankind is not along geographic or racial lines, but between those who understand and practice the experimental method and those who do not understand and practice it.

George Sarton, 1935

What You Can Do With the Science Discovery Series

Your computer and Science Discovery Series Labs can transform your home or classroom into a flexible and inexpensive science laboratory. By doing the temperature activities suggested in the Experimenter's Guide, you can discover some unusual aspects of everyday events. Instead of taking for granted that a cold soda 'loses its cool' in a warm room, you can measure how rapidly its temperature increases. Instead of just remembering how hot or cold a day was, you can use your computer to monitor and keep a record of up to 121 temperatures during any time period you choose.

The use of computers to take data and do calculations is common in modern scientific laboratories. With a computer and the Science Discovery Series Temperature Lab, many scientific investigations involving heat energy can be done easily in the home or classroom. As you do the projects in the Experimenter's Guide, you will be using the computer in a way that is now essential in modern science and engineering.

Other Science Discovery Series Labs will have special sensors and other scientific equipment that can be used to measure light intensity and other aspects of our physical environment. Each Lab will have an Experimenter's Guide with easy–to–follow activities which will show you how to use this special equipment to set up your own laboratory. These Labs will be available as part of the Science Discovery Series.

Special Qualities of the Laboratory Station

Three hundred years have passed since Galileo, with his telescope, opened the enormous vista of the night. In those three centuries the phenomenal world, previously explored with the unaided senses, has undergone tremendous alteration in our minds.

Loren Eiseley

The Temperature Lab contains an Experimenter's Guide, a Science Discovery Series Interface, Temperature Lab Diskette, a temperature sensor and a thermometer. By connecting the interface to your computer, using a television set or monitor, and adding any Science Discovery Series Lab, you have a Laboratory Station.

A laboratory station is as portable as your computer. Because Science Discovery Series Labs usually require only household materials for experiments and activities, you can set up your station in any convenient room in your home or in the classroom—anywhere there are electrical outlets.

Modern scientists use special equipment to increase the powers of the senses of touch, sight, and hearing. There are several remarkable features of the Laboratory Station which extend our ability to observe the natural world.

The sensors in all Science Discovery Series Labs are powerful extensions of your computer's 'senses'. They can measure quantities such as temperature and light level. Or, they can be used to start or stop a clock inside the computer.

The temperature sensor can sense and record changes in temperature that would be too small to be consciously felt by the human body. The light sensor in the Science Discovery Series Light Lab, like those in a camera light meter, can measure the brightness of a light source.

A personal computer can record signals from sensors at least 60 times each second. You can use your computer to record events which happen faster than you could possibly detect. Your eyes cannot detect changes in the brightness of a light which occur in less than one–fifteenth of a second. Many natural phenomena happen faster than this. For example, the burst of light first emitted from the Light Stick included Science Discovery Series Light Lab changes too quickly to be seen by the naked eye and recorded by hand. However,the computer's 'eyes' can see these changes immediately and record them at the same time.

Any Commodore 64 Computer, equipped with a disk drive and a joystick can be used with the Science Discovery Series Labs. The computer and the Science Discovery Series Labs can extend your senses, record data quickly, and be a precision timekeeper. It can be a gateway to scientific discovery by helping you gather information, analyze it, and display the results of an experiment in a way that is easy to understand. All of this can be done at a fraction of the cost of the scientific equipment each Science Discovery Series Lab replaces.

None of this happens by itself. You and the computer are a team. Your computer can do wonderful things for you if you use it creatively.

The Science Discovery Series Temperature Lab

The Science Discovery Series Interface

This piece of special equipment is the key to the Science Discovery Series. With the interface, you can connect sensors, lights, and other scientific devices to your computer. The interface can be connected to control port 2 on the right side of the Commodore 64 Computer after loading instructions have been entered for any software used with it.

The Experimenter's Guide

The Experimenter's Guide introduces you to the Science Discovery Series, and the Science Discovery Series Temperature Lab. Activities and experiments involving temperature measurement are carefully

explained. The Experimenter's Guide also has suggestions on how to use and modify BASIC programs to record, analyze, and display data.

The Temperature Lab Diskette

This 5¼" floppy diskette contains the programs needed to make observations and perform experiments using the temperature sensor. With these programs, you can display temperatures, recorded over a period of time, in the form of a graph or a data table. Or, you can see temperature measurements directly using an alcohol bulb thermometer simulation with a digital display. A description of the Temperature Lab Diskette programs are included in Appendix C.

The Temperature Sensor

The electronic temperature sensor measures temperatures between —5° C and 45° C (23° F and 113° F). The temperature sensor plugs into the left (blue) paddle input of the interface. Before using the sensor, your computer paddle input should be calibrated in order to record more accurate temperatures. The calibration procedure is described in the section entitled "Using the Resistor to Calibrate".

The Thermometer

This alcohol bulb thermometer is used to help check readings from the temperature sensor so the computer can determine temperature more accurately. The thermometer can also be used for calibrating your temperature sensor.

The Standard Resistor

The standard resistor included in your Temperature Lab plugs into either the left (blue) or right (orange) paddle input on the interface. By using the standard resistor and following the calibration procedure described later in this chapter, you can calibrate your computer's paddle inputs. This will usually give you more accurate temperature measurements from your Temperature Lab Sensors.

The Sensor Adjustor

The electronic temperature sensor has a small sensor adjustor attached to it. Certain Commodore 64 Computers have a different type of paddle input and a sensor adjustor should be attached to each sensor used with these computers.

Preparing to Use the Temperature Lab Equipment

Before using Temperature Lab equipment to do actual experiments, you will need to do six things:

1. Set up a Commodore 64 Computer system with a disk drive and connect a joystick to control port 1 on the right side of the computer.
2. Make a working copy of the Temperature Lab Diskette.
3. Load your Temperature Lab Software.
4. Test to see if you need to use the sensor adjustor with your computer.

5. Use the standard resistor to calibrate in order to get more accurate readings from your computer's paddle inputs.
6. Check the Science Discovery Series Interface and Temperature Lab components to see that they work properly with your computer.

Making a Working Diskette

Your master Temperature Lab Diskette is write protected. You must make a working copy of the master diskette that is not write protected so that temperature calibration information and data files can be stored on your disk. Details on calibration and saving data are included later in this manual.

To make a working copy of your diskette, you can load and run the 1541 Backup Program that has been included on your disk courtesy of Commodore Business Machines, Inc. Follow the instructions below:

Note: *The Science Discovery Series Interface should not be plugged in to a control port when you are entering instructions from the keyboard to copy a disk.*

1. Turn on the computer, disk drive, and monitor.
2. Insert your master copy of the Temperature Lab Diskette into the disk drive. Be sure it has a write protect label on it.
3. Type in the command LOAD"I541 BACKUP",8 and press the RETURN key. Wait about 30 seconds for the program to load.
4. Type the command RUN and press the RETURN key.
5. When you see a screen titled SINGLE DISK BACKUP V1.0 with a blinking cursor in the BACKUP COMMAND BOX, press the RETURN key.
6. When the blinking cursor appears in the DESTINATION BOX type in the desired name of your working disk as TEMPERATURE and press the RETURN key.
7. When the blinking cursor has moved beyond a comma at the end of the word TEMPERATURE, type in a disk ID number of Ø2 and press the RETURN key. **Note:** *The ID number must be 2 digits.*
8. Insert your DESTINATION DISK (blank working diskette) into the disk drive and press the RETURN key.
9. Wait while the DESTINATION DISK (working diskette) is formatted and then insert the SOURCE DISK (the master Temperature Lab Diskette) in the drive and press the RETURN key.
10. When asked to verify the SOURCE DISK, press the RETURN key again and wait several minutes while the contents of the master diskette are read into the Commodore 64 memory buffer.
11. When the reading is finished then insert the DESTINATION DISK (the working diskette) into the disk drive and press the RETURN key.
12. Wait a few minutes while the information from the Commodore 64 memory buffer is transferred to the DESTINATION DISK.

Loading the Temperature Lab Software

To load the software, follow the directions below:

1. Make sure your interface is not plugged into a control port.
2. Turn on your computer and disk drive.
3. Insert your working Temperature Lab Diskette into the disk drive.
4. Type the command LOAD"*",8 and press RETURN.
5. When the word READY appears on the screen, type in the command RUN.
6. Wait about a minute for the program to load.

Note: *The interface must be unplugged from either control port whenever loading instructions or other information is being typed into the Commodore 64 via the keyboard.*

Testing to See if You Need the Sensor Adjustor

Once the software is loaded, you can see if your Commodore 64 paddle inputs are reading temperatures properly with the sensor adjustor in place. To do this:

1. Plug a joystick into control port I on the left side of the computer.
2. Press the red joystick button to move from the title screen to the first instruction screen.
3. Follow the instructions on the screen and plug the interface into control port 2.
4. Plug the temperature sensor *with the sensor adjustor attached,* into the left (blue) paddle input of the interface.
5. Press the red joystick button again to proceed to the main menu.
6. Move the joystick to the left (←) to display the thermometer bulb.
7. The temperature sensor and the real alcohol bulb thermometer should both be at room temperature. Compare the temperature in °C displayed on the screen thermometer with the temperature shown on the alcohol bulb thermometer.
8. If the temperature of the screen thermometer and the alcohol bulb thermometer are within about 3°C of each other, then always plug the sensor adjustor into the interface and then a sensor or standard resistor into the adjustor.
9. If the temperature displayed on the screen is about 10°C lower than the temperature of the alcohol bulb thermometer, *remove the sensor adjustor, you don't need it.*

Using the Resistor to Calibrate

Each Commodore 64 Computer responds differently to changes in the electrical resistance of the sensor. The calibration procedure produces numbers, called calibration constants, which relate electrical resistances to the paddle readings from your computer. If the paddle inputs of your computer are not calibrated, the temperatures read from your sensor may be off by as much as 5°C. By using the standard resistor with the paddle calibration program, and following the procedure below, the calibration constants and other information you need to get accurate temperatures from paddle readings will be stored on your working diskette.

If you want to get more accurate temperature readings using another Commodore 64 Computer, you will have to repeat the resistor calibration procedure. Follow the instructions below to use the resistor to calibrate your paddle inputs:

1. Load the Temperature Lab Software from your working diskette.
2. Make sure a joystick is plugged into control port 1. Press the red joystick button to continue.
3. Follow the instructions on the screen and plug the interface into control port 2.
4. Plug the blue sensor into the left (blue) paddle input of the interface. If you have an orange sensor, follow the instructions on the screen for the orange sensor.
5. Press the red joystick button to display the main menu.
6. Choose the CALIBRATE option by pushing the joystick down (↓).
7. When the RESISTOR and SENSOR CALIBRATION options appear on the screen, choose the RESISTOR option by pushing the joystick down (↓).
8. Remove all sensors from the interface.

Note: *If you have determined that the sensor adjustor was needed, remove it from the temperature sensor and plug it into the standard resistor.*

9. Follow the instructions on the screen and insert the standard resistor (with the adjustor, if needed) in the left (blue) paddle input of the interface. A new screen will appear.
10. Follow the instructions on the screen and remove the standard resistor (with the adjustor, if needed) from the left (blue) paddle input and plug it into the right (orange) paddle input.
11. As soon as the paddle readings of the standard resistor have been recorded for both paddle inputs, the original CALIBRATION option screen should reappear.
12. Press the red joystick button to return to the main menu and the calibration information will be calculated and stored on your working diskette.
13. To enter the main menu, remove the standard resistor from the right (orange) paddle input. Insert the temperature sensor in the left (blue) paddle input (with sensor adjustor, if needed).

Note: *If you need the sensor adjustor, you can secure it to the end of the temperature sensor with a piece of electrical tape.*

The temperature readings are usually accurate to 1 or 2° Celsius once the paddle inputs are calibrated and the sensor adjustor, if needed, is in place between the sensor and the interface paddle input. Sometimes when the temperature sensor is not accurate, the resistor calibration will not give better temperature readings. If this is the case, or if you want more accuracy, you will need to calibrate your sensor. See Appendix D.

Checking the Temperature Lab Equipment

Before doing any experiments, you should always make sure your equipment is working correctly and read the directions thoroughly.

To test Temperature Lab components, we recommend that you take temperature readings of room air, ice water, and other objects.

To do this, first collect the following things:

Temperature Lab Diskette
Science Discovery Series Interface
Temperature Sensor
Cup of ice mixed with water
Thermometer

If your software is not loaded, remove the interface from control port 2 and follow the instructions above to load it.

1. To begin, plug a joystick into control port 1.
2. Plug the interface into control port 2.
3. Plug the temperature sensor into the left (blue) paddle input in the upper left corner of the interface.
4. Move the joystick to the left (←) to select the BULB Program. You should now see a picture of an alcohol bulb thermometer with the temperature of the sensor displayed on the screen in degrees Fahrenheit and degrees Celsius.
5. Dip the temperature sensor in and out of the cup of ice mixed with water.

The level of the liquid in the alcohol bulb thermometer shown on the screen should go up and down as the temperature changes. The numbers on either side of the screen are temperatures which correspond to those shown in the picture of the alcohol bulb thermometer. The numbers should change as the temperature changes.

Next, compare the temperature measured by your sensor with the temperature of your real alcohol bulb thermometer. In this way you can see if your Laboratory Station is responding correctly to temperature changes.

As you measure temperatures, watch the changes in the 'alcohol' level on the thermometer and the numbers of the screen. Put the glass bulb thermometer in the ice and water mixture. If you leave both the temperature sensor and the glass bulb thermometer in the ice and water mixture for 10 or 15 seconds, the temperature on the screen should be within one or two degrees of the thermometer reading. Both readings should be close to O°C.

Next, put the temperature sensor and the thermometer on the table to warm up. After about two minutes, the temperature of the sensor and the temperature of the thermometer should be within one or two degrees of each other. If the temperatures you are recording don't seem correct, consult the Trouble-Shooting Guide in Appendix H.

Since the sensor can read temperatures that range between —5° C (23° F) and 45° C (104° F), you can test the sensor by measuring temperatures in that range. Although measuring temperatures just outside that range will not harm the sensor, the readings on the screen will simply not go below —5° C or above 45° C.

How to Use
The Experimenter's Guide

Only a few of many possible temperature projects are described in the Experimenter's Guide.

Using the Temperature Lab Diskette, you can do the activities described in Chapters 2 and 3 of the guide step by step. Making careful observations is one of the skills of a good scientist. As an introduction to the features of the Temperature Lab, the first few activities involve making simple observations carefully.

As you proceed through the projects, they become more complex. By the time you reach the end of Chapter 2, and are very familiar with the equipment, you will be doing full–fledged scientific experiments designed to test important questions and generalizations about the natural world.

As you do the projects, you should try to fill in the data tables and graphs and answer the questions in the spaces provided. These questions will help you think about the significance of the activity you have been working on. Answers to the questions asked in each chapter and sample data and graphs are included in Appendix B at the end of the Experimenter's Guide.

Scientists often do an experiment many times. If the same experiment gives similar results each time it is tried, a scientist is more certain that the results are reliable and that there are no obvious problems with the experimental procedures.

If you want to do careful experiments you should plan on repeating the activities in the Experimenter's Guide several times. To record your observations and information, you should get a notebook that you can use for laboratory data. The section in Chapter 2 titled "Tips for Experimenters" explains how to set up your notebook. For your convenience sample copies of tables and graphs used in the activities have been added in Appendix F. These extra data sheets can be reproduced or copied by hand, filled in, and then taped or glued into a laboratory notebook.

The most creative use of the Science Discovery Series Labs is in designing original scientific experiments. If you want to do this you need to write your own programs and learn more about techniques for analyzing the data you collect. Appendix E will introduce you to Temperature Lab programming.

Chapter 2 contains explanations of some of the principles of heat and temperature. These principles form the basis for many of the

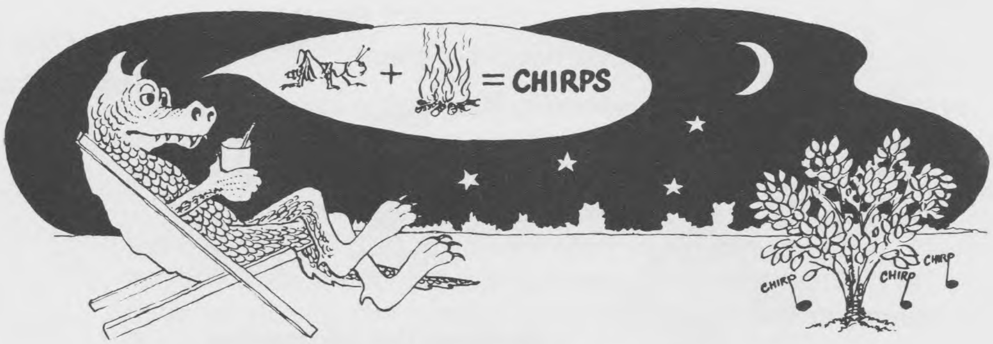
experiments and activities. If you wonder why things happen the way they do, you should read Chapter 2 carefully. You can go back and reread it from time to time as you do the experiments.

Doing Science With the Laboratory Station

This section discusses the way scientists often go about investigating the natural world. In order to learn more about doing science with your Laboratory Station, let's look at a project that can be done with the Science Discovery Series Temperature Lab.

Discovery

Suppose one very hot summer evening you thought that the crickets outside in your yard seemed to be chirping faster than usual. You might guess that crickets chirp faster on very hot nights, or perhaps you read or heard that crickets chirp more often as the temperature rises.



Wondering or Developing a Hypothesis

By drawing on previous knowledge or observations, you might recall that processes in many forms of life seem to occur more rapidly at warmer temperatures. For example, you may have noticed that your heart beats faster when you have a fever or you may have read that plants grow rapidly in the tropics, and reptiles move around more in hot weather. Based on these facts, you might develop a hypothesis. A hypothesis identifies general relationships between characteristics, properties, or events observed in nature. Once you have formulated a hypothesis you then test it to see if it works for your experiment.

In this case, when you recalled some of the effects of warm weather on different life forms, you could develop a general hypothesis about life:

> *Is it true that life processes occur more rapidly at higher temperatures?*

You could test this hypothesis by using what you have just learned about crickets. You might ask yourself: Can I test this hypothesis by finding out whether or not crickets chirp faster in warm weather? Does the number of chirps a cricket makes depend on the temperature? How can I find this out? How can I measure this?

Developing a Plan

One of the most difficult and important steps in a science project is figuring out what information is needed to test your hypothesis and

answer the questions that have been asked. Developing a plan and a set of procedures to obtain this information is also important. Often you will need to gather materials or equipment and make sure everything is working properly.

The best experiments limit the number of things that have to be measured at one time. The more things that have to be measured, the more problems there are in gathering and making sense of the information. Choosing a standard time period within which you can take measurements, and limiting the number of measurements taken are two ways of controlling the different things that have to be observed in an experiment. For the cricket experiment, you might choose to measure the number of cricket chirps and the temperature for one minute for four consecutive evenings.

Recording Information

One possible way to record the data is shown below.

Table 1-1: *Cricket Chirp Data*

Date	*Time*	*Temperature (°F)*	*Chirps Per Minute*
8/8/83	8:30 pm	73	131
8/9/83	9:15 pm	77	148
8/10/83	8:49 pm	67	109
8/11/83	9:23 pm	62	88

Studying the Information

We get closer to an answer when we study the data and arrange it in different ways that organize it and make it clearer. Since we want to find out what happens when the temperature increases, let's arrange the data in order of increasing temperature as shown below.

Table 1-2: *Cricket Chirp Data Placed in Order of Increasing Temperature*

Temperature (°F)	*Number of Chirps Per Minute*
62	88
67	109
72	131
77	148

From the Table you can see that the crickets you observed did chirp more often when the temperature was higher.

Now you have answered the main question by designing an organized experiment. But if you're like most scientists you won't stop here. You will begin to ask more questions which go deeper into the subject of your experiment.

You might ask: "What is the exact relationship between chirps and temperature? How does the number of chirps depend on temperature? Can I be more exact about my measurements? And if I find out about the relationship, can I learn how to use the cricket as a thermometer by calculating temperature from its chirp rate?"

Graphing the Information

A picture is worth a thousand words! At least many scientists think so. They commonly use graphs to picture the relationship between the different kinds of information they have gathered.

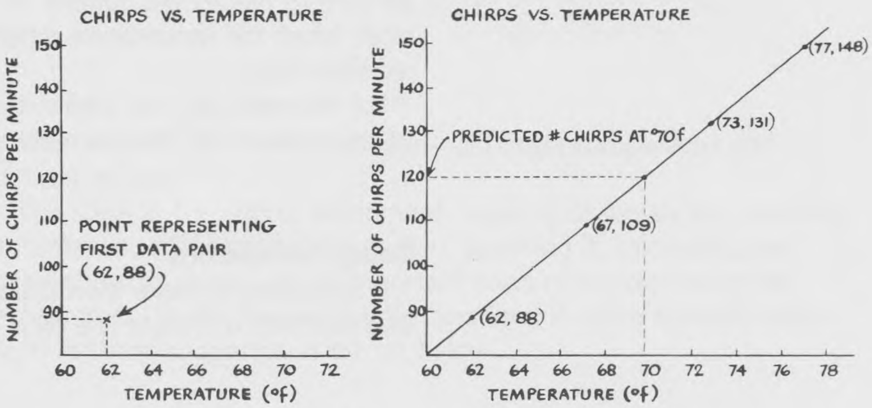


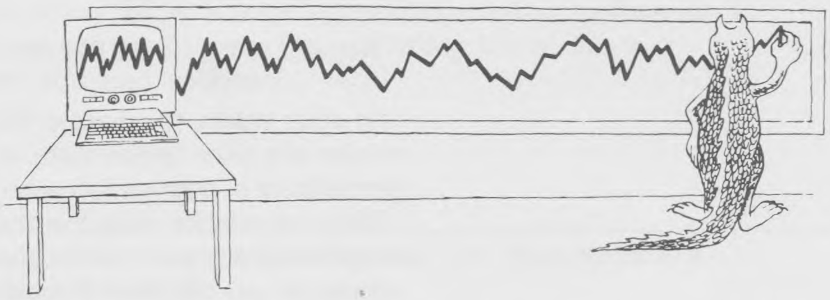
Figure 1–1 *Graph of cricket data*

Table 1–2 contains four pairs of numbers. In each pair one number shows the number of chirps and another represents the temperature at the time the chirps were recorded.

The graph consists of two lines called axes, the temperature axis and the chirp axis. They cross each other at a right angle. The numbers along the vertical axis represent the possible numbers of chirps per minute. The numbers along the horizontal axis represent the possible temperatures measured.

To plot a point on the graph, move from left to right along the temperature axis to the temperature being plotted. Then move up parallel to the chirp axis to a point opposite the number of chirps counted and place a dot at that location.

The graphs in Figure 1–1 show the plotted points. The first pair of numbers is shown on the left and all four number pairs in Table 1–2 are plotted on the right. By taking a ruler, it is possible to draw a straight line that almost passes through all the points in the graph on the right. This graph represents the relationship between chirps and temperature. It shows that at higher temperatures, there are more chirps.



To an experienced scientist the fact that the points lie more or less on a straight line suggests that the number of cricket chirps increases the same amount each time the temperature increases by 1°F.

At this point in the experiment you might decide to collect more data to make sure you did it right the first time. Then you can graph it, add it to the graph, or create another graph with the new data to see if the points also seem to lie along a straight line.

If the graph provides a good picture of the way crickets chirp, it can be used to predict the number of chirps you might expect on another night when the temperature differs from any of the nights you recorded data.

For example, you can predict that on a 70°F night a cricket ought to chirp about 120 times a minute.

Doing Calculations

It is possible to make the calculations needed to find an equation that describes a straight line on a graph.

Our cricket equation for temperature between 62°F and 77°F turns out to be:

Number of Chirps per Minute = 4 × (Temperature − 40°F)

In other words, to calculate the predicted number of chirps per minute at a given temperature, you should subtract 40 from the temperature in degrees Fahrenheit and then multiply by 4.

Why not practice using this equation! Pick a typical summer evening temperature and put it in the equation. What number of chirps per minute do you calculate? (For example, if the temperature is 70°F then:

Number of Chirps per Minute = 4 × (70 − 40) = 4 × 30 = 120

A Cricket Thermometer

It is possible to turn the equation above around to allow us to compute temperature from the number of chirps per minute.

$$\text{Temperature} = \frac{\text{Number of Chirps per Minute} + 40°\text{F}}{4}$$

The cricket is now a thermometer—although complicated and difficult to use!

The steps in the cricket experiment—making observations, recording information, studying the information, graphing it, calculating and drawing conclusions—are all important parts of a typical scientific experiment. Usually these steps are described in more scientific terms such as those suggested in the list below.

Steps in a Typical Scientific Experiment

1. Making Discoveries or Observations
2. Stating a Purpose or Hypothesis (Wondering)
3. Designing an Experiment
4. Recording Information
5. Studying the Information
6. Graphing the Information
7. Doing Calculations
8. Drawing Conclusions

Scientists do not usually follow these steps exactly. Sometimes the results of an experiment lead to additional questions. For example, does the equation describing how crickets chirp work below 60° F? Above 80° F? Does it work for all kinds of crickets? Does it work in other parts of the world?

Just as in the cricket example, many experiments raise more questions than they answer. The framing of new questions and the design of unusual experiments to answer them are part of what makes modern science such an interesting and creative endeavor. The Laboratory Station is a tool for new exploration. It allows you to bridge the gap between play and taking formal data in a well-equipped laboratory.

Suggested Readings

Cobb, Vicki. *Science Projects You Can Eat.* Philadelphia: J. B. Lippincott, 1972.

This book is one of the best books on doing science projects with supplies found in the kitchen. Several projects in this Experimenter's Guide were inspired by this book.

Herbert, Don. *Mr. Wizard's Supermarket Science.* New York: Random House, 1980.
A book full of ideas for experiments using household items.

Moorman, Thomas. *How to Make Your Science Fair Project Scientific.* New York: Atheneum, 1974.
This is an excellent resource for learning scientific methods.

Mott–Smith, Morton. *The Concept of Heat and its Workings Simply Explained.* New York: Dover, 1962.
As an elementary introduction to the theory of heat and its measurement, it is full of ideas for classical experiments on temperature and heat. The reader will learn a great deal about the properties of matter by studying the effects of heat and temperature.

Rogers, Michael. *The Measurement of Heat and Temperature: A History of Rich Discourse.* San Francisco: Exploratorium (3601 Lyon Street, San Francisco, CA, 94123), 1981.
This book has a delightful section on early attempts to develop temperature scales. It traces the history of the Laws of Thermodynamics in easy–to–understand terms.

Thompson, Philip D. "The Cricket: Nature's Thermometer." *Weatherwise* 36(4):190–191.
The author describes his experiments with a species of crickets in Colorado which he suspects is **Oecanthis niveus**. He finds the following equation relating temperatures with number of chirps per minute for his crickets:

Temperature (°F) = Number of Chirps per minute ÷ 5 + 43°F

Van Deman, Barry A. and Ed McDonald. *Nut and Bolts: A Matter of Fact Guide to Science Fair Projects.* Harwood Heights, IL: Science Man Press, 1980.
This guide contains a number of practical suggestions for how to choose a Science Fair topic as well as information on planning and doing experiments.

Walker, Jearl. *The Flying Circus of Physics with Answers.* New York: Wiley, 1977.
This book contains a large collection of questions about everyday physical phenomena. Extensive references are included. It is a gold mine for those looking for new projects.

Webster, David. *How To Do A Science Project.* New York: Franklin Watts, Inc., 1974.
This is a good introduction to science projects for the middle grades.

CHAPTER 2
Temperature and Its Measurement

When you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind. It may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the stage of science.

Lord Kelvin

Introduction

What is temperature? How is it measured? How is it different from heat? When carried out in order, the activities in this chapter should help you to answer some of these questions. After completing these activities you should have enough understanding about the ideas of temperature and heat to undertake the projects and experiments described in Chapter 3.

As you go through the projects, you will be asked to write down your observations and the results you get from the experiments you perform. Spaces for your answers are provided after each question. Each question is followed by a ■ and a number which corresponds to a number listed in Appendix B, "Comparing Project Results."

Appendix B contains the observations and results we obtained when we did the experiments in Chapter 2 and all the projects in Chapter 3. You can check your observations and results with ours.

Tips for Experimenters

Before you begin the temperature activities in this chapter and the projects in Chapter 3, you should read this section. It will help you obtain better results from your activities.

Getting Started

- A laboratory notebook is a diary used by scientists to keep a running account of ideas, observations, hypotheses, important data, graphs, calculations, and conclusions. You should get a bound notebook and write down your observations, data, and results. Each entry in the notebook should be dated and titled with the name of the experiment.
- Read through each activity completely before starting it so you will know ahead of time what is expected. You can then follow the instructions step-by-step without stopping. Stopping in the middle of an experiment where timing is important will change the results.
- Gather and organize all the materials and other items listed for an activity before beginning to work. Nothing is more frustrating than being in the middle of a project and finding that something essential is missing at a critical time during an experiment.

• Spilling the liquids used in the experiments on the computer can damage the computer equipment and the interface. It's important that you keep the containers of liquid away from the computer. You can put your containers of liquid on a separate table or in the center of a tray that can hold them and contain spills (such as a rectangular cake pan). Keep a sponge and a large bowl or pan handy to wipe up spills quickly.

• If you need to increase the distance between the sensor and the computer to do an experiment, you can make the distance between the interface and the sensor longer by hooking up one or more phonojack cables between the interface and the sensor. These extender cables can be obtained from your Temperature Lab dealer or electronic supply stores.

Materials and Equipment

• Use the temperature sensor with care. Don't put the sensor in nail polish remover (acetone),cleaning fluid (carbon tetrachloride), moth balls (naphthalene) or other organic solvents.

• Because styrofoam is a readily available low–cost insulator, styrofoam cups are recommended for several temperature activities. A liquid will warm up or cool down to room temperature more slowly in a styrofoam cup than in a glass or a paper cup. Other insulated containers, such as thermos bottles or ceramic cups, can be substituted if you want to avoid using disposable styrofoam cups.

Temperature Scales

• Scientists all over the world now use the Celsius scale (°C) for temperature measurements. We recommend that you use the Celsius scale for all your Temperature Lab activities, except Project Seven on daily weather monitoring. Most of the sample data tables and graphs in the Experimenter's Guide use the Celsius scale. However, if you prefer to use the Fahrenheit scale, you may select it for your measurements.

Taking Accurate Measurements

• Measurements are never perfectly accurate. The results of repeated observations will not always be the same since conditions are always changing. The computer was not designed originally to take steady measurements. There may be small fluctuations in the temperature being measured. You may see the temperature you are trying to measure go up and down by 1 or 2°C.

• Each temperature sensor and Commodore 64 Computer paddle input responds a bit differently to temperature changes. To obtain more accurate temperature measurements (within 1°C) you need to calibrate your paddle input and sensor. You can refer to Chapter 1 for instructions on how to use the resistor to calibrate the paddle input or refer to Appendix D for instructions on how to calibrate the sensor.

• The temperature sensor is more accurate at low temperatures. If you want 1° C accuracy, experiments should be designed which involve temperatures of 35°C or less.

Repeating Experiments

• A well–designed experiment usually gives measurements that are repeatable. Repeatable measurements are not always exactly the same but rather they are similar. If you want to repeat an experiment several times and analyze your data, reproducible samples of useful tables and graphs are located at the back of the Guide.

• In a good experiment the results of two observations should be similar enough to allow you to draw the same conclusions each time. After you have finished each activity, you may want to compare your results and conclusions to ours. Notes summarizing the results we obtained from each experiment are included in Appendix B.

If There Are Problems

If the activities or experiments don't give the results you expect, check your set–up carefully.

- Are the computer and television set or monitor plugged in correctly?
- Is the diskette inserted correctly?
- Is the interface inserted in the proper connector?
- Is the temperature sensor inserted in the left (blue) paddle input correctly?
- Have you followed all instructions carefully?
- Did you make any changes in the recommended procedures? If you did, you should think about how these changes may affect the results of your experiments.
- Did you check the Trouble–Shooting Guide in Appendix H?

If your problems appear to be caused by a bad sensor, interface, or diskette, consult your dealer.

Locke's Test—Feeling Heat and Cold

The chill of an ice cream cone on your tongue, the searing heat of a fire, and the feverish brow of a sick person are all familiar. People experience heat and coldness every day. Most of us use the sense of touch as a crude thermometer: We feel someone's brow to detect a fever, we test the water with a toe, or we step outdoors to check the temperature.

In 1690, John Locke, a well–known British philosopher, suggested a simple test to see whether or not 'feeling' temperature is a reliable method for measuring it. This test involves touching something warm right after fèeling something cold, and then touching the same warm object after feeling something hot. Let's try Locke's test using water.

Equipment and Materials

Three styrofoam cups
Ice cubes
Hot water
Cold water

Setting up Locke's Test

1. Place three styrofoam cups on a table.
2. Fill one cup with a mixture of ice and water.
3. Fill a second cup with hot water. The water should be as hot as your finger can stand.

4. In the third cup, mix equal amounts of the ice water and the hot water. (Do not include any ice cubes.)

Doing Locke's Test

1. Dip a finger into the ice and water mixture and count slowly to 10.
2. Pull your finger out of the ice and water mixture and dip it into the warm water.
3. How does the warm water feel? Write down your observations. Cold to Warm: ■1

____

____

____

4. Dip your finger into the hot water and count slowly to 10.
5. Pull your finger out of the hot water and dip your finger into the warm water.
6. How does warm water feel now? Write down your observations. Hot to Warm: ■2

____

____

____

To make sure your results are reliable, you should repeat Locke's test one or more times.

Conclusions About Locke's Test

The results of Locke's test seem amazing to many people. You should have observed that the apparent temperature of the water you felt depended on the temperature of your finger before you dipped it into the warm water. You have probably experienced this before. For example, after exercising, your hands may be so warm that everyone feels cold to you. Or, on a chilly day you may find yourself feeling someone's brow with your cold hands and thinking that the person has a fever.

From the results of Locke's test, we can draw the following conclusion: It appears that touch can be used to sense the difference between the temperature of your finger and that of another object. That is, you experience that something is either hotter or cooler than the present warmth or coolness of your finger. However, you cannot tell the exact temperature of the warm water by feeling it. So your sense of touch is not a thermometer. It can't measure temperature, only temperature difference. Now let's look at how we can measure temperature.

The Thermometer

Using the knowledge that some liquids expand when they are heated and contract when cooled, scientists realized they could measure the rise and fall of a liquid in a glass tube. By making a scale—equally dividing up the spaces on the glass tube between a high point and a low point—a thermometer could be constructed.

Because scientists disagreed about where the high and low points should be placed on a thermometer and about how many divisions should be drawn on the glass, it took almost 200 years to develop the familiar glass tube thermometer. The glass tube thermometer in the Temperature Lab consists of a tube filled with alcohol and sealed at the top. To make it easier to see the height of the alcohol, red coloring has been added to it.

A thermometer can be made using any material that changes its volume quickly when heat energy is transferred to it. Various gases and heavy liquids, such as mercury, have been placed in glass tubes instead of alcohol. Today, there are many new types of thermometers based on modern electronics.

A thermistor is a popular electronic thermometer used in science and industry. The thermistor consists of a tiny chip of material known as a semi–conductor because of the way it conducts electricity. Your temperature sensor contains a thermistor mounted inside a moisture–proof wand.

Measuring Temperature with the Laboratory Station

Let's use the Laboratory Station to measure two different temperatures and then to compare the two most popular scales for measuring temperature—Celsius and Fahrenheit.

Equipment and Materials

Science Discovery Series Interface

Temperature Sensor

Temperature Lab Diskette

3 styrofoam cups

Ice cubes

Hot water

Cold water

Other liquids (coffee, tea, soda)

Setting up the Experiment

1. Set up the Laboratory Station. (If you have forgotten how to do this, see Appendix A.)
2. Choose the BULB option.(See Appendix A.)

Observing Temperatures

1. Look at the display of the thermometer on the television set or monitor screen. You can see numbers on either side of the thermometer. The numbers on the left represent the temperature in degrees Fahrenheit and those on the right represent degrees Celsius.
2. Put your finger on the tip of the temperature sensor. What happens to the level of the alcohol in the thermometer on the screen? ■3

3. Fill a styrofoam cup with a mixture of ice and water.
4. Place the styrofoam cup in the pan or tray.
5. Put the temperature sensor into the cup and leave it there for a few minutes. What happens to the alcohol level in the thermometer on the screen? ■4

Comparing Celsius and Fahrenheit Scales

Celsius and Fahrenheit are the two most popular temperature scales in use today. Let's make some observations to get used to some of the differences between the two temperature scales.

The thermometer displayed on the screen allows you to study the relationship between these two temperature scales. Note that on the left side of the screen temperatures are displayed in degrees Fahrenheit. On the right side they are displayed in degrees Celsius.

Compare Celsius and Fahrenheit by looking at the scales drawn left and right on the sides of the thermometer on the screen. To practice seeing differences between the two scales, answer the following questions:

1. When it is 0° Celsius, what is the temperature in degrees Fahrenheit? _______°F. ■5
2. When it is 32° Fahrenheit, what is the temperature in degrees Celsius? _______°C. ■6
3. When it is 50° Fahrenheit, what is the temperature in degrees Celsius? _______°C. ■7

Recording Temperatures

To record a temperature at the side of the thermometer, press the **F3** key. The recorded temperature will be displayed under the current temperature in a different color.

Continue your temperature measurements. Measure any temperature that might interest you. Put the sensor under your arm, between your toes, in various liquids such as ice water, coffee, or soda. Breathe slowly in and out on the sensor. Be creative!

Remember that the sensor is only sensitive between temperatures just below that of ice water and just above normal body temperature. The range is −5°C to 45°C (23°F to 113°F).

Note: *Do not put the temperature sensor directly in your mouth.*

Use the listing below to write down your observations.

	Temperature	
Object	*Degrees Fahrenheit*	*Degrees Celsius*
1. Breathing	________	________
2. Cup of coffee	________	________
3. Glass of milk	________	________
4. Glass of soda	________	________
5. Toes	________	________
6. Ice water	________	________
7. Armpit	________	________
8. ________	________	________
9. ________	________	________
10. ________	________	________

Converting from Fahrenheit to Celsius

If you are familiar with using equations, you can calculate the temperature in one scale if you know it in the other scale. By representing degrees Fahrenheit with F and degrees Celsius with C, the conversion equations become:

$$C = \frac{5}{9}(F - 32) \qquad F = \frac{9}{5}C + 32$$

For example, to find C if F = 59° Fahrenheit, we can use the equation for C:

$$C = \frac{5}{9}(F - 32) = \frac{5}{9}(59 - 32) = \frac{5}{9}27 = 15$$

so that 59°F = 15°C.

Note: *These equations cannot be used to find the screen display of degrees Fahrenheit from screen the display of degrees Celsius. This is because, in the Temperature Lab programs, the displayed values of temperature are rounded to the nearest whole number. Using the screen value to change scales would cause rounding errors.*

Temperature—What is It?

Temperature is a measure of the concentration of heat energy stored in matter, but it is not the same thing as heat. For example, a bathtub full of water and a cup of water can be at the same temperature even though much more heat energy is stored in the bathtub simply because there is more water in the bathtub.

The temperature of any substance is a measure of how much energy is associated with the motion and vibrations of its atoms and molecules. If you want to understand heat energy and learn about the role of atoms and molecules, read the section titled "Molecules, Heat, and Temperature—What It's All About."

Even though touch is not a particularly reliable way to measure temperature, touch can be used to determine whether the temperature of an object is changing. If the temperature of an object is changing, it will start to feel either warmer or colder to the touch as time passes. If one object in contact with another object doesn't become hotter or colder in time, we say the two objects are at the same temperature. In other words, no heat energy is flowing from one object to another.

There are several principles relating temperature to heat energy. The following two principles help us understand some of the activities described in this manual:

> ***Principle 1:*** *If two objects of different temperatures are placed in contact, heat energy will flow from the object at the higher temperature to the object at the lower temperature until the two objects are at the same temperature and no longer exchange heat energy.*
>
> ***Principle 2:*** *If the objects are insulated from all other parts of the universe, the heat energy lost by the hotter object is the same as the heat energy gained by the colder object.*

Mixing Heat and Cold—Testing the Principles of Temperature

The principles of temperature are actually simplified statements of some of the 'official' laws of classical thermodynamics. We can apply these principles to develop hypotheses about what will happen if we mix various amounts of warm and cold water together.

Let's develop a hypothesis about mixing warm and cold water:

> *Hypothesis: When equal amounts of warm and cold water are mixed together, the final temperature of the mixture will be halfway between the temperature of the cold water and that of the warm water.*

Let's mix equal amounts of warm and cold water, measuring the temperatures of the warm and cold water just before and just after mixing.

Equipment and Materials

The Laboratory Station
Large pitcher of ice water
Large pitcher of lukewarm water (about 35°C)
Glass kitchen measuring cup
One 12–ounce styrofoam cup (large)
A large cake pan or tray

Note: *Ice water is the water poured off from a mixture of ice and water and contains no ice. Lukewarm water is water just warm to the touch.*

Setting up the Experiment

1. Set Up the Laboratory Station. (See Appendix A.)
2. Choose the BULB option. (See Appendix A.)
3. Place the two pitchers of water, the styrofoam cup, and the kitchen measuring cup in the large cake pan or tray or on a separate table.

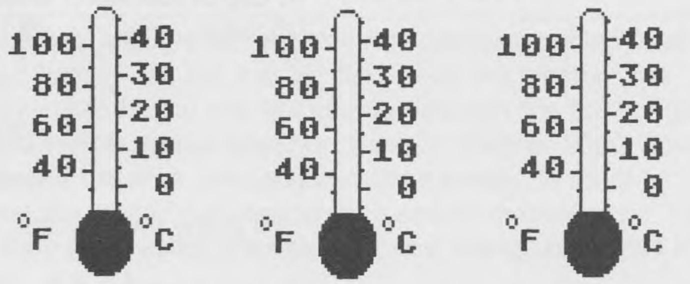
Note: *Because the ice water can gain heat energy from the surrounding air and the lukewarm water can lose heat energy to the surrounding air, you should do this experiment by taking your temperature readings as quickly as possible.*

Doing the Experiment and Predicting the Results.

Let's begin by measuring the initial temperature of the ice water and the warm water. Then we can try to predict on a diagram what the final temperature of a mixture of the ice water and warm water will be.

1. Dip the temperature sensor in the pitcher of ice water and stir the water with the sensor.
2. Watch the screen to see the 'alcohol' level of the thermometer bulb and the numbers indicating temperature on either side of the bulb go down.
3. Wait until the temperature reaches its lowest point. (Remember it might fluctuate within 1 or 2°C).

4. When the lowest temperature is reached push the **F3** key to record the temperature on the screen.
5. Write down the low temperature recorded on the screen _______°C. ■8
6. Dip the temperature sensor in the pitcher of warm water and stir the water with the sensor.
7. Repeat Steps 2–4 above. This time the 'alcohol' level of the thermometer bulb and the numbers on the screen will go up.
8. Write down the high temperature recorded on the screen _______°C. ■9
9. Draw the temperature levels in Figure 2–1. ■10



(1) ICE WATER **(2) WARM WATER** **(3) MIXTURE OF ICE WATER AND WARM WATER (PREDICTED)**

Figure 2–1. *Three thermometer bulbs.*

10. Examine the temperatures in Figure 2–1 and try to predict what temperature you will measure when after equal parts of the ice water and warm water are mixed together.
11. Sketch the predicted temperature in Figure 2–1, and write down the predicted temperature. _______°C ■11

Let's see how good our prediction is. Remember to do the following steps quickly so you don't lose too much heat.

1. Measure 1/2 cup of ice water in the kitchen measuring cup.
2. Pour the ice water into a styrofoam cup.
3. Measure 1/2 cup of lukewarm water in the kitchen measuring cup.
4. Pour the warm water into the styrofoam cup with the ice water and stir with the temperature sensor.
5. Watch the screen as the 'alcohol' level in the bulb and the temperature readings change. Wait until the temperature readings stop changing.
6. Press the **F3** key to record the temperature on the screen.
7. Write down the temperature of the mixture: _______°C. ■12
8. What do you notice about the temperature of the new mixture? ■13

Calculations

According to our principles of temperature, the new mixture should be about half-way between the temperatures of the lukewarm water and the ice water. You should have found this halfway temperature approximately from the sketches you made in Figure 2–1. You could also calculate the predicted final temperature using the equation below: ■14

$$t(\text{mixture}) = t(\text{cold}) + \frac{1}{2}[t(\text{warm}) - t(\text{cold})]$$

To test this half–way principle thoroughly you should try the experiment several times.

Further Investigations of Water Mixture Temperatures

If you are interested in finding out how the final temperature is affected by the amount of hot and cold water mixed together, try doing the experiment with different amounts of hot and cold water.

Follow the same steps as before but use 1/3 cup of ice water and 2/3 cup of lukewarm water. Record your observations below or in your laboratory notebook. ■15

t(cold) ______

t(warm) ______

t(mixture) ______

Fill in the thermometer bulbs below to show your results. ■16

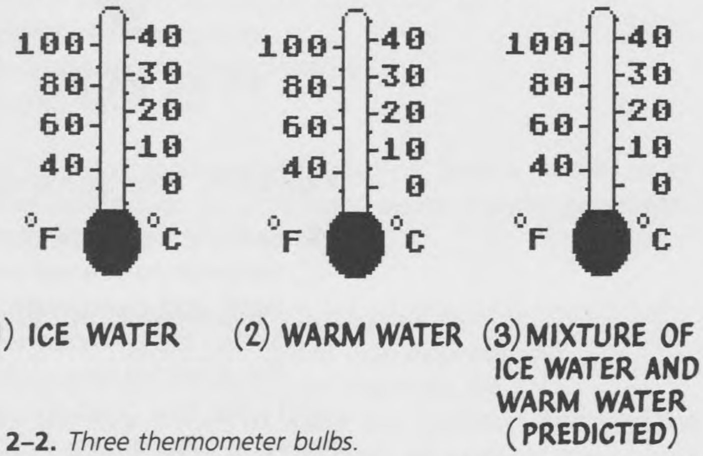


Figure 2–2. *Three thermometer bulbs.*

Next, try reversing the proportions by using 2/3 cup of ice water and 1/3 cup of lukewarm water. Record your observations below. ■17

t(cold) ______

t(warm) ______

t(mixture) ______

Fill in the thermometer bulbs below to show your results. ■18

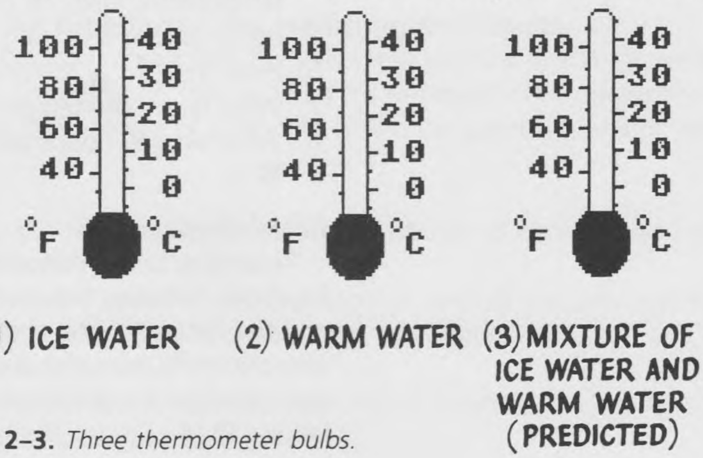


Figure 2–3. *Three thermometer bulbs.*

You may want to try proportions of hot and cold water other than those listed here. Can you draw any conclusions about the final temperature of the mixture when different proportions of lukewarm and cold water are used? ■19

Molecules, Heat, and Temperature—What It's All About

Early scientists thought of heat as a real substance which flows in and out of things—like the invisible flow of air we breathe. The current understanding of the relationship between the flow of heat energy and temperature is based on scientific theories about how molecules and radiation carry and exchange energy. In order to understand the meaning of temperature and its measurement, we need to learn more about the nature of heat energy contained in molecules.

The Movement of Molecules and Heat Energy

Most of the things we see and feel in our surroundings, including the air we breathe, are made of small particles called atoms and molecules.

The water in which you dipped the sensor consists of a very large number of molecules moving in all directions. Because of their motion, scientists say the water molecules contain heat energy. Both the air in a room and a container full of water consist of many molecules moving about wildly and colliding with each other and other objects.

If the average energy associated with the motion of molecules in another object in the room is lower than that of the air molecules, we say the object is colder than the surrounding air. The hotter air molecules collide with those in the colder object, transfer some energy, and slow down. As a result, some of the molecules in the colder object will gain energy and the object will become hotter.

Heat flow does not involve the flow of molecules from one object to another. Instead it consists of the loss of energy of the molecules in one object and the gain in energy of molecules in another.

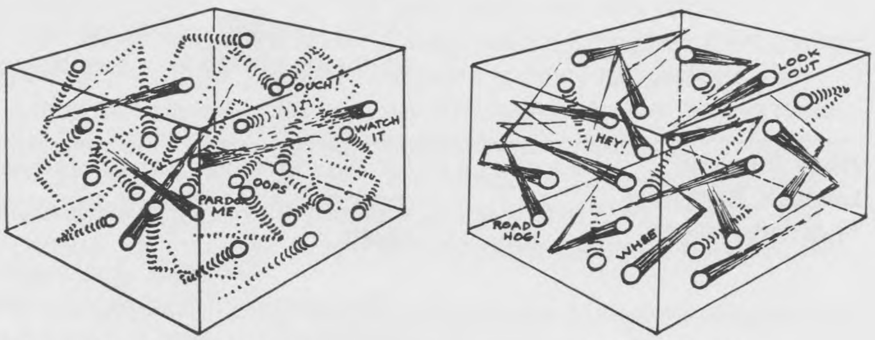
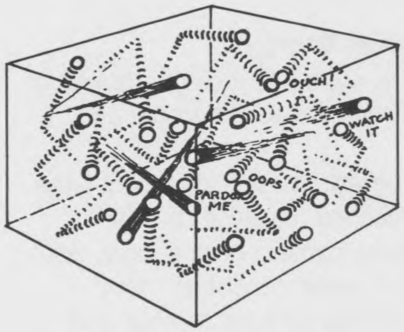


Figure 2–4. *Cold Molecules.* *Hot Molecules.*

Note: *If you have small round objects around the house such as marbles, tennis balls, or billiard balls, you can practice transferring energy from one to the other. Just start a hot molecule marble rolling toward a cold molecule marble. What happens when they collide?*
■20

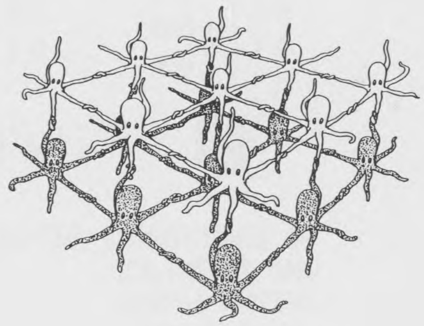
How Molecules Move in Gases, Liquids and Solids

Each type of material object stores heat energy differently. There are several ways material objects can store heat energy: 1. A gas, like air, consists of freely moving molecules which collide with each other and surrounding objects. 2. A liquid, like water, consists of molecules which stick together but can slither and slide past each other like worms in a glass container. 3. A solid object, like a lead brick, is made up of an enormous number of atoms which stick together so tightly that they cannot even slide around. Instead, they vibrate back and forth in various directions, as if attached to each other on all sides by tiny springs, or like octopi with all their arms extended holding on to each other.



Freely moving molecules.

Slithering Molecules.



Tightly–bound molecules.

Figure 2–5.

Heat as Radiant Energy

Heat energy can also be transferred to material objects by radiation. Light and microwaves are familiar examples of radiant energy that can cause objects to warm up. When radiation from the sun, an electric light, or a microwave oven is absorbed by an object, the atoms and molecules in the object move more rapidly.

Holding your hand near a light bulb that isn't on, and then turning on the light and feeling the heat flow into your hand is an example of an energy exchange caused by radiation.

Heat Energy, Locke's Test and Thermometers

For the molecules of the body are indeed so numerous and their motion so rapid that we can perceive nothing more than average values.

Ludwig E. Boltzmann

The concept of heat explains what we perceive in Locke's Test. By using touch we seem to sense the flow of heat energy. Something appears cold to the touch when heat energy flows from our fingers to

the object and warm to the touch when heat energy flows from the object to our finger. When an object we touch feels hot or cold, we sense whether the molecules in our fingers are speeding up or slowing down.

We can also explain the simple phenomenon we take for granted—the rise of the red alcohol in a glass tube thermometer.

When you place your finger over the bulb of your Temperature Lab glass tube thermometer, the alcohol rises. Why? The vibrating molecules in your finger collide with the molecules in the glass tube, which in turn collide with the red alcohol molecules inside the glass bulb. In this manner, the heat energy in your finger is transferred to the alcohol. When the alcohol is heated, the slithering molecules in the liquid move about more rapidly and need more space, so the alcohol expands and rises in the glass tube. When the alcohol in the thermometer cools down, the molecules slow down, the liquid contracts and falls.

Historical Notes on Temperature Scales

When thermometers were first developed, scientists didn't agree on the best way to associate numbers with the height of the liquid in a glass bulb thermometer. Numerous experiments were conducted to obtain high and low points on the thermometer. Low points included very cold air, ice during a severe winter freeze, and a mixture of salt with ice. High points included boiling water, animal blood, and melted butter! After picking a low point and a high point, scientists had to decide how many divisions or 'degrees' there should be between them.

In 1741, a Swede named Anders Celsius devised the Centigrade scale. His low point was ice water which he called zero degrees and his high point was boiling water which he called one hundred degrees. He placed one hundred equally–spaced marks along the glass tube from the zero–degree mark to the hundred–degree mark. The Centigrade scale (centi = hundred and grade = steps) has been renamed in honor of Celsius.

During the 18th and 19th centuries, a number of scientists proposed new temperature scales. For example, Ole Christensen Roemer, a Danish astronomer, chose the coldest object he could find as his first fixed point — common salt mixed with ice. His second fixed point was the temperature of boiling water. Influenced by the ancient Sumerians' fascination with multiples of six, Roemer divided the temperatures between the fixed points into sixty steps.

A Danish instrument maker named Gabriel Fahrenheit then changed Roemer's high–temperature fixed point to body temperature and added more divisions for accuracy. The temperature of boiling water became 212° Fahrenheit and freezing water became 32° Fahrenheit.

Although the fixed points in the Fahrenheit scale are not as easy to remember, it is extremely popular in the United States, Britain, and Canada. Scientists and people in most other countries, however, use the Celsius scale.

The equations for converting temperatures from the Fahrenheit to Celsius scales along with simple BASIC programs to perform temperature conversions are discussed in Appendix E.

CHAPTER 3
Temperature Projects

A Guide to the Projects

By measuring temperature and showing how temperature changes over time, the seven projects in this chapter will help you understand how heat energy works in the natural world.

The first project measures dewpoint, just as meteorologists do when they forecast the weather. It also helps us learn about evaporation and condensation.

Project Two focuses on how changes in temperature can be recorded over various time periods and displayed on graphs using the many features of Temperature Lab Software.

No temperature sensor or thermometer can record a new temperature instantly. In order to do projects involving the measurement of rapidly changing temperatures, you must know more about the 'response time' of the temperature sensor. In Project Three you will measure the sensor response time.

In Projects Four and Five you can find some answers to practical questions about how to keep drinks cold before a party and why salt is spread on icy roads. Project Six introduces you to heat energy changes during a chemical reaction.

The final project, Project Seven, describes how to observe daily temperature changes and relates these changes to the movement of the sun through the sky and local weather conditions.

Although the projects can be done in any order, we recommend that you complete Projects Two and Three before doing Projects Four, Five, Six or Seven.

Doing the projects should encourage you to make new observations and develop your own hypotheses and experiments. You may want to try your hand at writing your own programs to collect and analyze data. Appendix E introduces you to programming for the Temperature Lab in BASIC.

CHAPTER 3: Project One
Evaporation, Condensation, and Dewpoint

Dawn came, showing her rosy fingers through the early mists . . .
Homer

Evaporation and condensation are two very important natural processes which depend on heat energy. Rain, fog, mist, and clouds are formed by condensation. This project helps you learn more about evaporation and condensation by asking you to measure the dewpoint temperature just as meteorologists do when forecasting the weather. The dewpoint temperature is the temperature at which moisture starts condensing to form fog, rain, or snow.

Purposes

- To learn about evaporation and condensation.
- To measure dewpoint and find the temperature at which a mass of air will form a fog.

Equipment and Materials

The Laboratory Station
An empty tin can (with the label removed)
3 cups crushed ice
Room–temperature water
A 1–inch piece of hollow shoelace
A small rubber band

Note: *To prepare a small amount of crushed ice, you can wrap an old cloth around several ice cubes and hit the cloth with a hammer, or bang it on a hard surface 10 or 12 times.*

Condensation and Evaporation

In Chapter 2, the section titled "Molecules, Heat, and Temperature—What It's All About" explained that molecules in a liquid, such as water, slip and slide past each other. Even though these molecules attract each other and stick together, every once in a while a water molecule can accidentally gain enough heat energy to fly away. This process is called **evaporation**.

As water is heated up, more and more molecules evaporate. The evaporated water molecules become part of a gas consisting of water vapor or steam mixed with air molecules. The rate at which water molecules evaporate depends on several things: the temperature of the water; the pressure or density of the air surrounding the water; and the amount of moisture already in the air. We observe evaporation every day when we boil water and see condensed steam escaping from a pot or a kettle.

Condensation is the opposite of evaporation. If a certain amount of air containing water vapor is cooled, the water molecules will slow

down enough to stick together and become a liquid again. The fogged–up bathroom mirror after your hot shower is the result of condensation.

Whenever water and air are in contact, some water vapor molecules are condensing while other water molecules are evaporating. When the temperature is rising there is more evaporation than condensation, and when the temperature is falling there is more condensation than evaporation. Can you figure out why? ■1

Dewpoint

There is a maximum amount of water vapor that air can contain at a given temperature. Air that contains the maximum amount of water is said to be **saturated**. Cool air cannot hold as much moisture as warm air, and as saturated air is cooled, moisture condenses into droplets. The beads of liquid on a glass of ice water, morning mist, clouds, dew, and frost all result from saturated air being cooled.

The **dewpoint** is defined as the temperature at which moisture begins to condense out of air. This quantity is determined daily throughout the United States by the National Weather Service. If temperatures are expected to fall below the dewpoint, then mist, fog, frost, or rain can be forecast.

By measuring the dewpoint, we can learn a great deal about condensation and evaporation. There are two ways to measure dewpoint by using the Temperature Lab. The first method is very direct. Crushed ice is added to water in a can until moisture just starts to condense out of the air. In the second method, the dewpoint is determined by measuring the temperature at which evaporation takes place.

Measuring the Dewpoint Directly

If crushed ice is added piece by piece to a tin can containing water, the ice floats on top of the water. The water near the top of the can which comes from the melted ice will be cooler then the water further down. A band of small drops of condensed moisture will begin to form on the outside of the can. The bottom of the band of condensed moisture represents the line between the temperature at which condensation takes place and temperatures too warm for condensation to occur. The temperature of the water opposite the band is the dewpoint temperature.

The surface temperature of the tin can at the bottom of the band of condensed moisture and the temperature of the water inside the can which is just behind the bottom of the outside band of condensation are approximately the same.

Let's use the temperature sensor to determine the dewpoint.

Materials

An empty tin can
Crushed Ice
Room–temperature water
A large cake pan or tray

Setting Up and Doing the Experiment

1. Set up the Laboratory Station. (See Appendix A.)
2. Choose the BULB option from the menu. (See Appendix A.)
3. Fill the tin can about half–full of room–temperature water. (20°C is fine.) Use your sensor to measure temperature if you wish.
4. Place the tin can in the cake pan or tray.
5. Prepare about 1/2 cup of crushed ice.
6. Look to see if small beads of water are forming on the outside of the can. If you see any, pour out the water and start over again with warmer water in the can.
7. Put the temperature sensor in the water in the can.
8. Place a marble–sized chunk of ice in the can.
9. Wait about a half–minute and then watch for little beads of water—condensation—around the outside of the can, about halfway up the side, as the ice chills the water.
10. If no condensation appears, when the ice chunk has melted, add another similar–sized piece of ice.
11. Repeat Step 9 until you see a band of condensation form around the outside of the can.

Note: *It is sometimes tricky to spot the condensation as it often consists of a very light layer of tiny water droplets. Sometimes wiping the surface of the can with a tissue paper or paper towel and then immediate watching for the band of moisture helps.*

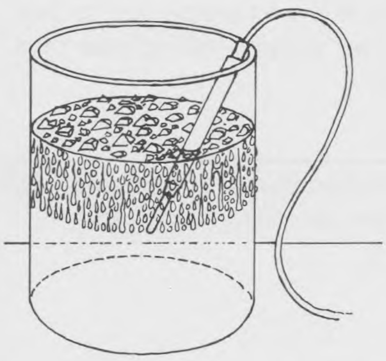


Figure 3.1–1. *Lifting the temperature sensor in the can of water.*

12. Carefully raise the temperature sensor in the water in the can until it is just opposite to the bottom of the band of condensation on the outside surface of the can. See Figure 3.1–1
13. Count to 20 slowly and then press the **F3** key on the computer to record the dewpoint temperature. Enter the recorded temperature in degrees Celsius below or in your laboratory notebook. ■2

Dewpoint Temperature, measured directly _______°C

Determining the Dewpoint Using Cooling by Evaporation

The United States Weather Service does not determine dewpoint directly as you just did—it takes too long. The method used by the Weather Service depends on a process called **cooling by evaporation**. When water is warm enough to evaporate, the fastest molecules containing the most heat energy boil off first and leave the slower molecules behind. When evaporation is taking place, the remaining liquid is cooler than before the evaporation started because the molecules that remain have less heat energy. For example, you feel cool before drying off after a bath or shower because your skin is heating up the water droplets on it, and the evaporation which results cools down the remaining water.

How can we measure the dewpoint by using cooling by evaporation? There are two important temperatures to measure to determine the dewpoint by this method.

First we need what is called the **dry bulb temperature**. This is the temperature of the surrounding air. It is called 'dry bulb' to distinguish

it from the other important temperature measurement necessary for dewpoint determination, **wet bulb temperature**.

Wet bulb temperature is found by covering a thermometer bulb with a wet cloth and waving it in the air and then measuring the temperature. Meteorologists do this with a device called a sling psychrometer, but we can use the temperature sensor in the same way.

Unless the air is saturated with water vapor, cooling by evaporation makes the wet bulb temperature lower than the dry bulb temperature.

The dewpoint is the temperature at which the water vapor condenses faster than the water molecules evaporate. It is a measure of the amount of water vapor at a particular temperature.

Meteorologists can find the dewpoint if both the wet and dry bulb temperatures are known. The number of degrees the temperature drops when the wet bulb temperature is measured depends on the rate of evaporation. The rate of evaporation depends on the amount of water vapor already contained in the air. When there are more water molecules in the air, there is less evaporation.

After taking many wet and dry bulb readings at different temperatures, meteorologists have constructed tables to determine the dewpoint. A Dewpoint Table is included below to enable you to look up the dewpoint after completing the next activity—taking your own wet and dry bulb temperature readings.

Measuring the Wet and Dry Bulb Temperatures

Let's measure the wet and dry bulb temperatures using the temperature sensor and then look up the dewpoint in the table.

Materials

1-inch piece of hollow shoelace
Small rubber band
A cup of room-temperature water

Setting up the Experiment

1. Set up the Laboratory Station. (See Appendix A.)
2. Choose the BULB option. (See Appendix A.)

Measuring Dry Bulb Temperature

1. If the temperature sensor has been in the room for the past few minutes, record its temperature by pressing the **F3** key. If the sensor is warmer or cooler than the room temperature you should wait several minutes before recording the temperature. Record the temperature in the space provided in Table 3.1–1.

Figure 3.1–2 *Temperature sensor with shoelace*

Measuring Wet Bulb Temperature

1. Slip the one-inch hollow shoelace on to the tip of the temperature sensor. Let about one-half inch of shoelace hang off the end.
2. Fasten the shoelace to the sensor tip with a small rubber band. See Figure 3.1–2.
3. Fill a styrofoam cup about half-full of room temperature water.

4. Place a styrofoam cup in the cake pan or tray.
5. Dip the tip of the sensor and shoelace into the cup of room–temperature water.
6. Take the temperature sensor out of the water and wave it back and forth vigorously for about two minutes.
7. Watch the screen to see how low the temperature goes as a result of evaporation from the water–soaked tip of the sensor. The lowest temperature is the wet bulb temperature.
8. Press the **F3** key to record temperature.
9. Finish filling in the table below by looking up the dewpoint in the Dewpoint Table on the next page. ■3

Table 3.1–1

LOCATION ____________ DATE ________

TIME OF DAY ________________________

DRY BULB TEMPERATURE _____ (°F)

WET BULB TEMPERATURE _____ (°F)

DEWPOINT _______

Questions

1. How do the dewpoints compare using the condensation method and cooling by evaporation? If they are not within 1° or 2°C of each other something may be wrong, and you might want to repeat your observations or check the method you used to read the Dewpoint Table. ■4
2. What would happen in your room if you cooled the air to the dewpoint without removing any moisture from it? ■5

---

3. Why doesn't moisture condense on surfaces in an air–conditioned room? ■6

Suggestions for other Projects

1. Why not monitor the dewpoint outdoors every day near the room where you keep the Laboratory Station and keep a record of the weather each day? You can attach one or more extender cables to the temperature sensor so it can reach outside. What are the weather conditions when there is a large difference between the dry bulb temperature and the dewpoint? A small difference? (Precipitation—rain, hail, snow, etc.—and wind direction and speed are good quantities to measure also and relate to the dewpoint.) ■7
2. You can measure the dewpoint inside and outside on the same day. Do you expect them to be the same? Why or why not? ■8

How to Read the Dewpoint Table

The Dewpoint Table below shows the temperatures in degrees Celsius. Let's suppose you measured a dry bulb temperature of 22°C and a wet bulb temperature of 19°C. The difference between the dry bulb and wet bulb temperatures is 3°C.

To find the dewpoint using the table below: start at t(dry) °C and look down the column to find the dry bulb temperature—in this case, 22°C. Then look along the temperature difference row—t(dry)°C – t(wet)°C—to find the number representing the difference between the wet and dry bulb temperatures— in this case, 3°C. Now, find the number at which the column and row intersect. The dewpoint, as shown in Table 3.1–2, is 17°C. The small "t" is the symbol for temperature.

Table 3.1–2. *Dewpoint Table.*

t_{dry} (°C) – t_{wet} (°C)

t_{dry} (°C)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
-4	-7																					
-3	-6																					
-2	-5	-8	-13																			
-1	-4	-7	-11																			
0	-3	-6	-9	-15	-24																	
1	-2	-5	-8	-13	-20																	
2	-1	-3	-6	-11	-17																	
3	0	-2	-5	-9	-14																	
4	1	-1	-4	-7	-11	-19																
5	3	0	-2	-5	-9	-16																
6	4	1	-1	-4	-7	-13	-21															
7	5	2	0	-3	-6	-11	-17															
8	6	3	1	-2	-5	-9	-14															
9	7	5	3	0	-3	-7	-12															
10	8	6	4	1	-2	-5	-9	-14	-28													
11	9	7	5	3	-1	-4	-7	-12	-22													
12	10	8	6	4	1	-2	-5	-9	-16													
13	11	10	8	5	3	-1	-4	-7	-13													
14	12	11	9	6	4	1	-2	-5	-10	-17												
15	13	12	10	8	6	3	-1	-3	-8	-14												
16	14	13	11	9	7	4	1	-1	-6	-10	-17											
17	15	14	12	10	8	6	3	0	-4	-8	-14											
18	16	15	13	11	9	7	4	2	-2	-5	-10	-19										
19	18	16	14	13	11	9	6	3	0	-4	-8	-15										
20	19	17	15	14	12	10	7	4	2	-2	-5	-10	-19									
21	20	18	16	15	13	11	9	6	4	1	-3	-8	-15									
22	21	19	17	16	14	12	10	8	5	3	-1	-5	-10	-19								
23	22	20	19	17	15	13	11	9	7	5	1	-3	-8	-15								
24	23	21	20	18	16	14	12	10	8	6	2	-1	-5	-10	-18							
25	24	22	21	19	17	16	13	12	10	8	4	1	-3	-7	-14							
26	25	23	22	20	18	17	15	13	11	9	6	3	0	-4	-9	-18						
27	26	24	23	21	20	18	16	15	13	10	8	5	2	-2	-6	-14						
28	27	25	24	22	21	19	17	16	14	11	9	7	4	-1	-3	-9	-16					
29	28	26	25	23	22	20	18	17	15	13	11	9	6	3	-1	-6	-12					
30	29	27	26	24	23	21	19	18	16	14	12	10	8	5	1	-2	-8	-15				
31	30	28	27	26	24	23	21	20	18	16	14	12	10	7	3	0	-5	-11				
32	31	29	28	27	25	24	22	21	19	17	15	13	11	8	5	2	-2	-7	-14			
33	32	30	29	28	26	25	23	22	20	19	17	15	13	10	7	4	0	-4	-10			
34	33	31	30	29	27	26	24	23	21	20	18	16	14	12	9	6	3	-1	-5	-12	-29	
35	34	32	31	30	28	27	26	24	23	21	19	18	16	14	11	8	5	2	-2	-8	-19	
36	35	33	32	31	29	28	27	25	24	22	20	19	17	15	13	10	7	4	0	-4	-10	
37	36	34	33	32	31	29	28	27	25	24	22	20	18	16	14	12	9	6	3	-2	-7	
38	37	35	34	33	32	30	29	28	26	25	23	21	19	17	15	13	11	8	5	1	-3	-9
39	38	36	35	34	33	31	30	29	27	26	24	23	21	19	17	15	13	10	7	4	-1	-6
40	39	37	36	35	34	32	31	30	28	27	25	24	22	20	18	16	14	12	9	6	2	-2

CHAPTER 3: Project Two

Graphing How Temperature Changes Over Time

The essential fact is that all the pictures which science now draws of nature . . . are mathematical pictures.

Sir James Jeans

Scientists use graphs often. Graphs are mathematical pictures of natural phenomena. They show relationships between things in a visual way by using number scales. In this project you will learn how to draw graphs to represent changes in temperature over different periods of time.

Purposes

- To understand how changes in temperature can be represented by a graph.
- To observe how the shape of the graph is affected by rapid temperature changes and slow temperature changes.
- To observe how changes in time scale affect the shape of a graph.

Equipment and Materials

The Laboratory Station
2 styrofoam cups
Ice water
Warm water
A large cake pan or tray

Two–Dimensional Graphs

A two–dimensional graph is any graph drawn on any fairly flat surface such as a television screen or a monitor screen or a piece of paper. Two–dimensional graphs have two axes: vertical and horizontal. Each axis has a scale which represents quantities being measured, and sometimes background lines or dots are drawn. See Figure 3.2–1.

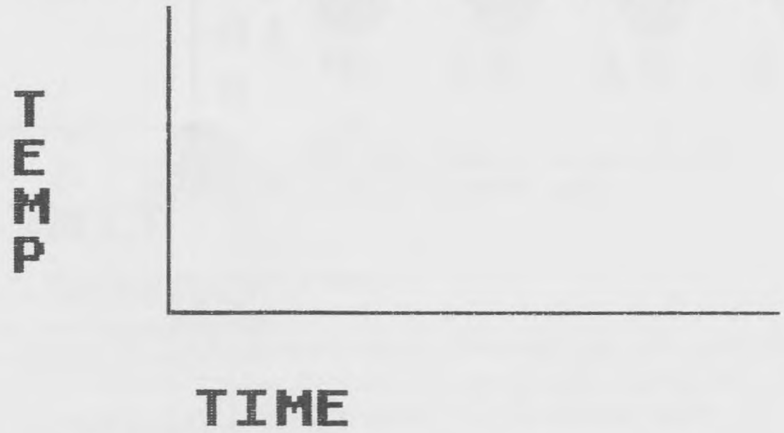


Figure 3.2–1. *Axes representing temperature as a function of time.*

The horizontal (left to right) distance along the time scale represents the time at which a certain temperature was recorded. The vertical (up–down) distance along the temperature scale represents the recorded temperatures.

To represent temperature changes over time, we can draw a graph using one axis for time and one for temperature. The time scale on the graph shows the time in minutes, seconds, etc. The temperature scale can show the temperature in degrees Fahrenheit or degrees Celsius or whatever other temperature scale you may wish to use. See Figure 3.2–2.

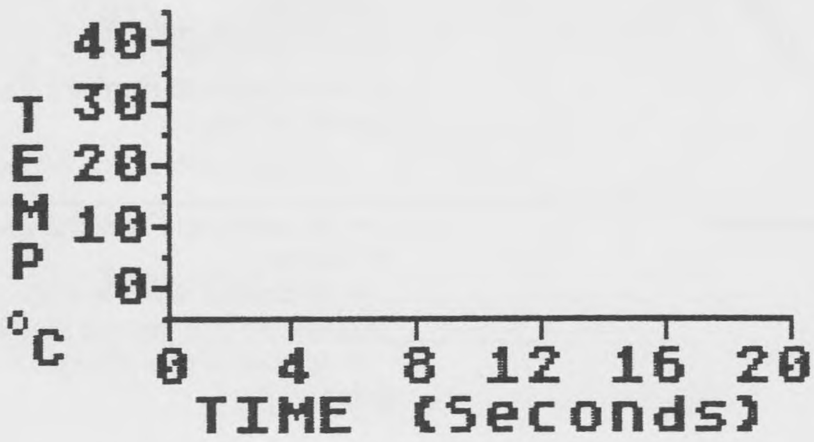


Figure 3.2–2. *Axes representing temperature as a function of time with the scales drawn.*

When a temperature over time graph is drawn, it consists of a series of dots known as **data points**. The location of each dot represents the temperature at a particular time. See Figure 3–2.3.

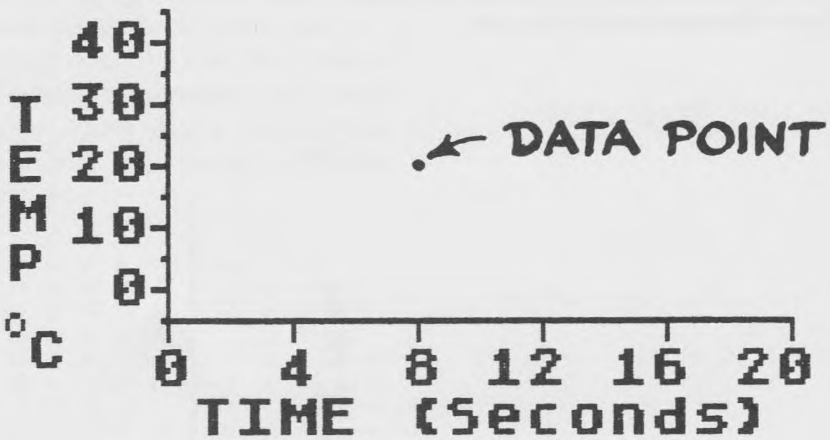


Figure 2.2–3. *Axes representing temperature as a function of time with one data point plotted. The point shows that t(Celsius) = 20 when elapsed time is 8 seconds.*

The dot representing a data point in Figure 3.2–3 tells us that 8 seconds after we started recording temperatures, the temperature was 20°C. Placing a dot on the graph is referred to as **plotting**.

DEMO Program

The Temperature Lab Diskette contains a demonstration (DEMO) program which lets you observe points being placed on a graph each time a temperature is measured. The DEMO Program shows how the temperature measurements you make relate to a graph of how temperature changes over time.

Observing and Making a Temperature–Time Graph with the DEMO Program

By setting up containers of different temperature liquids, and taking measurements with your sensor, you can see the temperature data you are gathering immediately transformed into a graph.

Setting Up the Observation

1. Set up the Laboratory Station. (See Appendix A.)
2. Pour some ice and water in one styrofoam cup, and lukewarm water in another.
3. Place the two styrofoam cups in the cake pan or tray.
4. Choose the DEMO option. (See Appendix A.)
5. Watch the entire sequence through once so that you are familiar with what happens on the screen.
6. Stick your sensor in one of the cups of water.
7. Return to the menu and choose the DEMO option again.
8. Move your sensor in and out and between the two cups of water as the thermometer moves across the screen.

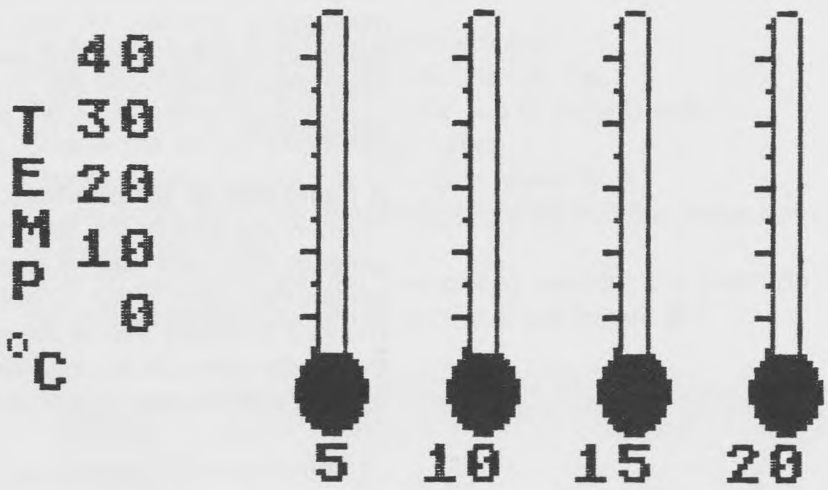


Figure 3.2–4. *Thermometer bulbs as they appear after moving across the screen in the DEMO option.*

9. Watch as the graph is drawn.

Repeat the DEMO Program several times until you are comfortable with the graph. You can do several things to collect temperature data for the graph. One interesting activity mentioned in Chapter 2 is breathing in and out on the sensor. By doing this activity, you can record your respiration rate.

Producing a Data Table by Reading a Graph

Create an interesting graph on the television set or monitor screen by following Steps 6-9 outlined above, and then filling in the data table below by reading the points from your graph. If you are not sure of how to do this activity or want to check your method, you can look ahead to Appendix B for a sample graph and data table. ■1

Table 3.2–1. *Data table for temperature as a function of time for 5–second intervals from 0 seconds to 20 seconds.*

TIME (SEC.)	TEMP. (°C)
0	
5	
10	
15	
20	

More Observations: Reading the Graphs

Let's use the SET UP EXPERIMENT graphing program to produce two more temperature vs. time graphs. The first will show the temperature rising rapidly. In the second, the temperature will rise more slowly. To make the next two observations you need a styrofoam cup full of ice and water and a cup of water which has been sitting in the room for 20 minutes or more and is at about room temperature.

A Rapid Rise in Temperature

When you transfer the temperature sensor rapidly from the ice water to the warm water it does not change temperature immediately. After about 10 seconds its temperature should have changed to almost that of the room–temperature water. Try letting the sensor warm up by using the SET UP EXPERIMENT program and running a 30–second experiment.

1. Pour some ice water in one styrofoam cup, and some room temperature water in another.
2. Place the temperature sensor in the cup of ice water.
3. Press the red joystick button to return to the menu showing the BEGIN EXPERIMENT option.
4. Select the CHOOSE TIME option. (See Appendix A.)
5. Choose a Total Time of 30 seconds. (See Appendix A.)
6. Next BEGIN THE EXPERIMENT (See Appendix A) and **at the same time** quickly transfer the sensor from the ice water to the room–temperature water.
7. After 30 seconds have passed, look at the completed graph on the television screen or monitor. Sketch your results in the graph on the next page. ■2

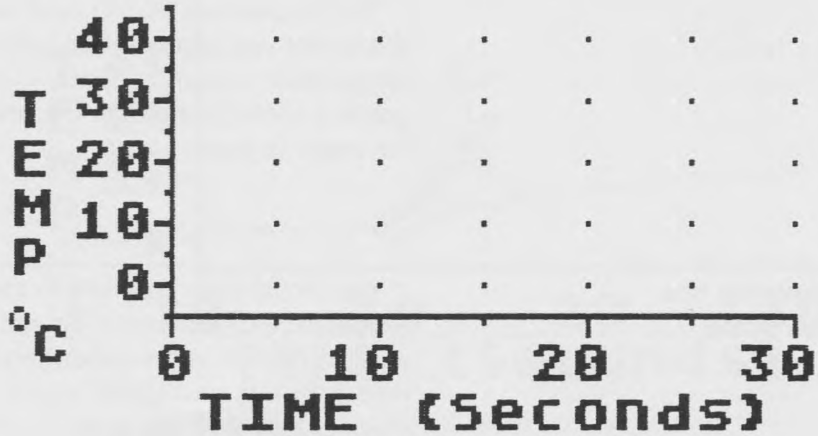


Figure 3.2–5. *Axes for graph of temperature as a function of time for a Total Time of 30 seconds.*

The temperature should have risen rapidly. Because of the rapid rise we say the curve has a large slope.

A Slow Rise in Temperature

If you transfer the temperature sensor suddenly from ice water to the air in the room, the sensor will eventually warm up to room temperature. It warms up more slowly in air than in water of the same temperature. To observe this more gradual warming do the following steps:

1. Put some ice and water in a styrofoam cup.
2. Place the styrofoam cup in the cake pan or tray.
3. Place the temperature sensor in the cup of ice and water.
4. Choose the SET UP EXPERIMENT option.
5. Choose a Total Time of 1 minute (See Appendix A.)
6. As you begin recording temperature, quickly pull the sensor out of the ice and water.
7. After 60 seconds (1 minute) have passed, examine the graph on the screen. Sketch your results on the graph below. ■3

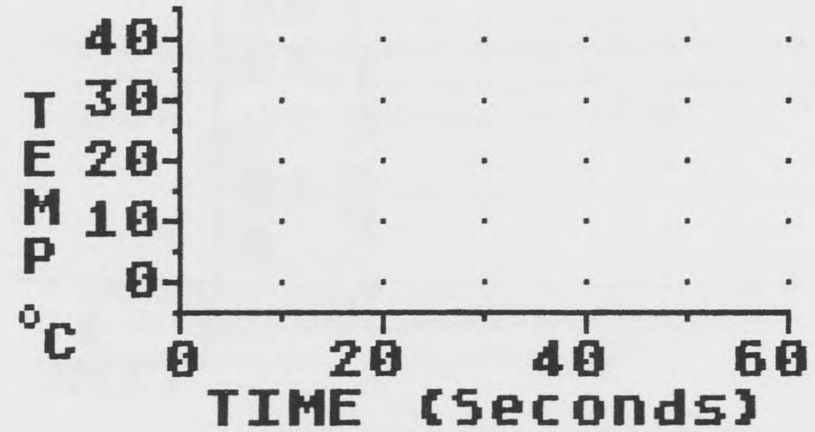


Figure 3.2–6. *Axes for graph of temperature as a function of time for a Total Time of 60 seconds.*

The temperature should have taken longer to rise than it did when the sensor was plunged into room-temperature water. Because the temperature rises more slowly in air than in water, the slope of the graph is more gentle than the one you just drew for the transfer from ice water to warm water.

Changing the Time Scale

You should have observed in the previous experiments that the temperature of the sensor did not rise to room temperature before 60 seconds passed. When producing a graph representing changes over time, scientists usually pick a time scale long enough to show all the changes that they interested in on the graph. In order to see the entire temperature rise on one graph, it is necessary to watch the sensor warm up in the air for about five minutes after it is removed from the ice water.

To do the five-minute sensor warming experiment follow the instructions below:

1. Set up the Laboratory Station.
2. Choose the SET UP EXPERIMENT option. (See Appendix A.)
3. Choose a Total Time of five minutes. (See Appendix A.)
4. Pour some ice and water in a styrofoam cup.
5. Place the styrofoam cup in the cake pan or tray.
6. Get ready to have the computer collect data for five minutes by placing the temperature sensor in the ice and water.
7. Begin the experiment. (See Appendix A.)
8. **At the same time**, pull the sensor out of the ice and water and put it down.
9. After the five minutes have passed, examine the completed graph on the screen. Draw a sketch of the ice-water-to-room-air warming curve on the graph shown below. ■4

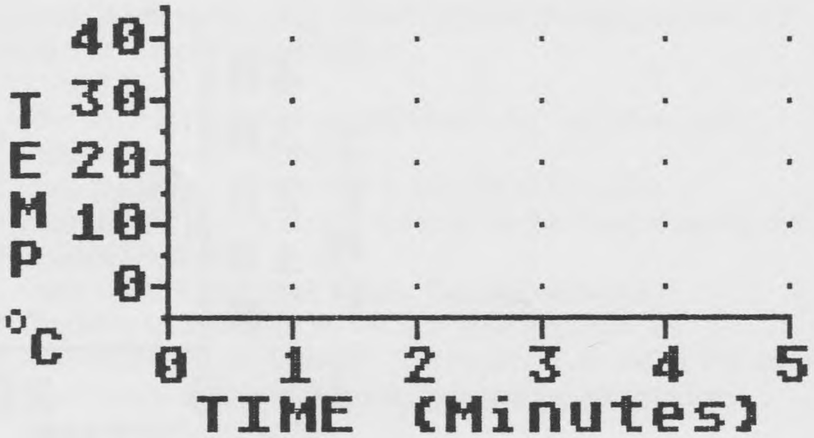


Figure 3.2-7. *Axes for graph of temperatures as a function of time for a Total Time of 5 minutes.*

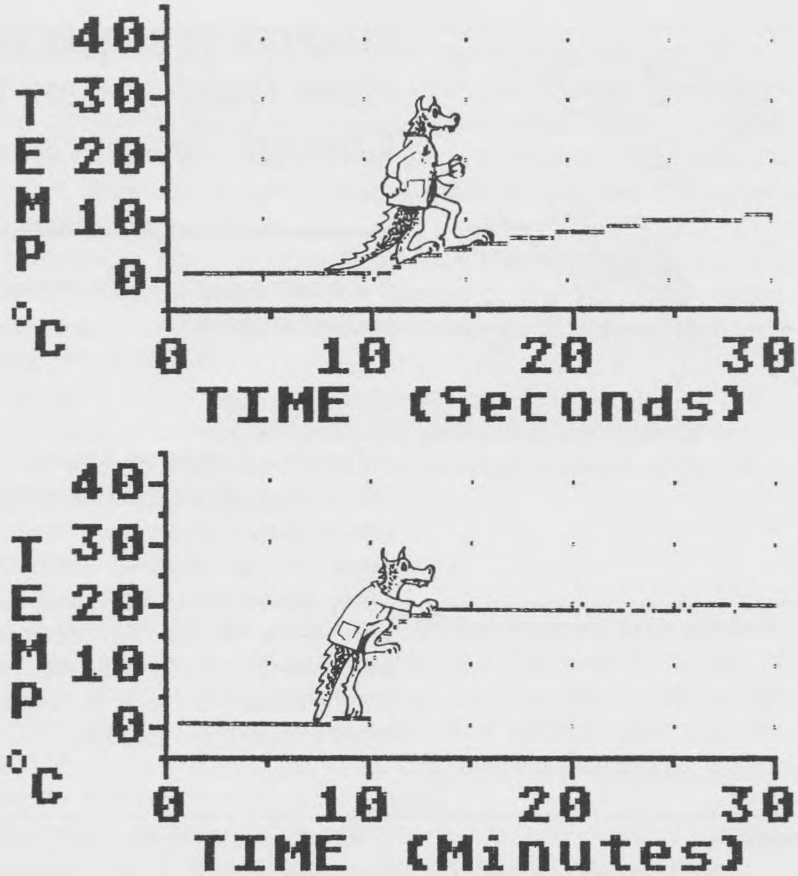


Figure 3.2–8. *These graphs represent data from two trials of the same observation. In both cases, a temperature sensor was pulled out of ice water and allowed to warm up slowly in room air. Because of the different time scales used, one graph appears to have a gentle slope while the other appears to have a steep slope. In the 30–second graph, the sensor was pulled out of the ice water after 11 seconds. In the 30–minute graph, the sensor is pulled out of the ice water after 10 minutes. The sensor appears to take 6 or 7 minutes to reach room temperature.*

Questions

You have just made the same observation twice using different time scales.

By examining the two ice water–to–air warming curves you sketched, and comparing them, you can answer the questions below.

1. Compare the five–minute and the one–minute (60 seconds) graph. Is 60 seconds a long enough time to record the change in temperature from ice water temperature to the temperature of the air in the room? ■5

2. Is the slope of the five–minute warming curve you just drew steeper or more gentle than the slope of the ice water–to–air warming curve using a 60–second time scale? ■6

3. If you observe a difference between the steepness of the slope in the 60–second experiment and the five–minute experiment, can you explain the reason for the difference? ■7

CHAPTER 3: Project Three

How Quickly Can The Sensor Change Temperature?

It is much easier to make measurements than to know exactly what you are measuring.

J.W.N. Sullivan

The time it takes your temperature sensor to react and respond to temperature changes is important. To be able to measure how temperature changes over time, it is necessary to know how long it takes for your sensor to reach its final temperature so that you can safely record the temperature as data. Although the term 'response time' has a very special meaning for scientists and engineers, for the purposes of this project, 'response time' will mean the time it takes for the sensor to reach its final temperature when it undergoes a rapid temperature change.

Purposes

- To measure how quickly the sensor responds when the temperature of its surroundings suddenly changes.
- To learn more about what affects the response time of the sensor.
- To learn more about how heat energy is transferred to a temperature–measuring device.

Equipment and Materials

The Laboratory Station
Two large styrofoam cups
Ice cubes
Ice water
Lukewarm water
A large cake pan or tray

What is Response Time?

Remember the last time you had a fever? You had to hold a thermometer under your tongue for four or five minutes. This is because it takes a certain amount of time for heat energy to be transferred from one object to another. If the thermometer was taken out of your mouth too soon, the total amount of heat energy would not be transferred and the temperature reading would be too low.

How long do you have to wait to record temperatures with the Temperature Lab Temperature Sensor? To answer this question, you will have to find how long it takes your sensor to reach final temperature. The cooling and warming curves you obtained in the last project would have been much steeper if the sensor responded instantly.

What Does Response Time Represent?

Response time is a measure of how rapidly heat energy flows between the temperature sensor and the object whose temperature is being measured. Response time depends on many things. One way you can discover what these things are is to measure response time in different situations. By asking several questions you can find out what influences response time.

For example, does response depend on the material you put in contact with your sensor? Does it depend on the size of the sensor or thermometer, or the size of the object you put in contact with your sensor?

Further, it would seem that response time also depends on the temperature difference between the sensor and the material in contact with it. Is response time shorter when a sensor undergoes a small temperature change?

Measuring Response Time

Let's consider the first question: Does the response time depend upon the material in contact with the sensor? In order to answer this question, you can produce a warming curve by transferring the sensor from ice water to room–temperature water, and compare it to the warming curve which results when the sensor is transferred from ice water to room–temperature air instead.

By looking carefully at the warming curves, you can find out the response time of your sensor in water and in air. Knowing the response time is very important. You will be doing many experiments involving air and water temperature. You need to know that your sensor is not capable of recording temperature changes which occur faster than its response time.

Setting up the Experiment

1. Set up the Laboratory Station. (See Appendix A.)
2. Choose the SET UP EXPERIMENT option. (See Appendix A.)
3. Choose a Total Time of 30 seconds and a temperature scale of Celsius. (See Appendix A.)
4. Put some ice in a styrofoam cup.
5. Add enough water to the cup so that the tip of the sensor will be covered.
6. Place the sensor tip in the ice and water.
7. Pour room–temperature water into another styrofoam cup.
8. Place the two styrofoam cups in the cake pan or tray.

Recording The Temperatures

1. Get ready to transfer the temperature sensor from the ice and water to the room–temperature water.
2. Choose the BEGIN EXPERIMENT option. Begin recording temperatures, and at the same time, plunge the sensor into the room–temperature water.
3. Wait until the 30 seconds are up.

Determining the Response Time

One way to determine the approximate response time of the sensor is to draw a graph of the warming curve and estimate the time from the graph.

After the 30-second experiment is finished, press the red joystick button to see the menu. Next, choose to see the DATA TABLE.

When the data table appears, you will notice that in the list of data, some numbers are highlighted. These numbers will be lighter than the numbers above and below them. The highlighted numbers are a *selection* of data points. Because it is so time-comsuming to graph all 121 data points collected, it is easier to choose points at regular intervals to be plotted on the graph.

This group of selected data points can be used to make a summary data table. Then, each data point in the summary data table can be plotted in each of the vertical lines on the graph.

Copy the highlighted data temperatures from the screen onto Table 3.3-1 below. ■1 (See Appendix A for a summary of instructions and Appendix F for an extra copy of the table.

Table 3.3-1. *Data table for filling in highlighted temperatures for a 30-second time period.*

TIME (60th SEC.)	TIME (SEC.)	TEMP (°C)
0	0	
60	1	
120	2	
180	3	
240	4	
300	5	
360	6	
420	7	
480	8	
540	9	
600	10	

TIME (60th SEC.)	TIME (SEC.)	TEMP (°C)
660	11	
720	12	
780	13	
840	14	
900	15	
960	16	
1020	17	
1080	18	
1140	19	
1200	20	

TIME (60th SEC.)	TIME (SEC.)	TEMP (°C)
1260	21	
1320	22	
1380	23	
1440	24	
1500	25	
1560	26	
1620	27	
1680	28	
1740	29	
1800	30	

Note: *The definition of response time we use in the Temperature Lab is easy to understand and measure, but when an experiment is repeated several times, the definition does not lead to very consistent results. The standard definition of response time involves analyzing how long it takes for a temperature to reach 63.2% of the difference between its initial and final value as it undergoes change. If you want to analyze your data again using the standard definition, you will probably get more consistent results.*

Next plot the values of temperature in the graph shown below: ■2

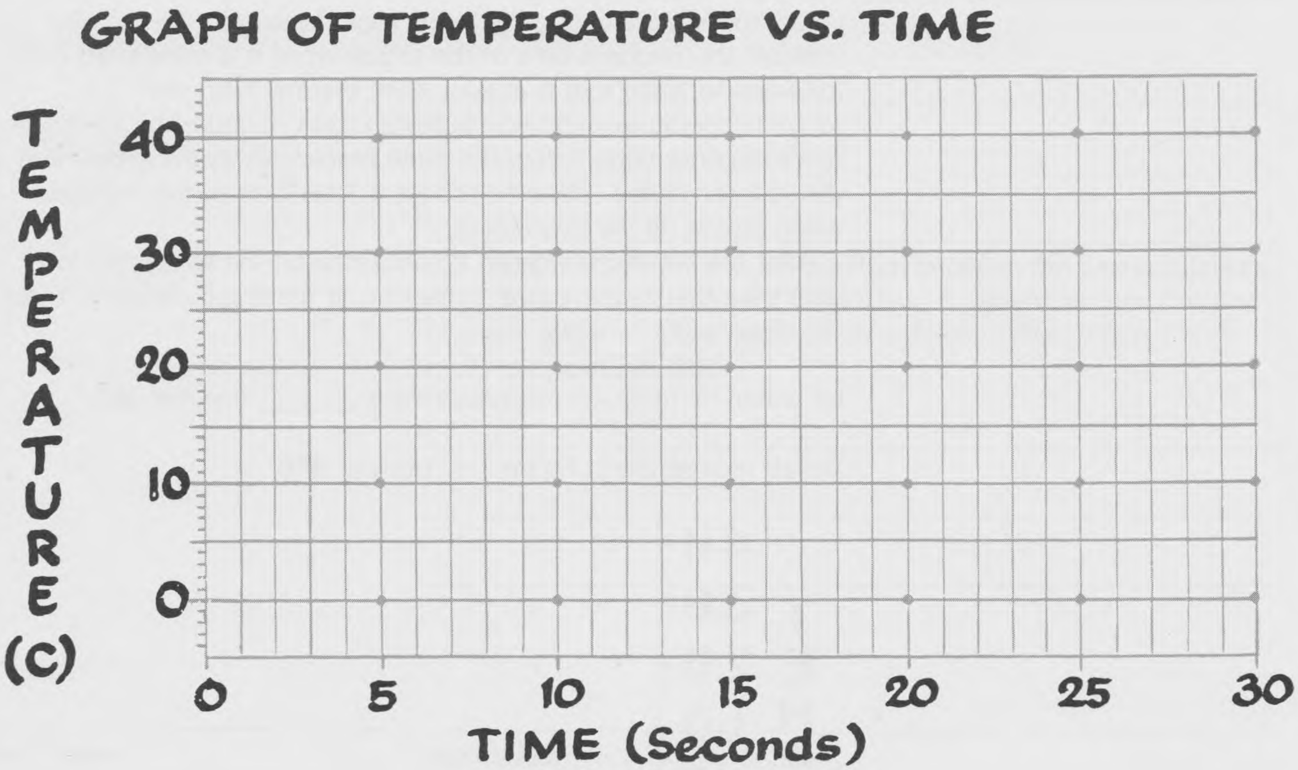


Figure 3.3–1. *Graph for a Total Time of 30 seconds.*

Look at the graph you've just made. How many seconds passed before the temperature reached its final value? By looking at the graph you will see a point at which the line levels off and does not increase or decrease substantially. Enter the sensor response time below.

Ice–water–to–room–temperature–water response time is _______ seconds. ■3

Note: *Sometimes when the temperature measured is between two values it appears to fluctuate up and down by one degree. The fluctuation shows up in the graph as a wobbly line. See Figure 3.3–2.*

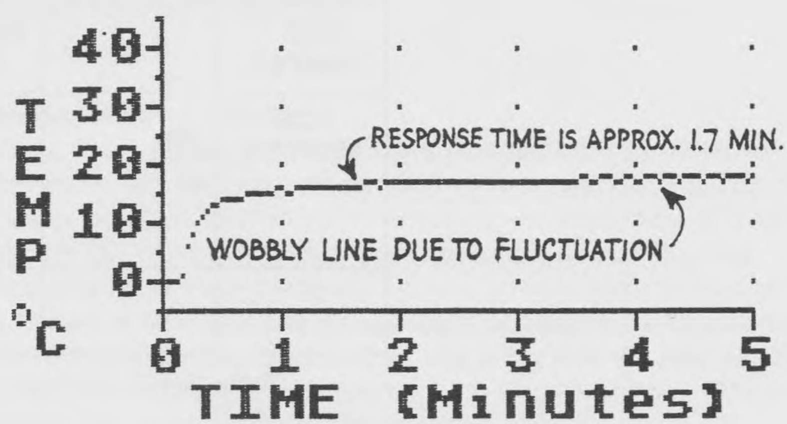


Figure 3.3–2. *Response time of a sensor transferred from ice water to air.*

Other Response Time Experiments

There are several other response time experiments you can do. For example, you can measure the response time of the sensor when it is taken from ice water and left in the room to warm. You can also measure the response time of the sensor when it is transferred from ice water to water that is at least 10°C warmer than the room-temperature water you first used. Let's measure the ice-water to air response time. Follow the same procedures as the experiment you just completed. This time choose a Total Time of five minutes when setting up the experiment.

After the five-minute graph is completed on the screen, try to determine the response time by looking at the graph direction. Enter the response time below.

Ice water-to-room-air response time is _______ minutes. ■5

Sketch your results in Figure 3.3-3 below. ■6

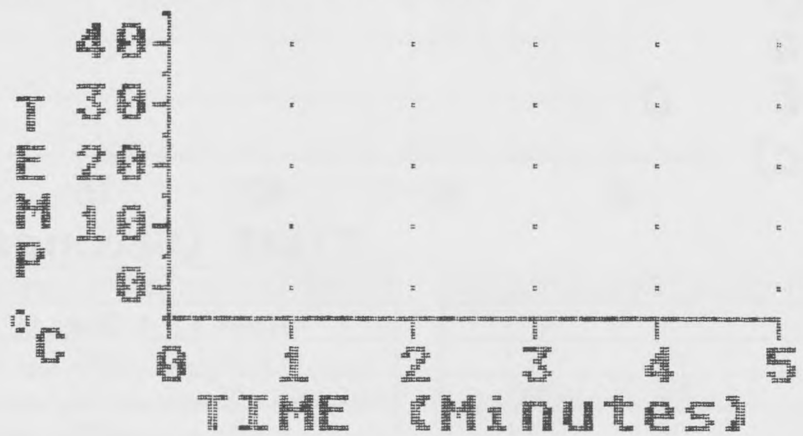


Figure 3.3-3. *Axes for 5-minute graph.*

You might want to summarize your results in a table. See Figure 3.3-2.

FIRST MEDIUM	INITIAL TEMP (°C)	SECOND MEDIUM	FINAL TEMP(°C)	APPROX. RESPONSE TIME
ICE WATER		ROOM TEMP. WATER		
ICE WATER		ROOM AIR		

Table 3.3-2. *Summary of approximate response-time results.*

Note: *If you repeat these experiments several times you may find several different values for response time for each situation.*

Questions

1. Does the substance, water or air, which surrounds the temperature sensor affect the response time? Why or why not? ■7

2. Does the difference in temperature between the two substances affect the response time very much? That is, when the final container of water is warm, is the response time different than when it is at room temperature? ■8

The Three Cooling and Heating Processes

Discussion

In Chapter 2, the section titled 'Molecules, Heat, and Temperature—What it's All About' explained two principles of temperature. Let's use these principles and the results of the experiment you have just done as a basis for understanding heating and cooling.

The change in energy of the molecules in any material body that is heated or cooled occurs by three processes. First, molecules in surrounding material can collide with molecules in the object and exchange energy. This process is known as **conduction**. Second, if the surrounding material is a gas or liquid warmer or colder parts of it can flow past the material being heated or cooled and exchange energy with it. This is known as **convection**. Finally, radiant energy, such as light, can be transferred to or from the material. This is called **radiation heating** or **cooling**.

Newton's Law of Cooling

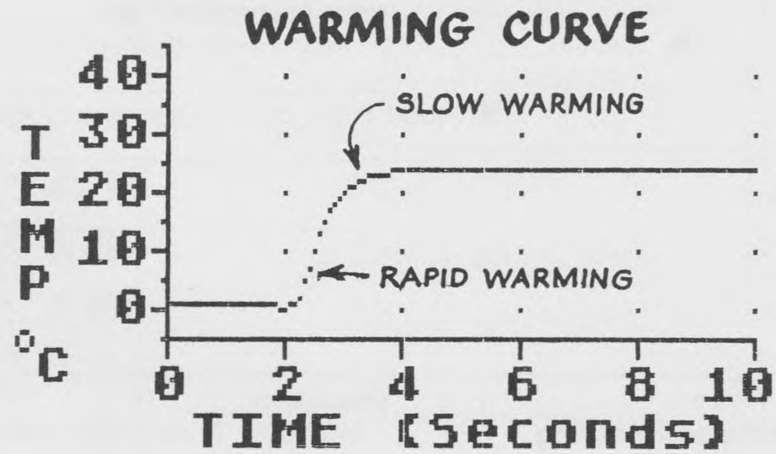
When the Temperature Lab Sensor is plunged from ice water to warm water, it is being heated by all three processes. A large cup of ice water placed in a warm room would also be heated by all three processes but more slowly than the small sensor. A cup of coffee would cool by all three processes. There is an approximate physical law known as Newton's Law of Cooling which seems to account for the effect of all cooling processes: *At any given time the rate at which an object cools (or heats) is proportional to the temperature difference between the object and its surroundings.*

For example, when the temperature difference doubles, so does the rate of cooling.

The Shape of the Sensor Warming Curve

Newton's Law of Cooling helps explain the shape of the Temperature Lab Sensor warming curve. When the sensor is first plunged into warm water, it has a temperature of about 0°C. Thus its rate of warming is rapid. As each second passes it is closer in temperature to the warm water which surrounds it, and the rate of warming is slower and slower. The warming curve is steep at first and then becomes steadily flatter.

The cooling curve is rather similar: at first the rate of cooling is rapid. It then becomes slower and slower.



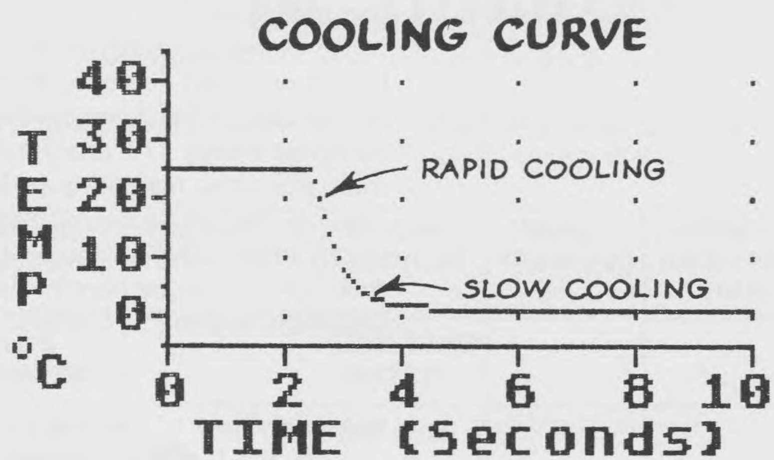


Figure 3.3–4. *Typical warming and cooling curves.*

Ideas for Other Observations

1. In the activities you just did, you took the sensor from ice water to room–temperature water. Try it the other way around. Will the response time be different? ■9
2. Try surrounding the end of the temperature sensor with a hunk of clay before response times are measured. Does the clay matter? If so, how does its size affect the response times? ■10

CHAPTER 3: Project Four
Keeping Your Soda Cold

—*Too hot, too hot!*
—Leontes in Shakespeare's
The Winter's Tale

When we want a cold drink on a hot day we add some ice cubes to the drink. After a few seconds pass we should have a cool refreshing glass of iced tea or lemonade. How does ice cool liquids so well? We depend on the cooling effectiveness of ice to prevent foods from spoiling as well as to cool our lemonade. In this project you will learn about a concept known as **latent heat of fusion**. It will help you understand why ice cools so effectively.

Purposes

- To review Newton's Law of Cooling (and Warming).
- To learn about the latent heat of fusion stored in ice.
- To use the Law of Cooling and the idea of latent heat of fusion to answer a practical question.

Equipment and Materials

The Laboratory Station
8 ice cubes
Two 8–ounce glasses (not styrofoam)
Room–temperature water
A large cake pan or tray

A Practical Question

Suppose you have planned a party and you want to serve cold drinks to your friends as soon as they arrive—only ten minutes from now. In front of you on the table are several glasses of room–temperature soda and a bowl of ice cubes.

It's a hot day and you'd like the drinks to be as cold and refreshing as possible ten minutes from now when they are served. Should you add the ice cubes right now? Or should you add the ice a couple minutes before serving the drinks?

Can you design an experiment to answer this practical question? Before devising an experiment, let's consider some more about the theory of heat energy absorption and the flow of heat energy between ice and air or water. Perhaps we can develop a hypothesis which will allow us to predict the answer to this question. A hypothesis, remember, is a statement that identifies general relationships between characteristics, properties, or events observed in nature.

Heat Energy in Ice

In Project One we discussed the process of condensation in which water molecules in air stick together to become a liquid when cooled. In this process water molecules which had formed a gas changed to a liquid state. If we cool the water enough, it will change to a solid state. This happens at 0°C (32°F). Solid water is known, of course, as ice. The molecules of ice are much more tightly bound to each other than the molecules in water. Ice is very rigid compared to water because the molecules are no longer free to slide past each other.

When an ice cube at 0°C is placed in warm water, it will cause much more cooling than an equal mass of water at 0°C. (You can easily set up an experiment to show this.) When the heat energy from the liquid is absorbed by the ice, most of it is needed to break the solid bonds which keep the ice molecules bound closely together. This allows the ice to become a liquid. Once enough energy has been provided to break the bonds between the ice molecules, any remaining heat energy is transferred to the melted ice water. This energy goes into increasing the speed at which the water molecules slither past each other. The heat energy needed to change ice at 0°C to water at 0°C is known as the **latent heat of fusion**.

Ice cools liquids effectively because so much of the heat energy in the liquid goes into melting the ice before the temperature of the melted ice can be raised. This loss of heat energy in the liquid surrounding the ice causes the liquid to cool off.

A Hypothesis That Predicts the Best Way to Cool a Liquid

Earlier we discussed Newton's Law of Cooling (Project 3) which said that the rate of warming is proportional to temperature difference. A hypothesis based on this law could be:

> ***Hypothesis:*** *The rate at which an object warms up (or cools down) is greater when the temperature difference between the object and its surroundings is greater.*

The hypothesis suggests that when the average temperature of the ingredients of an ice and liquid mixture are closer to room temperature over a period of time, the mixture will warm more slowly then when the temperature of one of the ingredients—the ice, for example—is much lower over the time period.

Developing a Plan to Test the Hypothesis

Assume we have a mass of ice and a large enough mass of room–temperature water to cause the ice to melt completely in a certain length of time. Suppose we intend to measure the temperature of the mixture 10 minutes after the ice has melted. When should the ice be added?

If the hypothesis holds, the ice should be added immediately. After the ice melts, the mixture which is at a temperature between 0°C and room temperature should absorb heat energy from the room more

slowly than the ice would if the ice were left out in a bowl during most of the time period.

We can test the hypothesis in this way. If we measure the temperature changes that happen under both conditions over a 10–minute period, we can compare the results. So, we measure the temperature changes when ice is added at the beginning of the 10–minute period and then measure the changes that occur when ice is added at a later time.

Testing the Cold Soda Hypothesis

You can take two glasses of room–temperature water (or soda if you like) and record temperature changes in one glass for 10 minutes when you add two ice cubes to it right away.

You can then record the temperature changes in the second glass for 10 minutes, but wait until six minutes have passed before adding the ice.

Let's test our hypothesis and answer the soda–cooling question by doing an experiment.

Setting up the Experiment

1. Set up the Laboratory Station. (See Appendix A.)
2. Choose the SET UP EXPERIMENT option. (See Appendix A.)
3. Choose a Total Time of 10 minutes and a temperature scale of degrees Celsius. (See Appendix A.)
4. Fill two 8–ounce glasses with exactly the same amount of tap water at about room temperature.
5. Place the glasses in the large cake pan or tray.
6. Let the glasses sit in the room for about 30 minutes or use the alcohol bulb thermometer (or the temperature sensor and the BULB program on the Temperature Lab Diskette) to check that the water and the room–air temperatures are the same.
7. Have four ice cubes of *equal size* handy in the freezer.

Doing the Experiment

Trial 1: Adding Ice Immediately

1. Take two ice cubes out of the freezer, put them in a small dry bowl and proceed immediately to step 2.
2. Place the temperature sensor in the first glass of water.
3. Begin the experiment. (See Appendix A)
4. At the end of the 10 minutes, look at the data table.
5. Copy the highlighted numbers shown on the screen and plot the graph. (See Appendix A) using Figure 3.4–1. ■1

Figure 3.4–1. *Temperature graph for first trial, 10 minutes.*

TOTAL TIME 10 MINUTES

INVESTIGATOR ____________

TRIAL NUMBER 1 ______ DATE ______

DESCRIPTION OF PROJECT *Add two ice cubes to a glass of room temperature liquid immediately. Recording temperatures for 10 minutes.*

DATA TABLE (Highlighted Numbers)

TIME (SEC.)	TIME (MIN.)	TEMP (°C)
0	0.0	
30	0.5	
60	1.0	
90	1.5	
120	2.0	
150	2.5	
180	3.0	
210	3.5	
240	4.0	
270	4.5	
300	5.0	

TIME (SEC.)	TIME (MIN.)	TEMP. (°C)
330	5.5	
360	6.0	
390	6.5	
420	7.0	
450	7.5	
480	8.0	
510	8.5	
540	9.0	
570	9.5	
600	10.0	

GRAPH OF TEMPERATURE VS. TIME

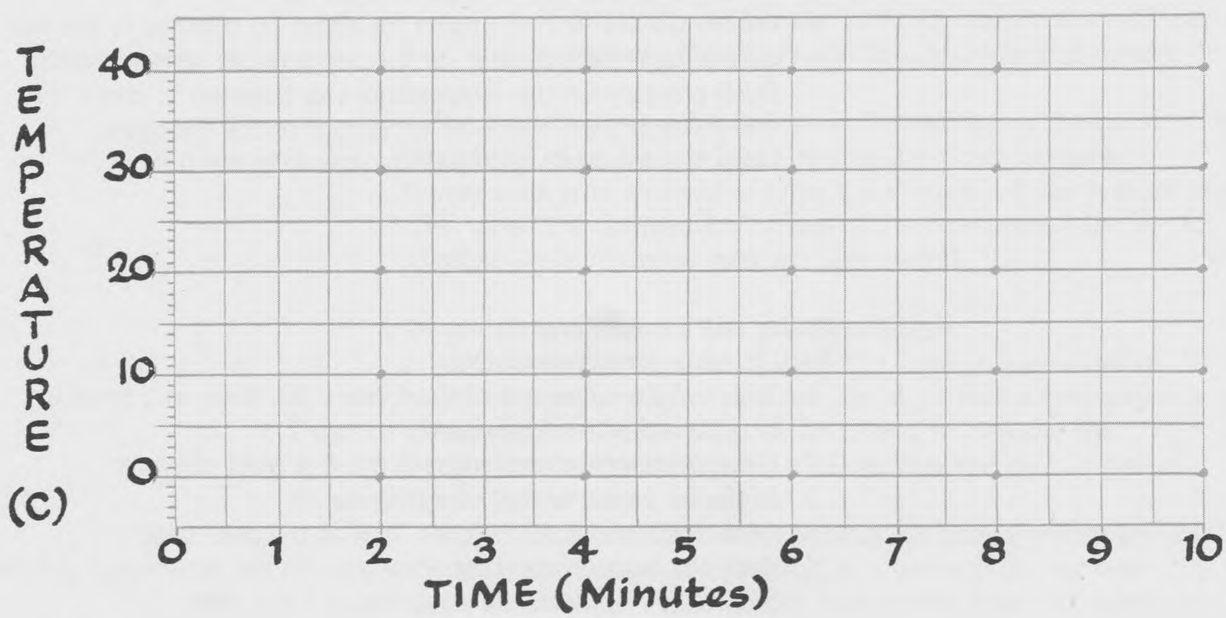


Figure 3.4–2. *Temperature graph for second trial, 10 minutes.*

TOTAL TIME 10 MINUTES

INVESTIGATOR ______________________

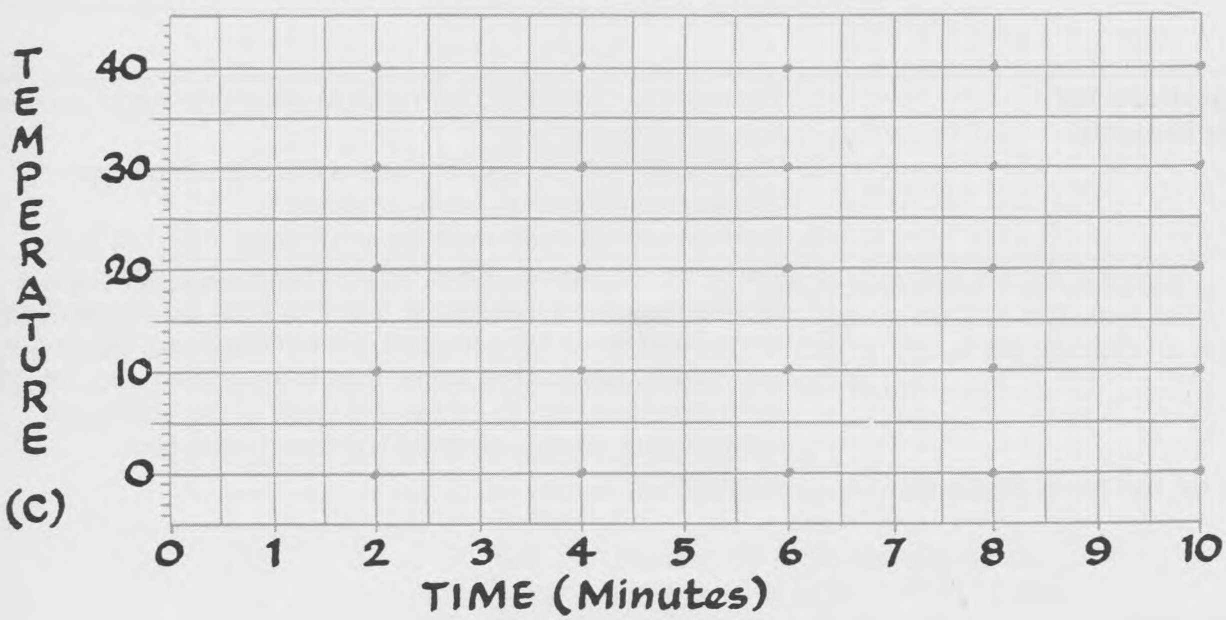
TRIAL NUMBER 2 ________ DATE ____________

DESCRIPTION OF PROJECT Record temperatures for 10 minutes in a second glass of room temperature liquid. Two ice cubes are added after 6 minutes have clapsed

DATA TABLE (Highlighted Numbers)

TIME (SEC.)	TIME (MIN.)	TEMP (°C)
0	0.0	
30	0.5	
60	1.0	
90	1.5	
120	2.0	
150	2.5	
180	3.0	
210	3.5	
240	4.0	
270	4.5	
300	5.0	
330	5.5	
360	6.0	
390	6.5	
420	7.0	
450	7.5	
480	8.0	
510	8.5	
540	9.0	
570	9.5	
600	10.0	

GRAPH OF TEMPERATURE VS. TIME



Trial 2: Waiting to add ice

1. Return to the SET UP EXPERIMENT option. (See Appendix A.)
2. Choose a Total Time of 10 minutes and a temperature scale of degrees Celsius. (See Appendix A.)
3. Take two ice cubes out of the freezer, put them in a small dry bowl and proceed immediately to step 4.
4. Place the temperature sensor in the second glass of water.
5. Begin the experiment (See Appendix A) but *do not* add any ice yet.
6. After about six minutes (you can see the time pass by watching the graph on the screen) add the two ice cubes and any melted ice surrounding them in the bowl.
7. At the end of 10 minutes, look at the data table.
8. Copy the highlighted numbers from the screen and plot the graph (see Appendix A) using Figure 3.4–2. ■2

Note: *Since the difference in the final temperatures is not large, you may need to repeat this experiment several times to see which method of adding ice causes the final temperature of the water to be coldest most of the time.*

Questions and Conclusions

Which method works the best for keeping your soda cold after 10 minutes? ■3

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Does the hypothesis seem valid? ■4

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Suggestions for Other Projects

1. You might try this activity with a liquid other than water, such as fruit juice, soda, or milk.
2. What happens if you start out with a liquid at refrigerator temperature rather than room temperature.
3. Suppose you use much more ice and it doesn't all melt at the end of the 10 minutes. What happens?
4. Styrofoam cups are insulated so that they keep the temperature of the liquid inside fairly constant. Cold drinks stay colder and warm drinks stay warmer longer than in an ordinary cup. Try using styrofoam cups to contain the water in this activity and compare your results with those you found using glass containers.

CHAPTER 3: Project Five

Kitchen Chemistry I: Salt and Ice

In order to understand this absorption of heat into melting ice . . . I put a lump of ice into an equal quantity of water . . . if a little sea salt be added to the water heated to only 74°C or 76°C, we shall produce a fluid sensibly colder than ice was in the beginning, which has appeared a curious and puzzling thing . . .

Joseph Black

At sometime or other, we've all taken a belly–flop on a patch of slippery ice. Many people sprinkle salt on icy sidewalks and we are familiar with trucks sprinkling salt on icy roads. Salt obviously melts the ice—but how? What changes happen when salt is added to ice? In this project you will learn more about the idea of latent heat of fusion explored in Project 4 by doing experiments with salt and ice.

Purposes

- To study temperature changes when salt is mixed with ice.
- To learn more about the latent heat of fusion.

Equipment and Materials

The Laboratory Station
Table salt (1/4 cup)
Crushed ice (2 cups)
Two identical drinking glasses (not styrofoam)
Two small bowls
A teaspoon
One styrofoam cup
A large cake pan or tray

A Simple Observation: What Happens When Salt and Ice Mix?

Why is salt used on icy roads in the winter? If you put equal amounts of crushed ice in two glasses and then add some salt to one of the glasses, you should be able to answer this question. To observe what happens when salt is added to ice:

1. Crush about one cup of ice.
2. Fill each of the two identical drinking glasses about half full with crushed ice.
3. Place the glasses in the large cake pan or tray.
4. Add one teaspoon of table salt to the first glass.
5. Using the spoon, stir the contents of the two glasses alternately for two or three minutes.

Some of the ice in each glass will be melted after a few minutes. Is there any difference in the amount of water which appears to be melted in each glass? Describe the differences you observe. ■1

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You may want to check for differences in the amount of melting by carefully pouring off the melted water from the glass that had the added salt into an empty bowl. The next step is to pour off the ice water from the second glass into another bowl. Which bowl has the most water (melted ice) in it?

What do your results tell you about why salt is spread on icy roads? ■2

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Background on Salt and Water

Salt is a chemical compound which contains two chemical elements—sodium and chlorine. Each salt crystal has an equal number of sodium atoms and chlorine atoms bound together. A small white crystal of table salt contains billions and billions of sodium and chlorine atoms.

When salt is mixed with water it dissolves, and the grains can no longer be seen. If you've never observed this, try mixing salt with water and watch it disappear. As part of the dissolving process the sodium and chlorine atoms in the salt crystal become separated and mingle with the water molecules.

From your first observation above, it appears that when table salt is mixed with crushed ice, the sodium and chlorine attack the chemical bonds which hold the water molecules together as a chunk of ice. The salt melts the ice.

Forming a Hypothesis About Salt and Ice

In Project Four we learned that it takes energy to melt ice because energy is needed to break the chemical bonds that hold the ice together. The energy needed to melt the ice is called the **latent heat of fusion.**

When salt melts ice, what is the source of the energy needed to melt the ice? Ice is water that has all of its molecules held tightly together. A water molecule is made up of atoms of oxygen and hydrogen. One possibility is that the energy to melt the ice is taken from the vibrating atoms of hydrogen and oxygen contained in the ice.

In other words, as the ice melts, the energy needed to melt the ice comes from slowing down the motion of the atoms of hydrogen and oxygen that make up the ice molecules. The heat energy stored in the

vibration of a typical atom in the ice would be reduced during the melting process. As the ice melts, the molecules loosen their bonds, so the energy with which the loosened molecules slither around in the liquid is reduced when they slow down. If the heat energy stored in the liquid molecules is less than that in the vibrating atoms in the solid ice, the temperature of the water mixed with the salt should be lower than the original temperature of the ice.

If this is true, you might ask, why doesn't the very cold water re–form into a block of ice? It appears that the sodium and chlorine atoms from the dissolved salt crystal prevent the ice from forming.

It is difficult to make ice with salt water! If you want to try, fill one ice tray with salt water and another with ordinary tap water. Put the trays in the freezer. Check for freezing every 10 minutes or so for about an hour.

A Hypothesis on Chemical Melting

Let's develop a hypothesis which states what we've just discussed.

> ***Hypothesis:*** *If a chemical causes a solid to change to a liquid state, the energy necessary for that change is taken from the heat energy of the solid. The temperature of the resulting liquid will be lower than that of the original solid.*

Using Salt and Ice to Test the Hypothesis

Designing an experiment to test the chemical melting hypothesis is relatively simple. All we need to do is mix a solution of salt and water with crushed ice and monitor the temperature changes using the temperature sensor.

Setting up the Experiment

1. Set up the Laboratory Station. (See Appendix A.)
2. Choose the SET UP EXPERIMENT option. (See Appendix A.)
3. Choose a Total Time of 30 and a temperature scale of degrees Celsius. (See Appendix A.)
4. Fill a styrofoam cup with crushed ice to about $^1/_3$ full.
5. Place the temperature sensor in the cup of ice.
6. Fill the second styrofoam cup about $^1/_3$ full of room–temperature water.
7. Add two teaspoons of table salt to the room–temperature water.
8. Stir the mixture with the spoon, *not the sensor,* until all the salt is dissolved.

Doing the Experiment

1. If the temperature sensor hasn't been in the cup of crushed ice long enough to cool down completely, wait about one minute before continuing.
2. Begin the experiment. (See Appendix A).
3. Wait five seconds and then add the salt water to the ice and stir gently with a spoon.
4. After the data collection is complete, look at the data table.

5. Copy the highlighted numbers from the screen and plot the graph (See Appendix A) using the table in Figure 3.5–1. ■3
6. If 30 seconds is too short a time, try a 1–minute experiment. See Appendix F for a graph.

Questions

1. Do the results you found agree with the chemical melting hypothesis? ■4

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2. On the basis of your results, can you explain why salt and crushed ice are used in old–fashioned hand–cranked ice cream freezers? ■5

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Suggestions For Other Projects

1. What would happen if you repeated the experiment using more salt? Less salt? Why not try it?
2. Try to find other salts (for example, Lite™ salt—potassium chloride—is available in the supermarket) or chemicals that melt ice, and do the experiment again. A hypothesis can never be proven, but it should be tested in many ways.
3. Using the procedures described in this project it is possible to determine the latent heat of fusion for ice. To determine the quantity, you must know the mass of the ice in the styrofoam cup, the mass of the melted ice water, and the total drop in temperature after the salt is added to the ice. The definitions and equations needed to determine the latent heat of fusion can be found in most physics textbooks used in high school physics courses or introductory college physics courses.

Figure 3.5–1. *Thirty–second graph showing the effect of salt on the temperature of ice.*

TOTAL TIME 30 SECONDS

INVESTIGATOR ____________________

TRIAL NUMBER __________ DATE __________

DESCRIPTION OF PROJECT *Salt and Ice: Add salt to ice after 5 seconds and record temperatures for 30 seconds.*

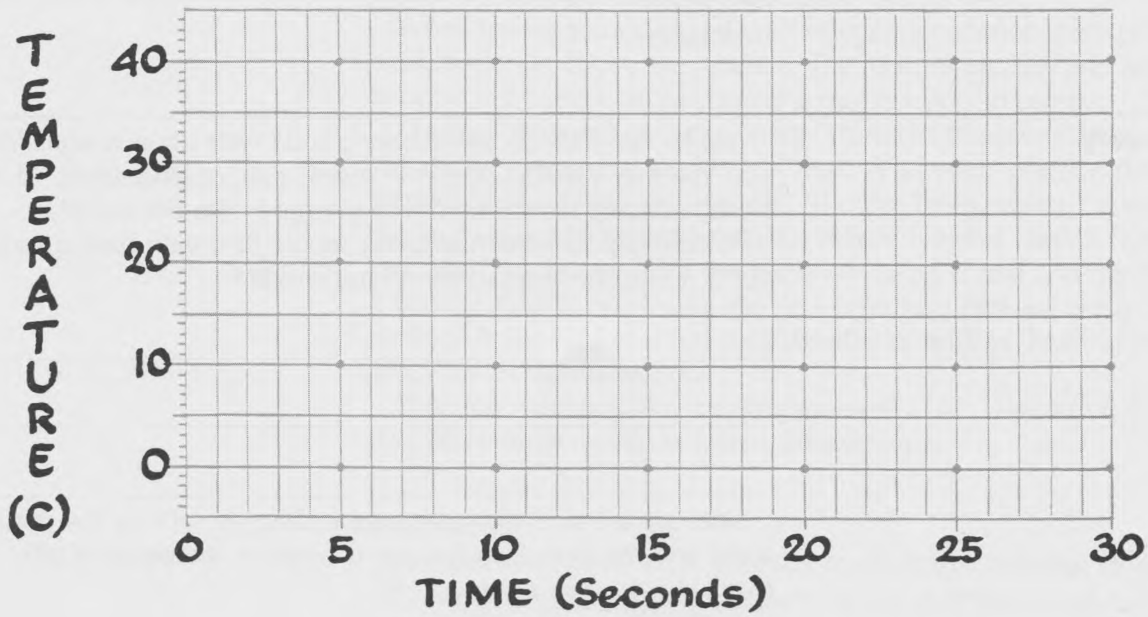
DATA TABLE (Highlighted Numbers)

TIME (60th SEC.)	TIME (SEC.)	TEMP (°C)
0	0	
60	1	
120	2	
180	3	
240	4	
300	5	
360	6	
420	7	
480	8	
540	9	
600	10	

TIME (60th SEC.)	TIME (SEC.)	TEMP (°C)
660	11	
720	12	
780	13	
840	14	
900	15	
960	16	
1020	17	
1080	18	
1140	19	
1200	20	

TIME (60th SEC.)	TIME (SEC.)	TEMP (°C)
1260	21	
1320	22	
1380	23	
1440	24	
1500	25	
1560	26	
1620	27	
1680	28	
1740	29	
1800	30	

GRAPH OF TEMPERATURE VS. TIME



CHAPTER 3: Project Six

Kitchen Chemistry II: Baking Soda and Vinegar

I love fool's experiments. I am always making them.
Charles Darwin

Heat energy plays an important role in the chemical reactions that happen around us all the time. When we bake cakes and muffins, chemical reactions take place in the batter as the oven heats it. Cakes and muffins rise because gases are released as heat is applied to the batter. In Project Six you will learn about the flow of heat energy during chemical reactions by experimenting with two common household materials—baking soda and vinegar.

Purposes

- To learn about heat energy exchanges during chemical reactions.
- To study how the temperature changes over time when baking soda is mixed with vinegar.

Equipment and Materials

The Laboratory Station
Baking soda (1/2 cup)
Vinegar, 5% acidity (1 cup)
Two 8–ounce styrofoam cups
A large cake pan or tray
A tablespoon
Refrigerator
Desk lamp

Discovery

Just for fun let's mix some baking soda with some vinegar. Watch out! You may want to do this in a sink, pan, or large bowl. To do the mixing put two tablespoonsful of vinegar in the bottom of a styrofoam cup. Dry the measuring spoon, fill it with baking soda, and dump it into the vinegar. What happens?■1

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Since we are studying temperature changes, let's do the mixing again and see if you can feel any changes in temperature after the foaming has taken place.

1. Put two tablespoons full of vinegar in each of two styrofoam cups.

2. Let the vinegar warm up to room temperature if its been in the refrigerator. You can use the BULB option and temperature sensor or your small alcohol bulb thermometer to compare the vinegar temperature to the room temperature.
3. Place one of the cups of vinegar in a bowl, pan, or sink.
4. Add one tablespoon of vinegar to the cup of vinegar.
5. When the foaming stops, feel the mixture with your finger.
6. Feel the cup of plain vinegar with your finger also. Does there seem to be any difference in the temperature of the liquid in each cup? ■2

If you want to have some outdoor fun, you can mix the baking soda with vinegar in the bottom of a soft drink bottle, seal it quickly with a cork, and watch the cork take off like a rocket.

Warning: A lightweight bottle not intended for use with carbonated liquid should not be used. It could shatter. (*Mr. Wizard* explains how to make a baking sodavinegar rocket launcher in more detail in his book, *Supermarket Science Book*.) Be sure to point the bottle away from people, animals, or objects! This experiment should be done under **adult supervision** only.

Background on Chemical Reactions

Sometimes when two substances are mixed together, a chemical reaction takes place and new substances are formed.

When baking soda is mixed with vinegar, a common gas—carbon dioxide—forms during the reaction. The mixture bubbles and foams because the carbon dioxide, being a gas, is trying to escape.

During a chemical reaction, energy stored in the chemicals is sometimes released in the form of heat. A chemical reaction that releases heat is called **exothermic**. At other times, energy is needed by the new chemicals produced in a reaction. In this case, a reaction can take heat energy from the chemicals being mixed and transform it into the energy needed by the new chemicals that are being created. A chemical reaction that absorbs, or pulls in, heat is known as an **endothermic** reaction.

Chemical reactions, like the life processes which depend on them, take place more rapidly at higher temperatures.

Definitions

Exothermic Reaction: A chemical reaction that releases, or gives off heat, and causes the temperature of the chemicals produced to rise.

Endothermic Reaction: A chemical reaction that absorbs, or pulls in heat and causes the temperature of the chemicals produced to fall.

Developing Hypotheses about the Baking Soda and Vinegar Reaction

The foaming that happens when the carbon dioxide is released seems to be energetic. Where does this energy come from? Because the mixture seemed cooler after the reaction took place we can assume that the reaction is *endothermic* and that heat energy is being taken from the baking soda and vinegar during the reaction.

Does the baking soda and vinegar reaction take place faster when the initial temperatures of the soda and vinegar are higher? Let's state two hypotheses:

> ***Hypothesis One:*** *A chemical reaction that bubbles and foams as it releases a gas is endothermic.*
>
> ***Hypothesis Two:*** *A chemical reaction occurs more rapidly (takes less time to complete) as the chemicals being mixed are raised to a higher temperature.*

Testing the Hypotheses

If Hypothesis One is correct and the reaction is endothermic then as the reaction takes place we should observe that the temperature of the mixture decreases. We can easily mix the baking soda and vinegar and record temperatures during the time the reaction takes place.

To test Hypothesis Two, we need to observe and compare the differences in how long it takes for the temperatures being measured to stop changing when the vinegar and baking soda start out cold and when they start out warm.

Let's do two experiments. First, we'll start with baking soda and vinegar which have been refrigerated and monitor the changes in temperature after the baking soda and vinegar have been mixed. Next, we'll warm some vinegar and baking soda to just above room temperature–about 30°C–under a desk lamp and monitor temperature changes again.

In this experiment, you will be mixing the baking soda and vinegar and recording the changes in temperature over a 30–second time period.

Setting Up the Experiment with Cold Chemicals

1. Set up the Laboratory Station. (See Appendix A.)
2. Choose the SET UP EXPERIMENT option. (See Appendix A.)
3. Choose a Total Time of 30 seconds and a temperature scale of degrees Celsius.
4. Place all chemicals at a safe distance from your computer (on another table or in a large cake pan or tray).
5. Place two tablespoons of vinegar in a styrofoam cup.
6. Add a tablespoon of baking soda to another cup.
7. Place the vinegar and baking soda containers in the refrigerator for about 30 minutes.
8. Place the vinegar and baking soda containers taken from the refrigerator into a large cake pan or tray.
9. Place the temperature sensor tip in the vinegar.

Doing the Experiment

Now, here we go! Read the directions over once or twice before you begin. Follow the steps carefully.

1. Get ready to dump the tablespoon of baking soda into the vinegar.
2. Next push the red joystick button to start collecting data and **at the same time** dump the spoonful of baking soda into the vinegar.
3. Watch the graph on the screen.
4. At the end of the 30 seconds, look at the data table.
5. Copy the highlighted numbers from the screen and plot the graph (See Appendix A) using the Figure 3.6–1. ■3

Analyzing the Cold Chemical Reaction

Does Hypothesis One hold? Is the reaction endothermic? By looking at the data table, find the temperature before the reaction took place and after the reaction was complete. What is the difference between the two temperatures? ■4

By looking carefully at the graph you have plotted, you should be able to tell about how long it takes the mixture to change to a new and fairly steady temperature for each time tried. About how long did it take? _______ seconds. ■5

You may want to repeat the experiment one or more times to see if you get about the same results for the time needed for the temperature change and the total temperature change.

Why doesn't the temperature change occur instantly? ■6

____

Is the response time you measured for the temperature sensor long enough to account for the time taken for the mixture to cool?

____

Setting Up the Experiment with Warm Chemicals

1. Add two tablespoons of vinegar to a styrofoam cup and one tablespoon of baking soda to another cup.
2. Place the baking soda and vinegar under a small desk lamp or in some other warm (not hot) location until the vinegar temperature is about 30°C.
3. Remove the source of heat and place the temperature sensor tip in the vinegar at the bottom of the cup.

Doing the Experiment Again

1. Repeat Steps 1–4 in the section above titled 'Doing the Experiment.'
2. Copy the highlighted numbers from the screen and plot the graph (See Appendix A) using the Table in Figure 3.6–2. ■3

Figure 3.6–1. *Baking soda and vinegar: cold reaction.*

TOTAL TIME 30 SECONDS

INVESTIGATOR ____________________

TRIAL NUMBER 1 ________ DATE ________

DESCRIPTION OF PROJECT Baking Soda and Vinegar "Cold" Reaction.

DATA TABLE (Highlighted Numbers)

TIME (60th SEC.)	TIME (SEC.)	TEMP (°C)
0	0	
60	1	
120	2	
180	3	
240	4	
300	5	
360	6	
420	7	
480	8	
540	9	
600	10	

TIME (60th SEC.)	TIME (SEC.)	TEMP (°C)
660	11	
720	12	
780	13	
840	14	
900	15	
960	16	
1020	17	
1080	18	
1140	19	
1200	20	

TIME (60th SEC.)	TIME (SEC.)	TEMP (°C)
1260	21	
1320	22	
1380	23	
1440	24	
1500	25	
1560	26	
1620	27	
1680	28	
1740	29	
1800	30	

GRAPH OF TEMPERATURE VS. TIME

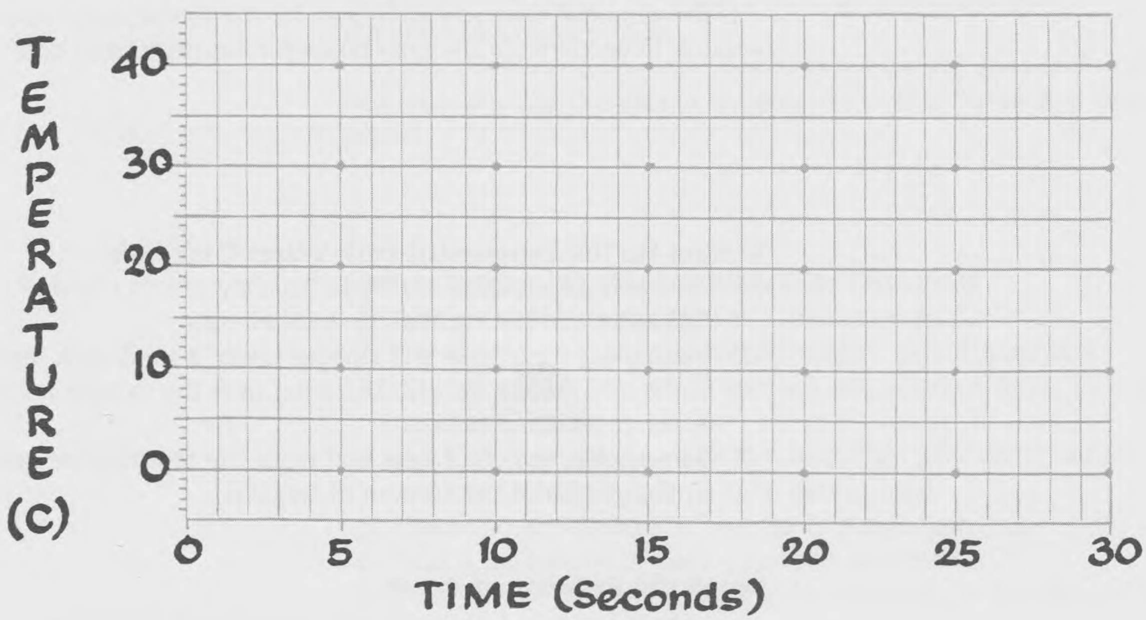


Figure 3.6–2. *Baking soda and vinegar: warm reaction.*

TOTAL TIME 30 SECONDS

INVESTIGATOR ____________________

TRIAL NUMBER 2 DATE ____________

DESCRIPTION OF PROJECT Baking Soda and Vinegar "Warm" Reaction.

____

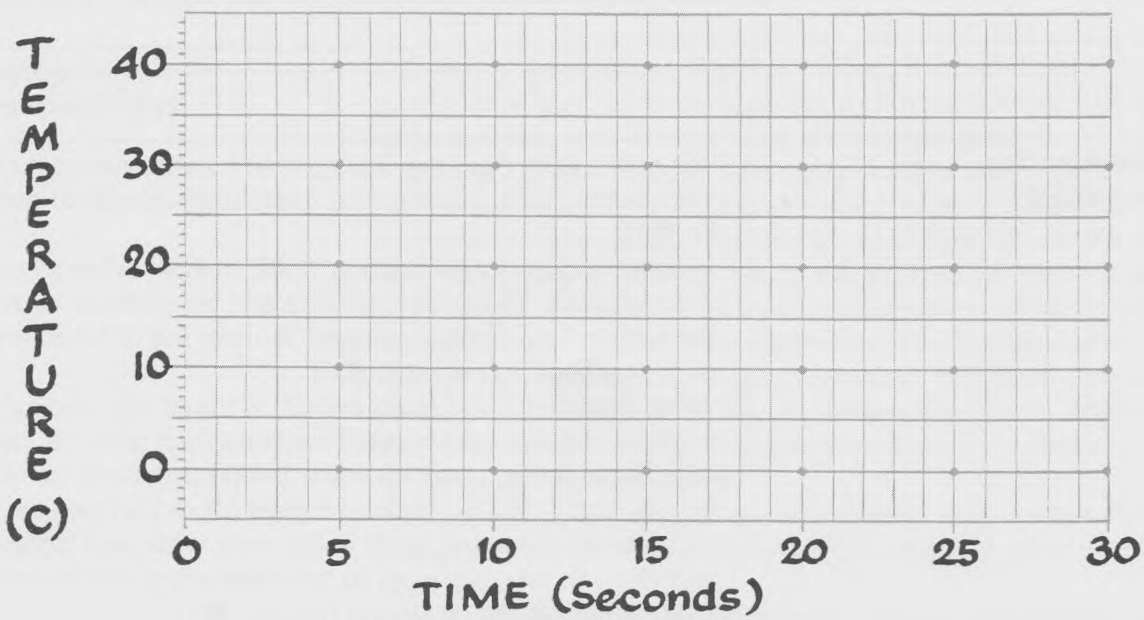
DATA TABLE (Highlighted Numbers)

TIME (60th SEC.)	TIME (SEC.)	TEMP (°C)
0	0	
60	1	
120	2	
180	3	
240	4	
300	5	
360	6	
420	7	
480	8	
540	9	
600	10	

TIME (60th SEC.)	TIME (SEC.)	TEMP (°C)
660	11	
720	12	
780	13	
840	14	
900	15	
960	16	
1020	17	
1080	18	
1140	19	
1200	20	

TIME (60th SEC.)	TIME (SEC.)	TEMP (°C)
1260	21	
1320	22	
1380	23	
1440	24	
1500	25	
1560	26	
1620	27	
1680	28	
1740	29	
1800	30	

GRAPH OF TEMPERATURE VS. TIME



Analyzing the Data

Do both hypotheses hold? In order to answer this question you might want to look carefully at your graphs from both trials and the results of your data and summarize the results in Table 3.6–3 below. ■7

Table 3.6–3. *Data summary of vinegar and baking soda experiment.*

	INITIAL TEMPERATURE VINEGAR/SODA (°C)	FINAL TEMPERATURE VINEGAR/SODA (°C)	TEMPERATURE DIFFERENCE (°C)	TIME TO REACH FINAL TEMPERATURE (SECONDS)
TRIAL 1: COLD CHEMICALS				
TRIAL 2: WARM CHEMICALS				

Conclusions

By examining the data table above,what conclusions can you draw about Hypothesis One? Is the reaction endothermic at both temperatures? ■8

____

____

What conclusions can you draw about Hypothesis Two? Does the chemical reaction occur more rapidly when the baking soda and vinegar are warm? ■9

____

____

Suggestions for Other Projects

1. You might study how the cooling time for the mixture is changed if the baking soda is stirred into the mixture instead of dumped in. ■10
2. Suppose you start with twice as much vinegar. What influence does this have on the reaction time and temperature decrease of the baking soda–vinegar mixture? You can use different amounts of baking soda and vinegar. ■11
3. When double–acting baking powder is mixed with ordinary water, it undergoes a chemical reaction which gives off carbon dioxide gas. In fact, double–acting baking powder is useful in helping dough to rise, because it gives off carbon dioxide at room temperature and again in the oven while at a higher temperature. You may want to try observations and experiments to study double–acting baking powder. ■12

CHAPTER 3: Project Seven
Measuring Daily Changes in Air Temperature

Oh, what an uncertain thing
This picky weather is!
It blew and snew and then it thew
And now, by jing, it's friz!
Philander Johnson

Weather effects every aspect of our lives—the food we eat, the way we dress, how we feel, and many other things. In this project graphing daily temperatures will help you understand how daily temperatures relate to weather conditions.

Purposes

- To learn how to monitor changes in air temperature.
- To relate the observed changes in air temperature to other weather conditions
- To learn about radiant energy absorption.

Equipment and Materials

The Laboratory Station
Black tape or cloth
Aluminum foil
White shoe box

Changing Air Temperatures

During a typical 24–hour period of time, the outside air temperature goes up as the sun rises and moves through the sky, and goes down at night when the sun is no longer shining.

Meteorologists—scientists who study weather patterns—can get a lot of information from looking at a graph of temperature vs. time during a 24–hour period. They can tell what time of year the graph was made—spring, summer, fall, or winter. They can see if it was a sunny day or a cloudy day. They can answer many other questions from looking at a graph. At what time was local noon—when was the sun highest in the sky? About how much fuel did a community need to heat homes on the day the temperature graph represents? Was there a major change in the weather during the time the temperatures were measured?

In this project we suggest that you monitor daily temperature changes for several days while keeping a record of other weather conditions.

After monitoring the temperature on a given day, you can study the graph representing temperatures during the 24–hour period and see what other weather conditions seem to be related to temperature

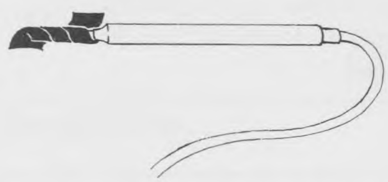
changes. You can learn how to relate the time of local noon to the high temperature reading on a sunny day. Or, if you are monitoring temperatures in the wintertime, you can calculate the 'heating degree days that fuel dealers use to predict when deliveries of fuel oil are needed.

A Simple Observation on Measuring Air Temperature

People are generally warmer in the sun and cooler in the shade. Is this true for temperature sensors? It seems reasonable to assume that when the sun is shining on a temperature sensor it is warmer than the surrounding air.

In order to test this statement, we could record the temperature with the temperature sensor placed in direct sunlight, and then measure the temperature again with the sensor in the shade. Since it is known that black surfaces absorb radiant energy while shiny surfaces reflect it, black tape and aluminum foil can be used to test the effects of direct sunlight on the temperature sensor.

Let's place a black absorber (black tape) over the sensor tip, place it in direct sunlight, and record the temperature. Next, let's place a reflector, like aluminum foil, over the tip and record temperature again.



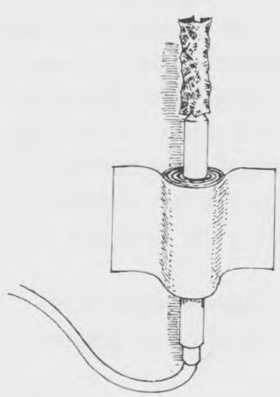
Sensor tip wrapped in black tape.

Setting up the Experiment

1. Set up the Laboratory Station. (See Appendix A.)
2. Choose the SET UP EXPERIMENT option. (See Appendix A.)
3. Choose a Total Time of 3 minutes and a temperature scale of degrees Celsius for the experiment. (See Appendix A.)

Measuring Temperature Rise With The Sensor In Direct Sunlight

1. Place the temperature sensor in direct sunlight. This can be done by placing your Laboratory Station close enough to a window or an open door to catch the sun. Or, you can place one or more extender cables between the interface and the temperature sensor so the sensor can extend outdoors.
2. Wrap a small piece of black tape around the tip of the sensor. Make sure the tape makes good contact with the tip of the sensor.
3. Start recording the temperature. After a minute, shade the sensor with your hand or a piece of folded paper.
4. Sketch the results in Figure 3.7–1. ■1



Sensor tip wrapped in aluminum foil.

Measuring the Temperature Rise With the Sensor Shielded From Direct Sunlight

1. Remove the black tape and place a piece of aluminum foil over the end of the sensor.
2. Place the sensor with the aluminum foil reflector in direct sunlight.
3. Start recording the temperature. After a minute or two, shade the sensor with your hand.
4. Sketch the results in the graph below. ■2

Figure 3.7–1. *Three–minute graph for sketching the changes in temperature when the sensor is wrapped in paper and placed in the sun.*

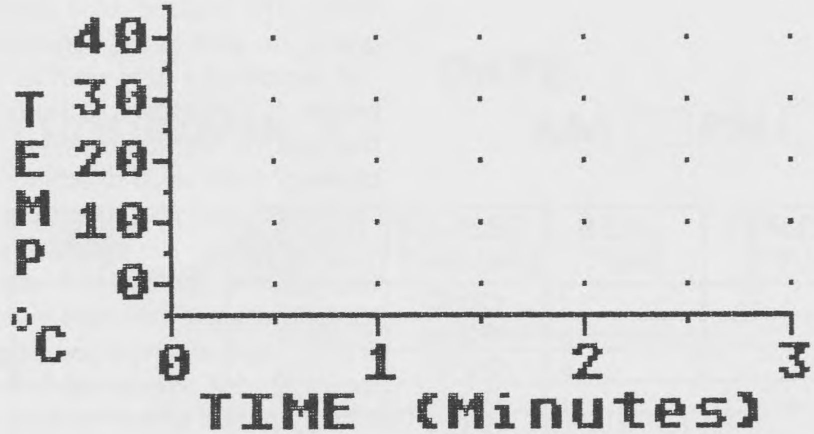
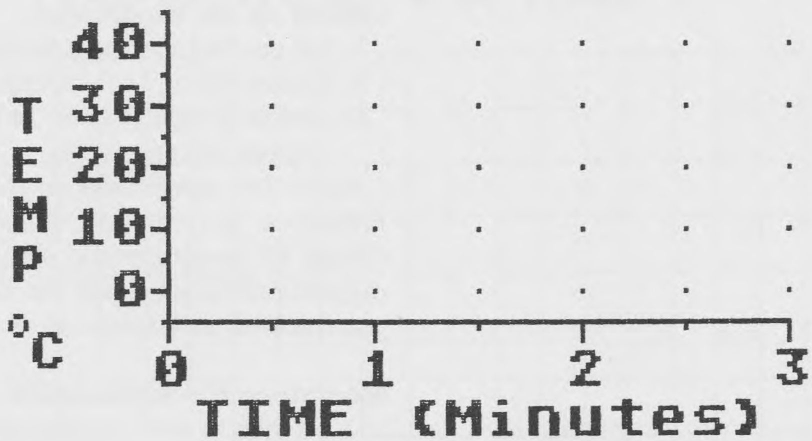


Figure 3.7–2. *Three–minute graph for sketching the changes in temperature when the sensor is wrapped in aluminum foil and placed in the sun.*
Mounted sensor

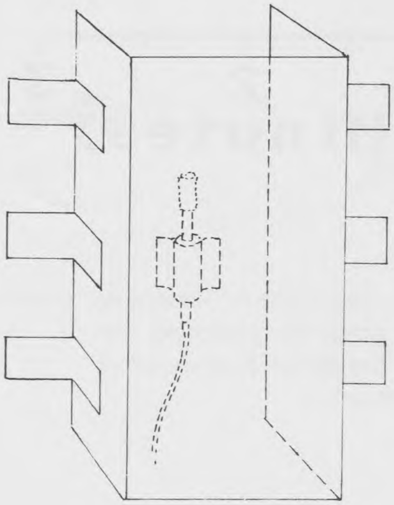


Look at the two sketches you obtained. Which combination of tape, foil, and shading would give the best measurement of the air temperature? ■3

____

____

Monitoring Temperature and the Weather During a Day



If the temperature sensor is wrapped in foil and placed in the shade outside, the outside air temperature can be monitored for 24 hours or more. A good time to start recording temperatures is 8 a.m. or 9 a.m. Although you can start recording at any time, comparing the 'real' time to the 'elapsed' time displayed on the graph is more difficult unless you start at the beginning of an hour.

A sample of a daily weather log, Figure 3.7–3, is included with this project. It is important to make weather observations on the same day that you monitor temperature. Is it sunny or cloudy? Is the wind blowing? From what direction? Is there any rain or snow? Are these conditions changing during the day?

The graph on the television set or monitor screen will show the elapsed time. You can fill in the actual time of day when each temperature was recorded in the blanks on the graph below (Figure 3.7–4). For example, if you begin monitoring at 9 a.m. (which is a recommended time to start), then 0 elapsed time is 9 a.m. real time, 1 hour elapsed time is 10 a.m. real time, and so on. To monitor you should do the following:

Setting up the Sensor

1. Mount the foil–wrapped sensor outdoors several feet above the ground so it is shaded from direct sunlight and surrounded by air. Air should be able to flow freely past the sensor.

(Hint: You can cut off the ends of a white shoe box and place it over a foil–covered sensor which has been taped to an outside wall. See the illustration.)

Setting up the Experiment

2. Set up the Laboratory Station. (See Appendix A.)
3. Choose the SET UP EXPERIMENT option. (See Appendix A.)
4. Choose a Total Time of 24 hours and a temperature scale of degrees Fahrenheit. (See Appendix A.)

Note: *The experiments on this project are all done in degrees Fahrenheit. Since the U.S. Weather service has not gone to degrees Celsius, all newspaper and electronic media weather reports are in degrees Fahrenheit. Using the Fahrenheit scale will make it easier for you to check your temperature readings.*

Monitoring the Temperature and Weather

1. Arrange to start the monitoring at the beginning of an hour and choose the BEGIN EXPERIMENT option.
2. Write down the starting time and begin monitoring.
3. You can watch the data as it is plotted on the screen, but if you plan to go to sleep or go off to your daily activities, you may want to turn off the television set or monitor for a while. This is fine, but *don't turn off the computer.* (Any time you choose to turn the television set or monitor back on, any data already collected will appear on the screen.)

The sample daily weather log and record of daily temperature changes are included in Appendix B (■4, ■5) along with our comments on the relationship between weather conditions and temperature changes.

Figure 3.7–3. *Daily Temperature Log.*

DAILY TEMPERATURE LOG

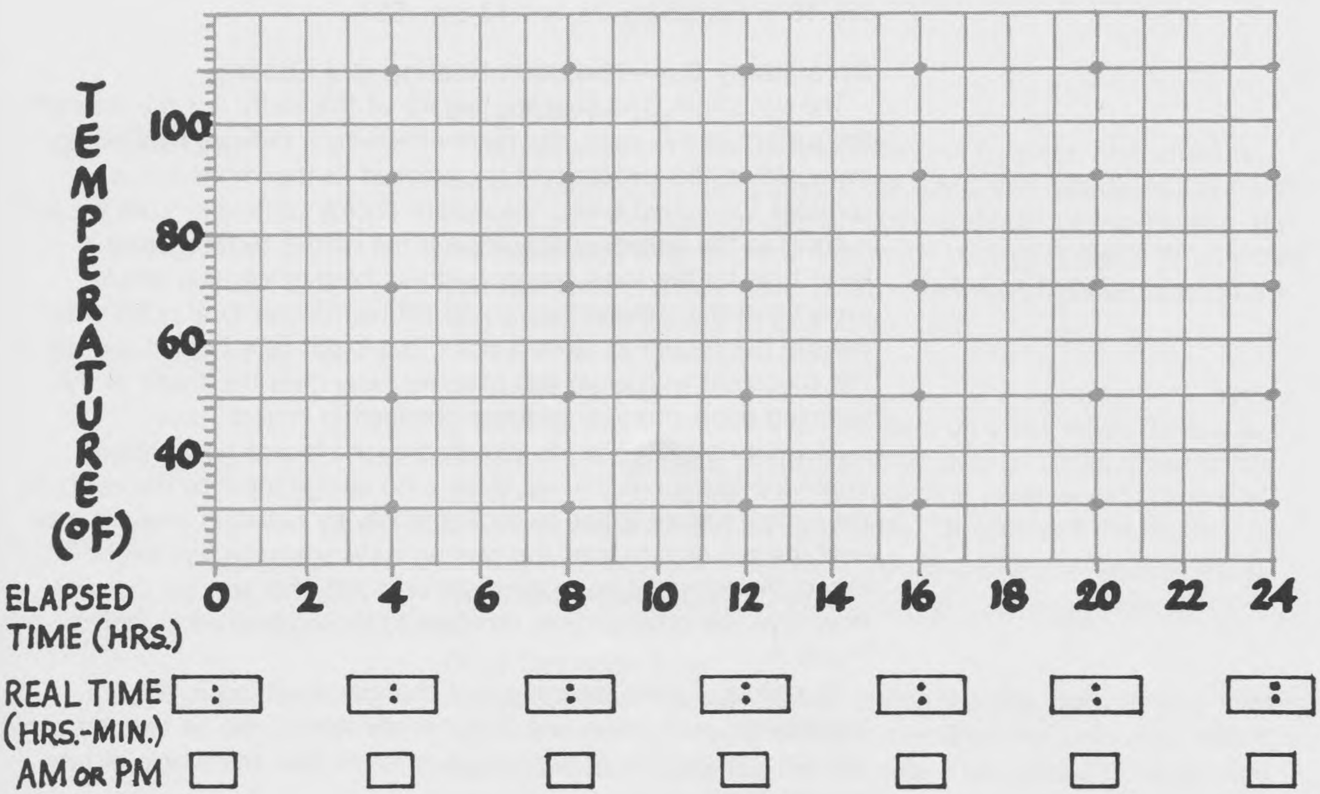
INVESTIGATOR **DATE**

STARTING TIME (HOUR:MIN.) **AM ☐ PM ☐**

ELAPSED TIME (MIN.)	ELAPSED TIME (HR.)	REAL TIME	TEMP. (°F)
0	0:00		
60	1:00		
120	2:00		
180	3:00		
240	4:00		
300	5:00		
360	6:00		
420	7:00		
480	8:00		
540	9:00		
600	10:00		
660	11:00		
720	12:00		

ELAPSED TIME (MIN.)	ELAPSED TIME (HR.)	REAL TIME	TEMP. (°F)
780	13:00		
840	14:00		
900	15:00		
960	16:00		
1020	17:00		
1080	18:00		
1140	19:00		
1200	20:00		
1260	21:00		
1320	22:00		
1380	23:00		
1440	24:00		

GRAPH OF TEMPERATURE V.S. TIME



Interpreting the Temperature Graph

The sun is almost totally responsible for the heating of the earth's surface. At a particular location, an increasing temperature can be due to the direct input of energy from sunlight or from warm air blowing into the region. A decreasing temperature can be due to heat energy radiating away from the earth when the sun isn't shining or to colder air blowing into a region. Occasionally the surface air will cool because cold air or cold precipitation (rain, snow, or hail) descends from higher altitudes where temperatures are colder. Now that you have completed your daily weather log and temperature graph, you may want to consider the the following discussion of temperature and different weather conditions. ■6

On a Calm, Sunny Day: At Local Noon

Suppose you recorded temperature on a calm, sunny day. You may note that the temperature tends to reach some maximum during the day, and a minimum at night. At what time of day do you observe the maximum? Before proceeding, let's figure out how to determine the time at which the sun is highest in the sky.

The most direct way to find local noon time is to watch the shadow of a vertical stick placed in the sun. When the shadow is shortest, the sun is highest in the sky. An easier way may be to use the times of local sunrise and sunset from a newspaper for your city or the city nearest to you. The midpoint of the time between sunrise and sunset will be the time of local noon.

For example, on July 10, 1983 in Harrisburg, Pa., the newspaper reported that the sunrise was at 5:44 a.m. and the sunset was at 8:40 p.m. By keeping track of hours and minutes, we find that 1:12 p.m Eastern Daylight Time is 7 hours and 28 minutes after 5:45 a.m. and 7 hours and 28 minutes before 8:40 p.m. Thus, local noon on July 10 in Harrisburg, Pa. is 1:12 p.m. EDT.

On a Sunny Day—Radiation Heating and Cooling

The sun's light is heating the surface of the earth. But the warmer the surface of the earth, the more effectively it radiates heat energy away. When the temperature has reached its maximum and is constant for a short while, the radiant energy coming in from the sun is equal to the radiant energy leaving the earth's surface. Since it takes time for the sun's energy to do its heating job, you would expect that the temperature would still be rising at local noon when the sun has passed its highest point, but is still fairly high in the sky. Is this consistent with what you observe? How does the shape of the warming curve compare to those obtained in Project Three?

At what time of night do you observe the lowest temperature? When the sun is not shining, there is no energy input to the earth, so the earth's surface is free to cool gradually by radiating away its heat until the sun rises to start the heating cycle again. So you might expect the temperature to decrease until just after sunrise. Does it? How does the cooling curve compare to those obtained in Project Three?

Of course, if there are important changes occurring in the atmosphere, such as passing fronts or rainstorms, the air temperature may be changing for reasons quite different than the simple picture just described.

Figure 3.7–4. *Daily Weather Log.*

DAILY WEATHER LOG

OBSERVER ______________ DATE ________

LOCATION ____________ STARTING TIME ______

DAY'S WEATHER:

- CLEAR ☐
- PARTLY CLOUDY ☐
- PRECIPITATION
  - RAIN ☐
  - SNOW ☐
  - OTHER ____________
  - TIME ____________
- WIND DIRECTION
  - NORTH ☐
  - EAST ☐
  - SOUTH ☐
  - WEST ☐
  - CHANGING ☐
- WIND SPEED
  - CALM ☐
  - BREEZY ☐
  - WINDY ☐

REMARKS ______________________________

____

____

____

____

On a Cloudy Day

You may wish to compare the difference between high and low temperatures for different days. If the day is very cloudy, not as much sunlight gets through the clouds, so there should be less heating. But the clouds also tend to prevent as much cooling at night. What would you expect for a temperature variation between high and low on a very cloudy day compared to a sunny day?

On a Windy Day

Suppose you monitor the temperature on a day when there is a brisk north wind. Since temperatures tend to be cooler closer to the earth's poles and warmer near the equator, what would you expect for a temperature trend on such a day? Of course, if the sun is shining and there is a north wind, two opposite mechanisms are at work, and either could dominate.

On a Day with Rain

Suppose there is a rain shower during the day. Rain, coming from high in the atmosphere, is usually cooler than the surface air. Also it is evaporating as it descends. Do you note a temperature change as a rain shower begins?

On a Day When the Weather Changes

If you recorded the time of change from sunny weather to cloudy weather, or when the weather changes to rain or snow, or to a sudden shift in the wind, you can interpret what effect this had on temperatures before and after that time.

On a Cold Day—Heating Degree Days

One interesting calculation can be made from the temperature data during a day. 'Heating Degree Days' is a quantity used by the National Weather Service as a measure of how cold a day is, and is a useful quantity for determining how much electricity or fuel oil was needed for space heating. The number of degree days for a particular day is defined as the average of the high and low temperatures during a day, subtracted from 65°F.

For example, suppose you monitor the ouside temperature on a winter day and find that the high is 52°F and the low is 40°F. The average of the high and low is 46°F. The number of degree days on that day is 65°F—46°F = 19DEGF.

In order to obtain degree days, you should start your 24-hour monitoring at a time which will include the early morning and late afternoon hours of the day. If you monitor temperatures on several different days, it may be instructive to calculate the number of degree days for each day and compare with the amount of heating energy used in your own home. The quantity of gas or electricity you use can be determined by meter readings. If your home is heated by fuel oil you won't be able to monitor its use easily. However, your oil dealer, by keeping track of the degree days in your community will estimate when to deliver oil to your home.

Conclusions

Each day at each location has different weather conditions. It is difficult to do repeatable experiments. By monitoring temperature over a number of days and interpreting the results carefully, you can learn a great deal about the science of meteorology.

The references listed below are recommended, if you want to design an extended temperature-monitoring project.

Suggested Readings

Allison, Linda. *The Reason for Seasons.* Boston: Brown and Yolla Bolly Press, 1975.

Battan, Louis J. *Weather in Your Life.* San Francsico: W.H. Freeman, 1983.

Thompson, Philip D. and Robert O'Brien. *Weather.* New York:Time-Life Books, 1973.

Forrester, Frank H. *1001 Questions Answered About the Weather.* New York: Dover, 1981.

Appendix A
General Instructions and Information

This appendix contains a summary of the standard instructions needed to set up various temperature experiments described in the Experimenter's Guide. Definitions of special words are also included. The instructions and definitions are listed below in alphabetical order for your convenience:

The Laboratory Station

Each activity requires the Laboratory Station. This includes the Science Discovery Series Interface, temperature sensor, the Temperature Lab Diskette,and your computer system.

Begin the Experiment

1. Choose the BEGIN EXPERIMENT option by pushing the joystick up (↑).
2. When the graph appears with the Total Time selected, press the red joystick button to begin recording temperature data.

Copy the Highlighted Numbers from the Data Table and Plot the Graph

After the data is collected and graphed on the screen, you can display the data in table form and transfer a selection of it to a specially prepared table/graph for graphing. This allows you to keep a permanent record of special data of interest to you.

Appendix F contains table/graph combinations that can be constructed for each of the 16 possible total experiment times. You are invited to reproduce any of the graphs you need for your projects.

To fill out a table/graph data summary sheet:

1. After the data is collected, the graph of the data remains on the screen. Press the red joystick button to return to the menu screen.
2. The menu screen will now have a DISPLAY DATA option. Choose it by pushing the joystick down (↓).
3. Next choose the SEE TABLE option by pushing the joystick up (↑). The first 14 recorded times and temperatures will appear on the screen. A selection of the times and corresponding temperatures will appear as highlighted numbers.
4. Find the special table/graph in Appendix F corresponding to the Total Time for your experiment.
5. Copy the highlighted temperatures from the screen into the blank spaces in the table opposite the appropriate time.
6. Press the red joystick button to display the next group of temperatures. Copy these into the blanks in the table. Continue this procedure until you have copied all the highlighted temperatures.
7. Next, plot each time and temperature from your summary Data Table on the graph immediately below the table. Each vertical line on the graph corresponds to a time value in the table. To avoid confusion with the screen dots already placed in the background on the graphs you may want to plot open circles (o) instead of dots (.).

Choose the BULB option (and record temperatures)

1. Display the main menu options on the screen. If you are just starting, follow steps in the "Set Up the Laboratory Station" instruction to see the display. If you've been using other options, press the red joystick button repeatedly until you see the word BULB on the screen.
2. To see the BULB display, push the joystick to the left (←). You should see a picture of a thermometer bulb on the screen.
3. To record a temperature, press the **F3** key. The recorded temperatures will appear directly below the current temperature. Press the **F3** key each time you want to record a new temperature.

Choose the DEMO option

This option displays four temperature sensor readings at five-second intervals. In addition, 121 temperature values are recorded in the Total Time of 20 seconds. All temperatures collected are then displayed in a graph.

1. Display the main menu options on the screen. If you're just starting, follow the steps in the "Set Up the Laboratory Station" instruction to see the display. If you've been using other options, press the red joystick button repeatedly until you see the word DEMO on the screen.
2. To see the DEMO display, push the joystick to the right (→). You should see a picture of a bulb moving across the screen.

Choose the SET UP EXPERIMENT option

This option allows you to record 121 temperatures in any one of the 16 times you choose. As each temperature is recorded, it is displayed on a graph.

1. Display main menu options. If you are just starting, follow the instructions for "Set Up the Laboratory Station." If you've been using other options, press the red joystick button repeatedly until you see the words SET UP EXPERIMENT on the screen.
2. To get the menu screen needed for the set up, push the joystick up (↑).
3. Prepare to choose a time and temperature scale. (See instructions below.)

Choose a Total Time of _______ and a Temperature Scale in _______

The CHOOSE TIME option allows you to choose a total time over which the 121 temperatures are recorded from a menu of 16 time periods ranging from 10 seconds to 24 hours. The CHOOSE TEMPERATURE option allows you to record and display temperatures in either °C or °F. If you don't choose a temperature scale, the Celsius scale, which is most often recommended in the Experimenter's Guide, is selected for you. If you don't choose a time scale, a 10–second experiment is selected for you.

1. To choose a temperature scale, push the joystick to the left (←) to reach the temperature scale desired. The scale is indicated on the bottom of the screen.
2. To choose a time, push the joystick to the right (→).
3. When the CHOOSE TOTAL TIME menu screen appears, push the joystick down (↓) until the desired time is highlighted.
4. Once the time is chosen, press the red joystick button to return to the BEGIN EXPERIMENT menu.
5. Prepare to BEGIN the EXPERIMENT.

Ice and Water
A mixture of ice and water.

Ice Water
Water poured off from a mixture of ice and water. It contains no ice.

Lukewarm Water
Water which is barely warm to the touch.

Set Up the Laboratory Station

1. Set up and turn on your computer, television set or monitor, and disk drive. ***Leave the Science Discovery Series Interface unplugged.***
2. Plug a joystick into control port 1 on the right side of the Commodore 64 Computer.
3. Insert the Temperature Lab Diskette in the disk drive and enter the phrase: LOAD "*",8 from the keyboard and press RETURN.
4. After the program is loaded, enter the command RUN and press RETURN. Wait about a minute for the program to load.
5. Press the red joystick button to continue.
6. Plug the Science Discovery Series Interface into control port 2 on the right side of the computer.

7. Plug the temperature sensor into left (blue) paddle input of the interface.
8. Press the red joystick button to display the main menu options.

Note: *If you find that temperatures measured with your sensor when using the Laboratory Station are about 10°C too high, you should insert the sensor adjustor between the sensor and the paddle input on the interface. If the temperature readings are about 10°C too low, you should remove the sensor adjustor from the end of the sensor.*

Using the Resistor to Calibrate

This is the simplest calibration procedure. Using the standard resistor, the sensor adjustor (if needed) , and the interface you can calibrate the paddle inputs to your computer to try to increase the accuracy of temperature measurements.

1. Display the main menu options. If you are just starting, follow the steps in the "Set up the Laboratory Station" instruction. If you have been using other options, press the red joystick button repeatedly until the word CALIBRATE appears on the screen.
2. Push the joystick down (↓) to choose the CALIBRATE option and wait for the Calibration Program to load from your diskette.
3. Push the joystick down (↓) to choose the RESISTOR option.
4. Remove all sensors from the interface, if you needed the sensor adjustor to get proper temperature readings, plug it into the standard resistor before proceeding.
5. Follow the instructions on the screen and insert the standard resistor in the left (blue) paddle input of the interface. Wait while the calibration takes place.

   After the left paddle calibration is finished, you will be instructed to insert the standard resistor (and the sensor adjustor, if needed) in the right (orange) paddle input. Wait while the calibration takes place.
6. As soon as the calibration constants are calculated for both paddle inputs, the original calibration option screen should reappear.
7. Press the red joystick button to return to the main menu and the calibration constants will be stored on your diskette.
8. Remove the standard resistor from the right (orange) paddle input.
9. If the sensor adjustor is needed plug it into the end of the temperature sensor again before proceeding.

Note: *Certain Commodore 64 temperature sensors may not respond to resistor calibration. If you want greater accuracy, you will need to complete the full calibration procedure in Appendix D.*

Appendix B
Comparing Project Results

This appendix contains answers to questions contained in the manual as well as samples of the experimental results we obtained while making observations and doing the experiments.

It is unlikely that your results and ours will be exactly the same. Instead, the two sets of results should be similar. If we observe a rise in temperature in a particular project so should you. If our temperature graph looks like a sideways S curve so should yours.

If your results are not similar to ours, you should read through the instructions again to see that you have remembered to do everything necessary.

The answers to questions, sample graphs and data in this appendix give you an opportunity to verify that your results are reasonable.

Every place in the text corresponding to an answer to a question, sample result, or comment contained in this Appendix is marked with a ■. Each answer or comment is numbered consecutively for each chapter.

CHAPTER 2 Temperature and its Measurement

■ 1. When you transfer your finger from ice water to warm water, the warm water should feel 'hot' to the touch.

■ 2. When you transfer your finger from hot water to warm water, the warm water should feel 'cool' to the touch.

■ 3. When you put your finger on the tip of the temperature sensor the level of the alcohol bulb on the sensor should go up. This is assuming your finger was warmer than the metal tip of the temperature sensor.

■ 4. When you put the temperature sensor in an insulated cup, filled with plenty of ice and some water, the temperature shown on the television set or monitor should go down, after about 20 seconds, to a temperature somewhere between 0 °C, and 5 °C.

■ 5. When the temperature is 0 °C, the Fahrenheit temperature is about 32 °F.

Note: *Since temperature is rounded up, the nearest degree 0 °C can appear on the screen with either 32 °F or 33 °F.*

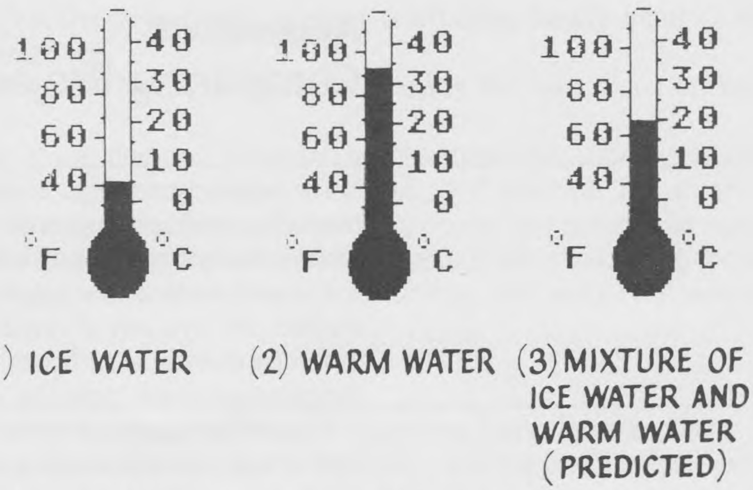
■ 6. By looking at the scales on the sides of the bulb on the screen, 32 °F is 0 °C.

■ 7. By looking at the scales on the sides of the bulb on the screen, 50 °F is 10 °C.

■ 8. The low temperature measured in our pitcher of ice water was 5 °C.

■ 9. See **Figure B–1.**

■ 10. The high temperature measured in our pitcher of warm water was 33 °C.



■ 9 **Figure B–1.** *Sketch of the predicted results when ice water is mixed with an equal amount of warm water.*

■ 11. Our predicted temperature for the mixture of equal parts of ice water and warm water based on the sketch was 20°C.

■ 12. Our measured temperature for the mixture of equal parts of ice water and warm water was 19°C.

■ 13. You should observe that the temperature of the mixture is about halfway between the temperature of the ice water and the temperature of the warm water.

■ 14. A more accurate method for predicting temperature of the mixture is to use the equation to calculate the predicted temperature. Our calculation of the predicted temperature of the mixture was as follows:

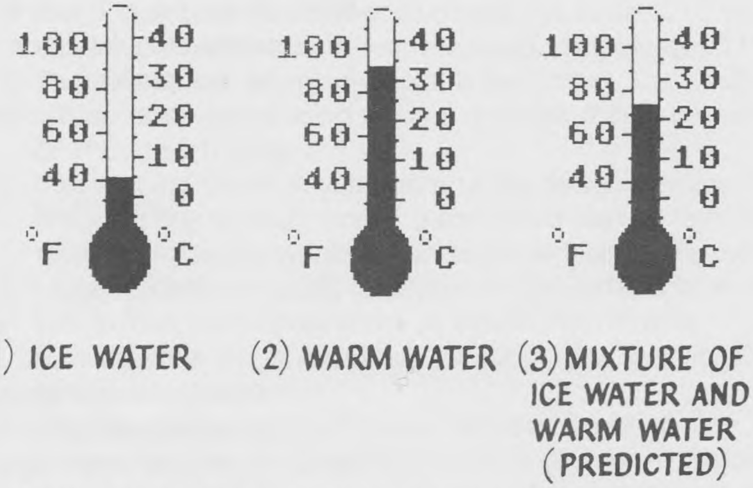
$$t(\text{mixture}) = t(\text{cold}) + \frac{1}{2}[t(\text{warm}) - t(\text{cold})]$$

$$= 5°C + \frac{1}{2}(33°C - 5°C) = 19°C.$$

The measured temperatures and the predicted temperatures were very similar. However, beware of the uncertainties in the Laboratory Station temperatures. The measured temperature could easily be 1 or 2°C above or below the calculated temperature.

■ 15. Our measured temperatures for the mixture of 1/3 ice water and 2/3 warm water were:

t(cold)	5°C
t(warm)	33°C
t(mixture)	23°C



■16 **Figure B–2.** *Sketch of the predicted results when 1/3 ice water is mixed with 2/3 warm water.*

■16. By looking at Figure B–2 we see that the predicted temperature based on the sketch is 24°C. A better prediction for the temperature of the mixture of 1/3 ice water with 2/3 warm water can be calculated from the equation:

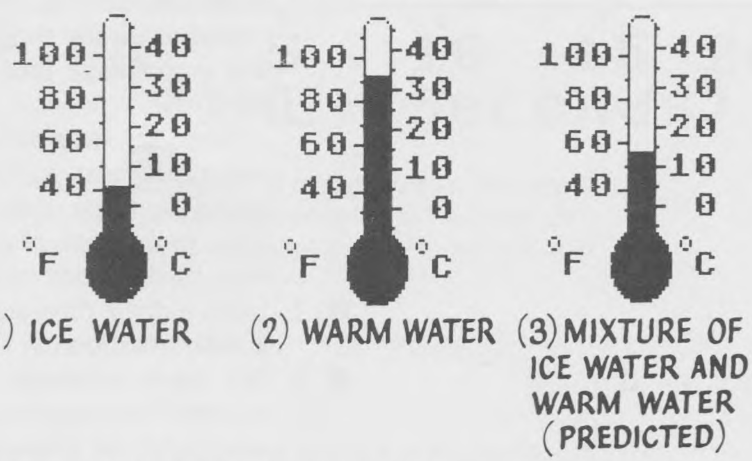
$$t(\text{mixture}) = t(\text{cold}) + \frac{2}{3}[t(\text{warm}) - t(\text{cold})]$$

$$= 5°C + \frac{2}{3}(33°C - 5°C) = 23.6°C.$$

Our measured temperature in this mixture is a bit below the calculated temperature.

■17. Our measured temperatures for the mixture of 2/3 ice water and 1/3 warm water were:

t(cold)	5°C
t(warm)	33°C
t(mixture)	12°C



■18 **Figure B–3.** *Sketch of the predicted results when 2/3 ice water is mixed with 1/3 warm water.*

■ 18. By looking at Figure B–3 we see that the predicted temperature based on the sketch is 14°C. A better prediction for the temperature of the mixture of 1/3 ice water with 2/3 warm water can be calculated from the equation:

$$t(\text{mixture}) = t(\text{cold}) + \frac{1}{3}[t(\text{warm}) - t(\text{cold})]$$

$$= 5°C + \frac{1}{3}(33°C - 5°C) = 14.3°C.$$

Our measured temperature of the mixture is more than 2°C below the calculated temperature.

■ 19. In general, when water of two temperatures are mixed the final temperature is between the two initial temperatures. Those who know enough mathematics and are willing to perform enough experiments should find that if the ratio of the amount of cold water to the amount of warm water is n ÷ m then

$$t(\text{mixture}) = t(\text{cold}) + \frac{n}{n+m}[t(\text{warm}) - t(\text{cold})]$$

■ 20. Any good marble shooter can tell you that when a fast marble (representing a hot molecule) collides with a slow marble (representing a cold molecule) the fast marble will slow down or stop while the slow marble will speed up. Thus, one marble transfers its energy to another.

CHAPTER 3
Temperature Projects
Project One

Evaporation, Condensation, and Dewpoint

■ 1. When the temperature of an object is falling, molecules in the object are moving more and more slowly. The likelihood of a water vapor molecule in the air colliding with an object's molecules, slowing down and condensing is higher than a condensed water molecule on the object's surface speeding up and evaporating. Thus more water molecules condense than evaporate.

When the temperature of an object is rising, the condensed water molecules on the surface of the object may gain enough energy from the hotter molecules in the object to evaporate. Thus, evaporation of molecules is likely to happen more often than condensation on the surface of the object.

■ 2. Using a direct measure of dewpoint on a warm September Sunday afternoon in Carlisle, Pennsylvania, gives 12°C.

■ 3. Our warm September Sunday afternoon in Carlisle had a recorded temperature of 25°C. Since the wet bulb temperature was 17 °C the difference between the dry and wet bulb temperatures is 8°C. Refering to the Dewpoint Table, we obtain a dewpoint of 11°C.

■ 4. Our directly measured dewpoint turned out to be 12°C while the dewpoint determined from the dewpoint table was 11°C. These results are acceptably close to each other. The results you obtain for dewpoint using the two methods should be within 1 or 2°C of each other.

■ 5. If you cooled the air in your room to the dewpoint without removing any moisture from it a fog would start to form in the room and moisture would condense on surfaces in the room.

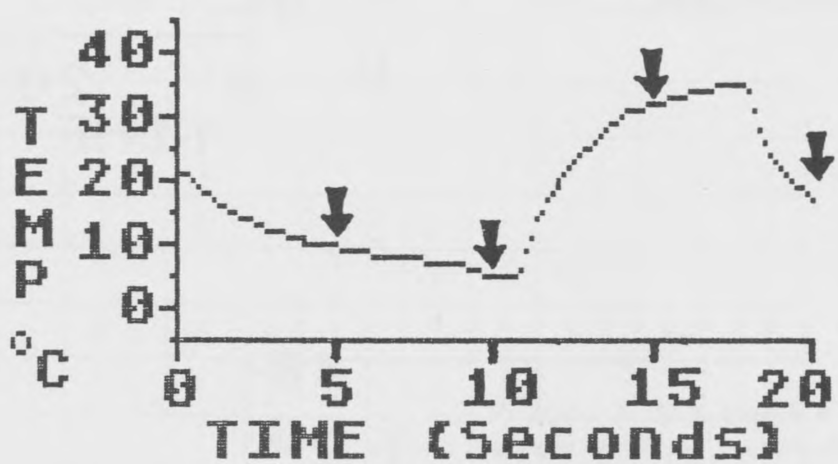
■ 6. Moisture does not usually condense on the surfaces in an air conditioned room because the air conditioner removes moisture from the air as it cools the room, thus lowering the dewpoint in the room.

■ 7. There is usually a large difference between the dry bulb temperature and the dewpoint on sunny days when the air is very clear. On cloudy, rainy, and snowy days as well as during hot, humid days there is usually a smaller difference between the dry bulb temperature and the dewpoint.

■ 8. The dewpoint should be the same inside and outside whenever no moisture has been added to or removed from the air. However, some houses and buildings with humidifiers add moisture to the air, and buildings with air conditioners remove moisture from the air. Humidifiers and air conditioners will change the indoor dewpoint relative to the outdoor dewpoint.

Project 2

Graphing How Temperature Changes Over Time

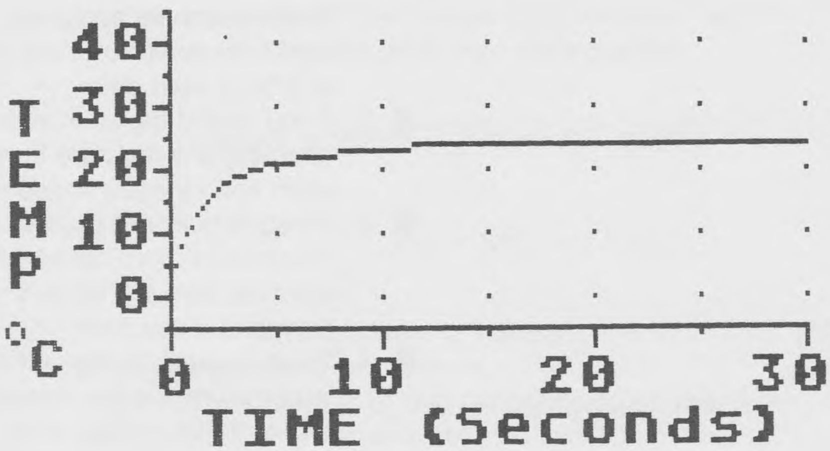


■ **1 Figure B–4.** *A graph of temperature vs. time over a 20–second time period obtained by using the DEMO program. The sensor was dipped alternately in hot and cold water.*

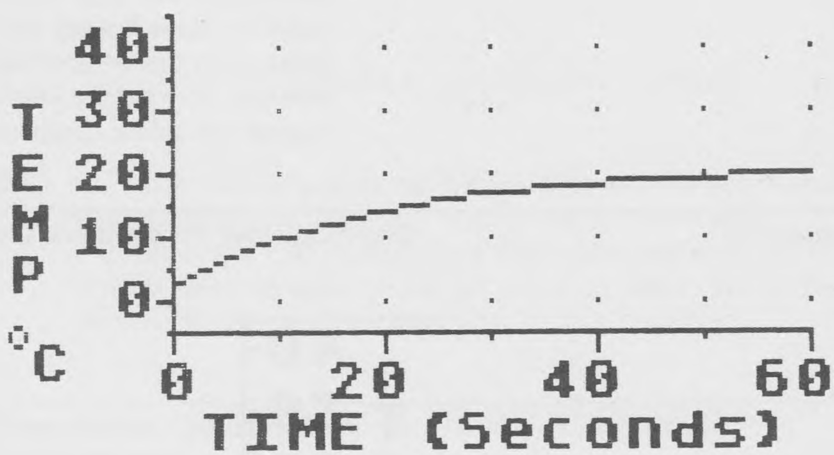
TIME (SEC.)	TEMP. (°C)
0	21
5	10
10	5
15	32
20	16

Table B–2. *Temperature as a function of time for 5–second intervals from 0 seconds to 20 seconds. Data was read from graph in Figure B–4.*

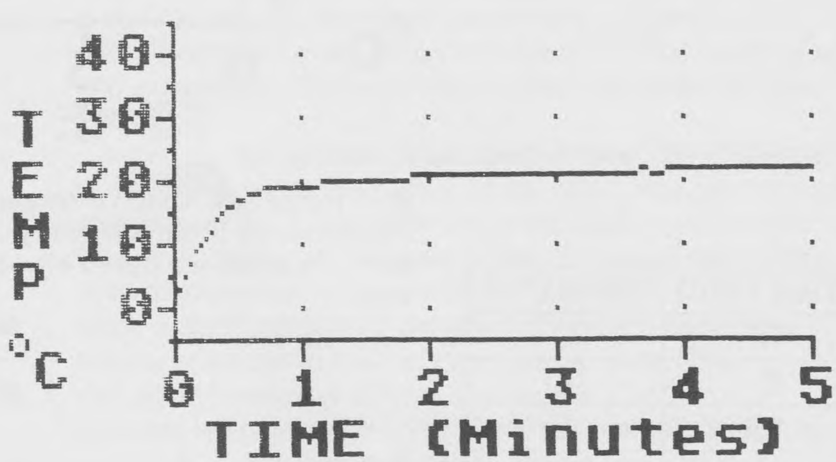
■ **2 Figure B–5.** *A graph of temperature vs. time over a 30–second time period. The sensor was quickly transferred from ice water to room–temperature water at the same time as the temperature recording was started.*



■ **3 Figure B–6.** *A graph of temperature vs. time over a 60–second time period. The sensor was quickly transferred from ice water to room–temperature air at the same time temperature recording was started.*



■ **4 Figure B–7.** *A graph of temperature vs. time over a 5–minute time period. The sensor was quickly transferred from ice water to room–temperature air at the same time the temperature recording was started.*



■ 5. By examining the 5–minute graph, we see that after 60 seconds the temperature is still 2 or 3 °C below its final temperature.

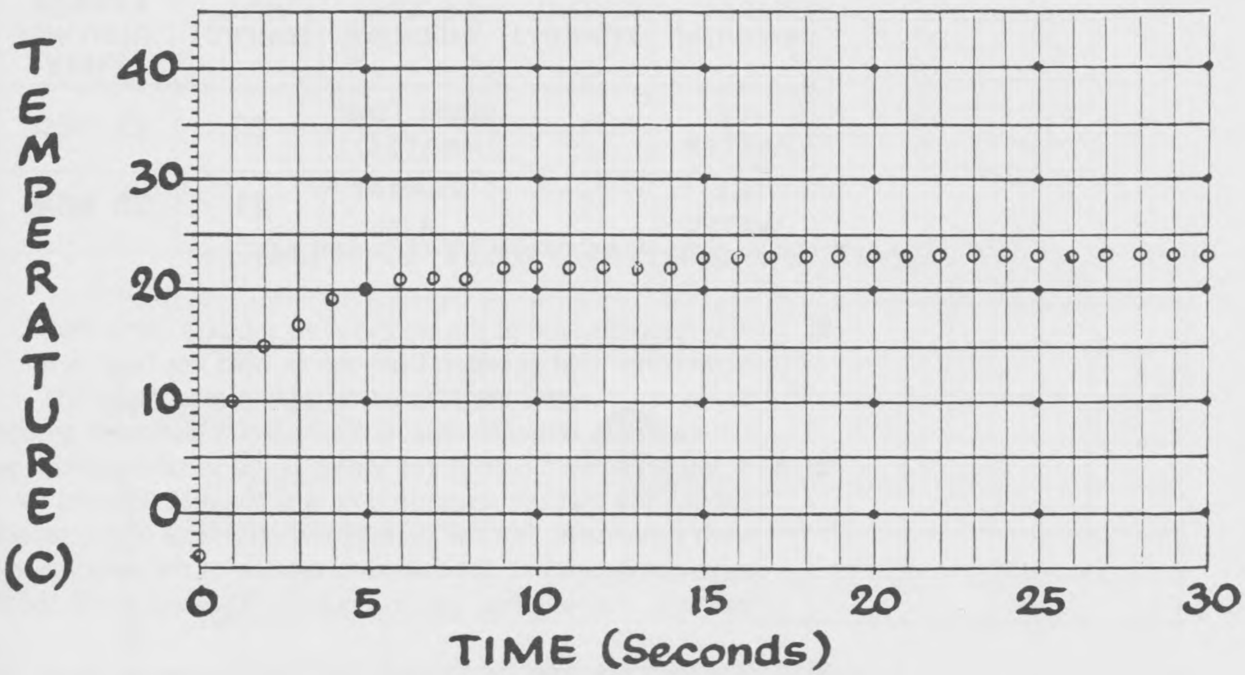
■ 6. The slope of the 5–minute graph is definitely steeper than that of the 60–second graph.

■ 7. The 5–minute graph has a much steeper slope than the 1–minute graph because its data points are recorded and plotted much more slowly. This allows more time for the sensor temperature to rise before its temperature is recorded.

Project 3 — How Quickly Can the Sensor Change Temperature?

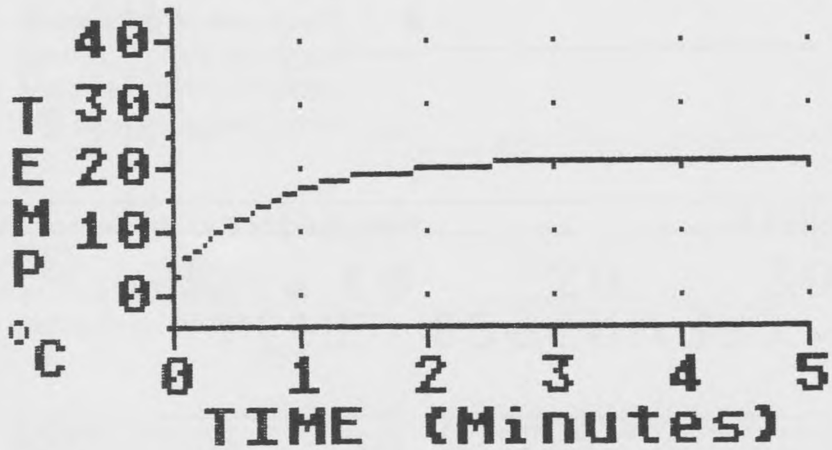
■ **1 Table B–3.** *Data table corresponding to an ice water–to–room –temperature water response time measurement.*

TIME (60th SEC.)	TIME (SEC.)	TEMP (°C)
0	0	1
60	1	10
120	2	15
180	3	17
240	4	19
300	5	20
360	6	21
420	7	21
480	8	21
540	9	22
600	10	22
660	11	22
720	12	22
780	13	22
840	14	22
900	15	23
960	16	23
1020	17	23
1080	18	23
1140	19	23
1200	20	23
1260	21	23
1320	22	23
1380	23	23
1440	24	23
1500	25	23
1560	26	23
1620	27	23
1680	28	23
1740	29	23
1800	30	23



■ **2 Figure B 8.** *Graph corresponding to an ice water– –to–room– temperature water response time measurement.*

■ 3. By examining the graph we see that the temperature of the sensor, when transferred from ice water to room–temperature water, stopped changing after 15 seconds and remained at 21°C. Thus, the approximate response time is 15 seconds.



■ 4 **Figure B–9.** *Graph of response time when sensor is transferred from ice water to room–temperature air.*

■ 5. By examining Figure B–9 it appears that the response time of the temperature sensor when transferred from ice water to room air is about 2.5 minutes.

■ 6 **Table B–4.** *Two-medium transfer table.*

FIRST MEDIUM	INITIAL TEMP(°C)	SECOND MEDIUM	FINAL TEMP(°C)	APPROX. RESPONSE TIME
ICE WATER	1	ROOM TEMP. WATER	23	15 SEC.
ICE WATER	1	ROOM AIR	21	25 MIN.

■ 7. The response time of the temperature sensor in air is much slower than that in water. Does the air hold less heat? Is it higher than water? We attempt to explore reasons for the differences in response time in the Project 3 discussion section.

■ 8. If you experiment with hotter water as the second medium you should find that the response time is somewhat different for each experiment, but the average response time of the sensor does not depend on the final temperature of the sensor. For example, the response time in Figure B–10 below is still about 15 seconds.

■ 9. The response time for warming and that for cooling should be the same. If you try determining the response time for cooling remember that there is a lot of normal variation from experiment to experiment.

■ 10. If the temperature sensor is surrounded with a hunk of clay it should slow down the response time of the sensor in proportion to its mass. This is because the clay and the sensor both have to warm or cool before a final temperature is reached. Energy has to be transferred between many more molecules.

Project 4 **Keeping Your Soda Cold**

■ **1 Table B-5.** *10-minute data table and graph. Ice cubes added immediately.*

TOTAL TIME 10 MINUTES

INVESTIGATOR ____________

TRIAL NUMBER 1 DATE ____________

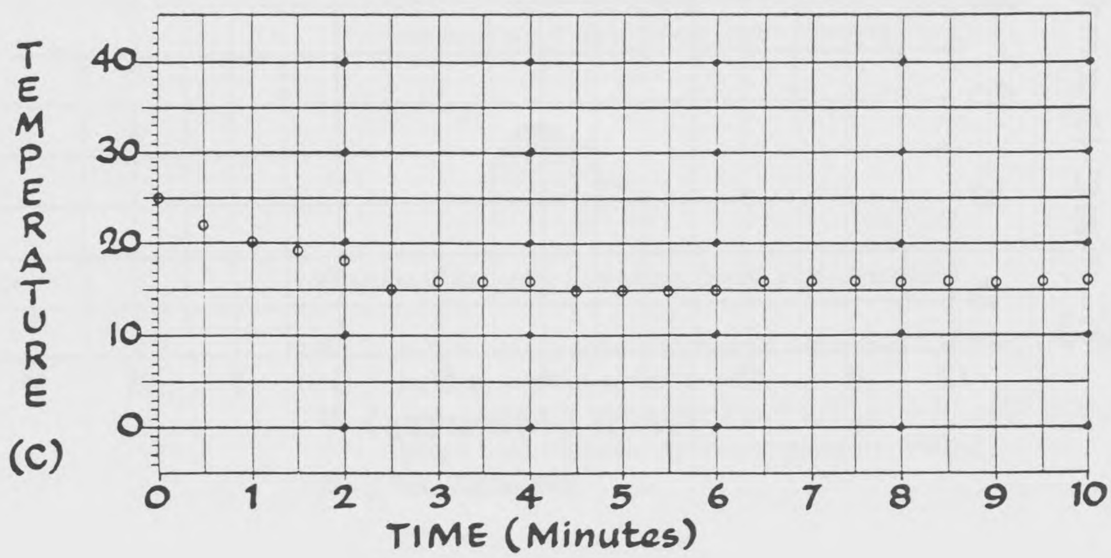
DESCRIPTION OF PROJECT Add two ice cubes to a glass of room temperature liquid immediately. Recording temperatures for 10 minutes.

DATA TABLE (Highlighted Numbers)

TIME (SEC.)	TIME (MIN.)	TEMP (°C)
0	0.0	25
30	0.5	22
60	1.0	20
90	1.5	19
120	2.0	18
150	2.5	15
180	3.0	16
210	3.5	16
240	4.0	16
270	4.5	15
300	5.0	15

TIME (SEC.)	TIME (MIN.)	TEMP. (°C)
330	5.5	15
360	6.0	15
390	6.5	16
420	7.0	16
450	7.5	16
480	8.0	16
510	8.5	16
540	9.0	16
570	9.5	16
600	10.0	16

GRAPH OF TEMPERATURE VS. TIME



■ **2 Table B–6.** *10–minute data table and graph. Ice cubes added after 6 minutes.*

TOTAL TIME 10 MINUTES

INVESTIGATOR ____________

TRIAL NUMBER 2 DATE ____________

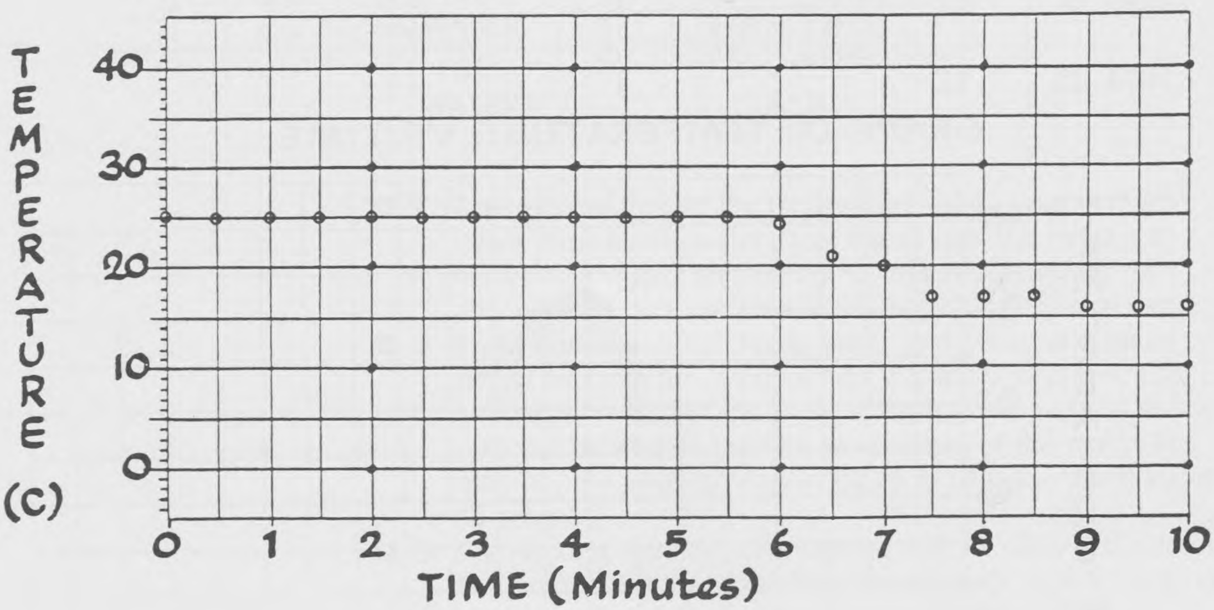
DESCRIPTION OF PROJECT Record temperatures for 10 minutes in a second glass of room temperature liquid. Two ice cubes are added after 6 minutes have elapsed

DATA TABLE (Highlighted Numbers)

TIME (SEC.)	TIME (MIN.)	TEMP (°C)
0	0.0	25
30	0.5	25
60	1.0	25
90	1.5	25
120	2.0	25
150	2.5	25
180	3.0	25
210	3.5	25
240	4.0	25
270	4.5	25
300	5.0	25

TIME (SEC.)	TIME (MIN.)	TEMP. (°C)
330	5.5	25
360	6.0	24
390	6.5	21
420	7.0	20
450	7.5	17
480	8.0	17
510	8.5	17
540	9.0	16
570	9.5	16
600	10.0	16

GRAPH OF TEMPERATURE VS. TIME



- 3. In the sample data displayed in Table B–5, the lowest temperature is 15°C while the lowest temperature in Table B–6 is only 16°C. This would suggest that after 10 minutes the temperature will go slightly lower when ice is added immediately to room-temperature water than when it is added 6 minutes later.

  By doing the experiment several times we found that adding the ice immediately leads, in most cases, to slightly better cooling. The difference, however, in the lowest temperature found is small—no more than 1°C or 2°C.
- 4. Our results indicate the hypothesis—that the rate at which an object cools is greater when the temperature difference between an object and its surroundings is greater—is still valid.

Project Five

Kitchen Chemistry: Salt and Ice

- 1. By pouring off the melted water from the salted ice and unsalted ice, we found that there was definitely more water coming from the glass of salted ice. When salt is added to crushed ice, it causes more of the ice to melt in a given time period than when no salt is added.
- 2. Since salty water is less slippery than ice, salt is placed on icy roads to melt the ice in freezing weather.
- 3 See **Table B–7**.
- 4. In our salt and ice experiment we used a chemical (salt) to cause a solid (ice), to change to a liquid state. We found that the temperature of the resulting liquid (provided the room temperature water is not too warm) was lower than that of the original solid (ice). Therefore, the chemical melting hypothesis seems to hold for this case.
- 5. A mixture of salt and ice surrounding a metal container full of ice cream will be below 0°C and can thus cause the ice cream to freeze. The cranking turns paddles inside the container of ice cream to prevent large ice crystals in the ice cream, which would make it hard to eat, from forming.

Project Six

Kitchen Chemistry II: Baking Soda and vinegar

- 1. When baking soda and vinegar are mixed together, the mixture bubbles and foams for a while.
- 2. The mixture of baking soda and vinegar feels cooler to the touch than the plain room-temperature vinegar.
- 3 See **Table B–8**.

■ **3 Table B-7.** *Graph for Trial 1 of salt and ice. Ice added after 5 seconds.*

TOTAL TIME 30 SECONDS

INVESTIGATOR P.W.L.

TRIAL NUMBER 1 DATE Sept. 22

DESCRIPTION OF PROJECT Salt and Ice: Add salt to ice after 5 seconds and record temperatures for 30 seconds.

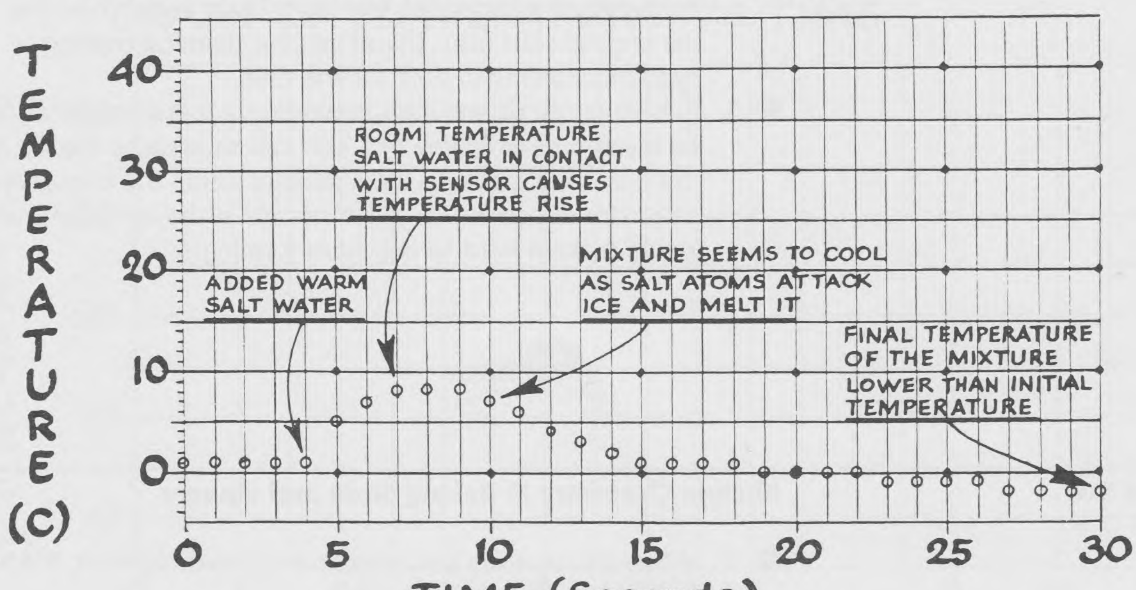
DATA TABLE (Highlighted Numbers)

TIME (60th SEC.)	TIME (SEC.)	TEMP (°C)
0	0	1
60	1	1
120	2	1
180	3	1
240	4	1
300	5	5
360	6	7
420	7	8
480	8	8
540	9	8
600	10	7

TIME (60th SEC.)	TIME (SEC.)	TEMP (°C)
660	11	6
720	12	4
780	13	3
840	14	2
900	15	1
960	16	1
1020	17	1
1080	18	1
1140	19	0
1200	20	0

TIME (60th SEC.)	TIME (SEC.)	TEMP (°C)
1260	21	0
1320	22	0
1380	23	-1
1440	24	-1
1500	25	-1
1560	26	-1
1620	27	-2
1680	28	-2
1740	29	-2
1800	30	-2

GRAPH OF TEMPERATURE VS. TIME



■ **3 Table B–8.** *Trials 1 and 2: Baking soda and vinegar.*

TOTAL TIME 30 SECONDS

INVESTIGATOR ____________

TRIAL NUMBER 1 and 2 DATE ____________

DESCRIPTION OF PROJECT Mix 1 tablespoon of baking soda with 2 tablespoons of vinegar.
Trial 1: vinegar at a low initial temperature.
Trial 2: vinegar at higher initial temperature.

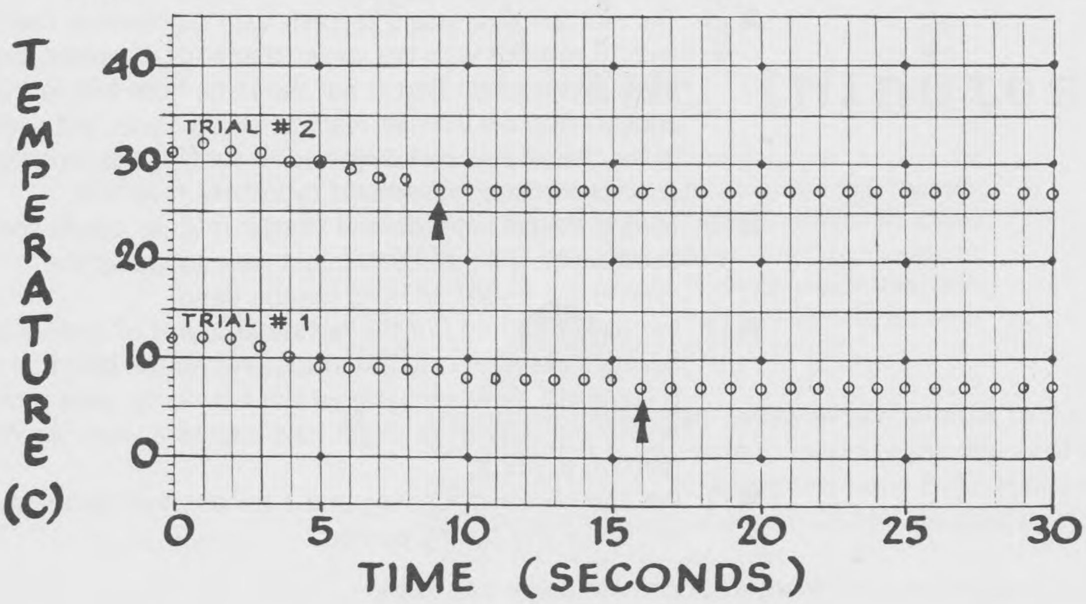
DATA TABLE (Highlighted Numbers)

TIME (SEC.)	TEMP(°C)	TEMP(°C)
0	12	31
1	12	32
2	12	31
3	11	31
4	10	30
5	9	30
6	9	29
7	9	28
8	9	28
9	9	27
10	8	27

TIME (SEC.)	TEMP(°C)	TEMP(°C)
11	8	27
12	8	27
13	8	27
14	8	27
15	8	27
16	7	27
17	7	27
18	7	27
19	7	27
20	7	27

TIME (SEC.)	TEMP(°C)	TEMP(°C)
21	7	27
22	7	27
23	7	27
24	7	27
25	7	27
26	7	27
27	7	27
28	7	27
29	7	27
30	7	27

GRAPH OF TEMPERATURE VS. TIME



■ 4. In our Trial 1 using refrigerated baking soda and vinegar, the temperature of the vinegar just before the baking soda was dumped into it was 12°C. The final temperature of the mixture was 7°C.

■ 5. It took about 16 seconds for our refrigerated baking soda and vinegar mixture to cool.

■ 6. The mixture doesn't cool instantly because it takes time for the chemicals in the vinegar and baking soda to react with each other. Even if the chemical reaction took place instantly, the temperature sensor would still need time to respond to the change in temperature. The 16 seconds that it took in our experiment for the mixture to cool down may be largely due to the sensor response time.

■7 **Table B–9.** *Data analysis of baking soda and vinegar.*

	INITIAL TEMPERATURE VINEGAR/SODA (°C)	FINAL TEMPERATURE VINEGAR/SODA (°C)	TEMPERATURE DIFFERENCE (°C)	TIME TO REACH FINAL TEMPERATURE (SECONDS)
TRIAL 1: COLD CHEMICALS	12	7	5	16
TRIAL 2: WARM CHEMICALS	31	27	4	9

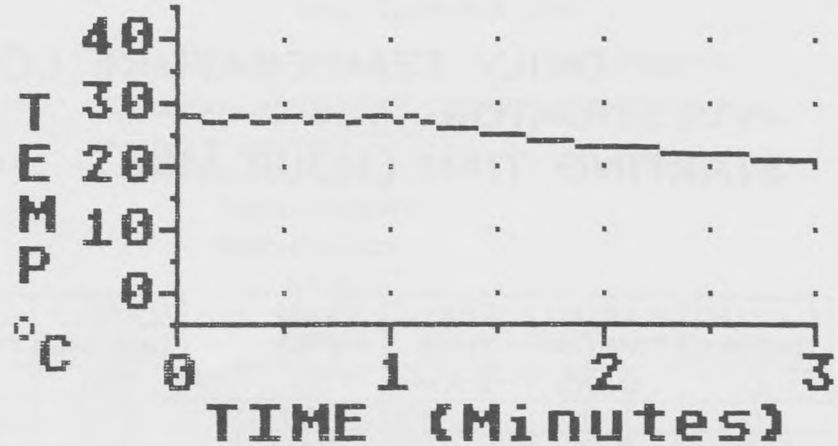
■ 8. In our Trial 2 with warm vinegar, the initial temperature of the vinegar was 31°C while the final temperature was 27°C. Both the cold and the warm reaction caused cooling, so both reactions are endothermic.

■ 9. The reaction time was 9 seconds with our warmer chemicals and 16 seconds with the cooler chemicals. However, the measured reaction time is not the same from trial to trial. It appears that the warmer reaction occurs faster, but several more trials should be completed to confirm this tentative conclusion. Thus, the second hypothesis may hold.

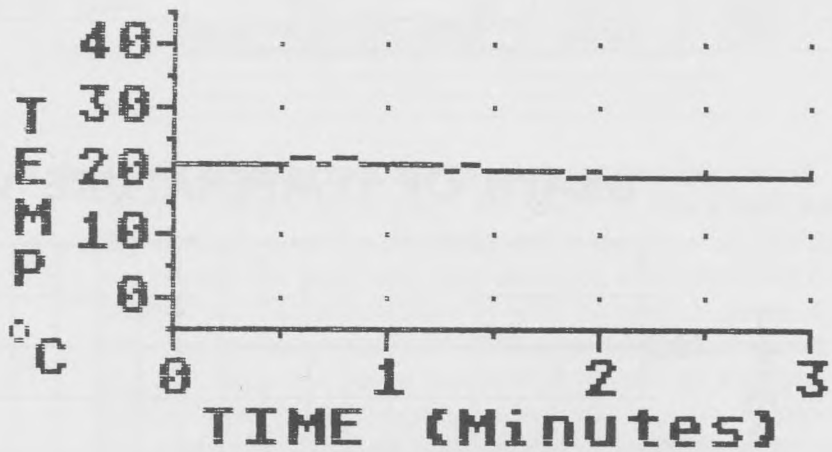
■ 10. Stirring the baking soda and vinegar mixture should speed up the reaction a bit, but you might have to repeat the experiment several times to see the trend.

■ 11. We have balanced out the relative amounts of vinegar and baking soda which are mixed together so the chemical reaction is complete. However, without this balancing, adding more of one of the substances might have caused a more vigorous reaction to occur.

■ 12. We also observed foaming and a temperature decrease with double–acting baking powder.



■ 1 **Figure B–10.** *Graph of temperature vs. time for a sensor covered with black tape. The sensor was placed in direct sunlight for several minutes. After the temperatures were recorded for one minute the sensor was shaded with a piece of folded paper. During the next two minutes, the temperature fell from 26°C to 21°C.*



■ 2 **Figure B–11.** *Graph of temperature vs. time for temperature sensor covered with aluminum foil. The sensor was placed in direct sunlight for several minutes before the temperature recording began. After temperatures were recorded for one minute the sensor was shaded with a piece of folded paper. In the next two minutes the temperature fell only slightly—from 21°C to 19°C.*

■ 3. The sun obviously heats up the sensor. In order to measure air temperature it is necessary to minimize the effects of the sun's heating. By looking at Figures B–11 and B–12 above we found that the combination of aluminum foil and shading gave the lowest recorded temperatures.

Note: *Our measurements were made indoors at noon on a late September day in Carlisle, Pennsylvania. Your results will vary with location, time of day and time of year.*

■ 4 **Table B–12.** *Daily temperature log.*

■4. DAILY TEMPERATURE LOG

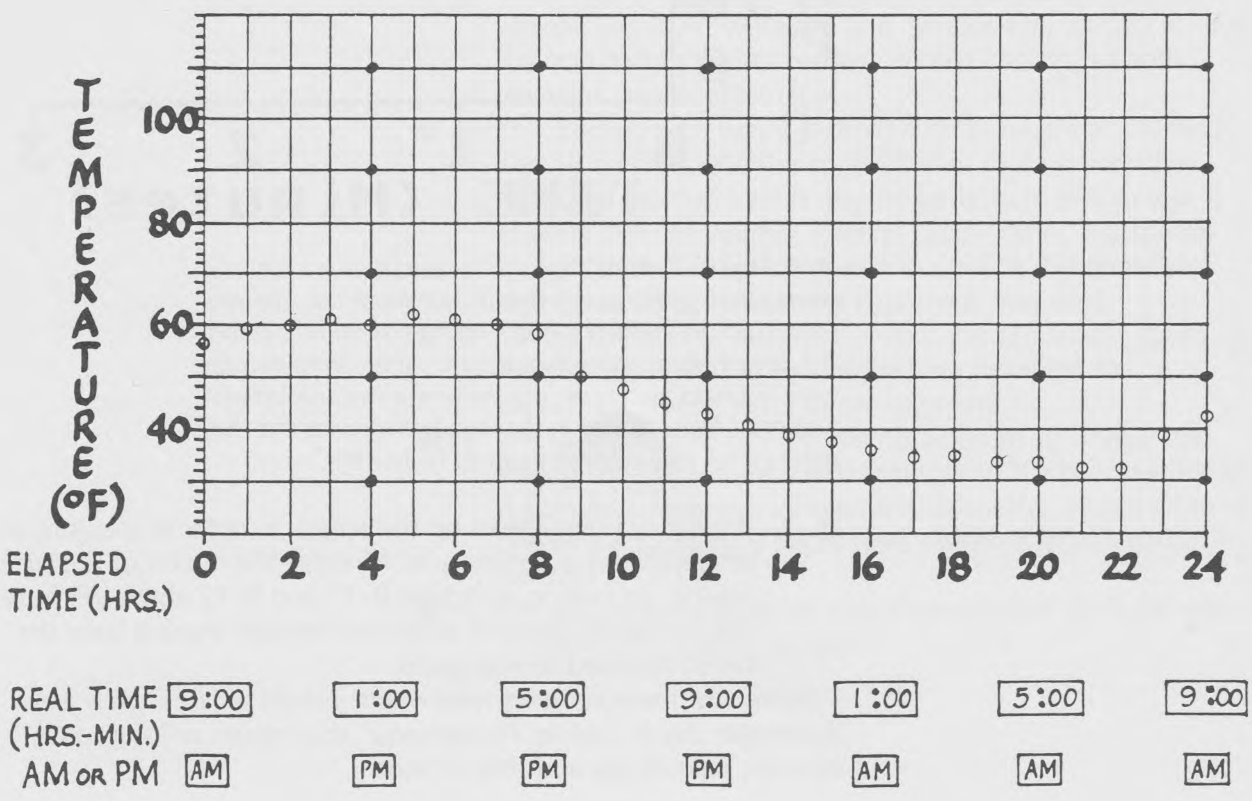
INVESTIGATOR P. W. L. DATE March 15-16

STARTING TIME (HOUR:MIN.) 9:00 AM ☑ PM ☐

ELAPSED TIME (MIN.)	ELAPSED TIME (HR.)	REAL TIME	TEMP. (°F)
0	0:00	9 AM	56
60	1:00	10	59
120	2:00	11	60
180	3:00	12 NOON	61
240	4:00	1 PM	60
300	5:00	2	62
360	6:00	3	61
420	7:00	4	60
480	8:00	5	57
540	9:00	6	50
600	10:00	7	47
660	11:00	8	45
720	12:00	9 PM	43

ELAPSED TIME (MIN.)	ELAPSED TIME (HR.)	REAL TIME	TEMP. (°F)
780	13:00	10 PM	41
840	14:00	11	39
900	15:00	12 MIDN.	37
960	16:00	1 AM	36
1020	17:00	2	35
1080	18:00	3	35
1140	19:00	4	34
1200	20:00	5	34
1260	21:00	6	33
1320	22:00	7	33
1380	23:00	8	39
1440	24:00	9 AM	42

GRAPH OF TEMPERATURE V.S. TIME



■ **5 Table B–13.** *Daily weather log.*

DAILY WEATHER LOG

OBSERVER P. W. L. DATE March 15-16

LOCATION Carlisle, PA STARTING TIME 9 a.m.

DAY'S WEATHER:

- CLEAR [x]
- PARTLY CLOUDY [ ]
- PRECIPITATION
  - RAIN [ ]
  - SNOW [ ]
  - OTHER ____________
  - TIME ____________
- WIND DIRECTION
  - NORTH [ ]
  - EAST [ ]
  - SOUTH [ ]
  - WEST [x]
  - CHANGING [ ]
- WIND SPEED
  - CALM [ ]
  - BREEZY [x]
  - WINDY [ ]

REMARKS Beautiful March day with clear sky and light breezes.

■ 6. We monitored the daily change in temperature from 9 a.m. on March 15 to 9 a.m. on March 16. March 15 was a clear sunny day with a few small puffy clouds off in the distance. The day was breezy. The night was calm and cool. From Table B–12 we see that the high temperature of 62°F occurred at about 2 p.m. The low temperature of 33°F occurred the next morning at 7 a.m. Since our sensor was located outside on a second story window there was probably morning frost on the ground. The ground is often a bit colder than the air higher up on calm mornings.

It is typical for the high temperature to occur about two hours after noon. Note that in mid–March near the vernal equinox the sun should set at about 6 p.m. and rise at about 6 a.m.

From a real time of 5 p.m. until a real time of 7 a.m. the next morning, the air temperature drop looks like a typical cooling curve as the heat energy stored in the air radiates energy into space. As the sun rose after 6 a.m. the temperature did not change for the first hour since the sun was still low in the sky. But, between 7 a.m. and 9 a.m. on March 15 the temperature rose from 33°F to 42°F.

Note that the 9 a.m. temperature of 56°F on March 14 is considerably warmer than the 9 a.m. temperature on the next morning. Are we heading for a cooler day because the night was so cold?

Appendix C
The Temperature Lab Software

The software included in the Science Discovery Series Temperature Lab comes on a 5¼ diskette and should run on any Commodore 64 Computer. The software is self-documented and should require little or no reference to this documentation for its use. The major features of the software are outlined in the functional diagram.

The Temperature Lab Software allows users to:

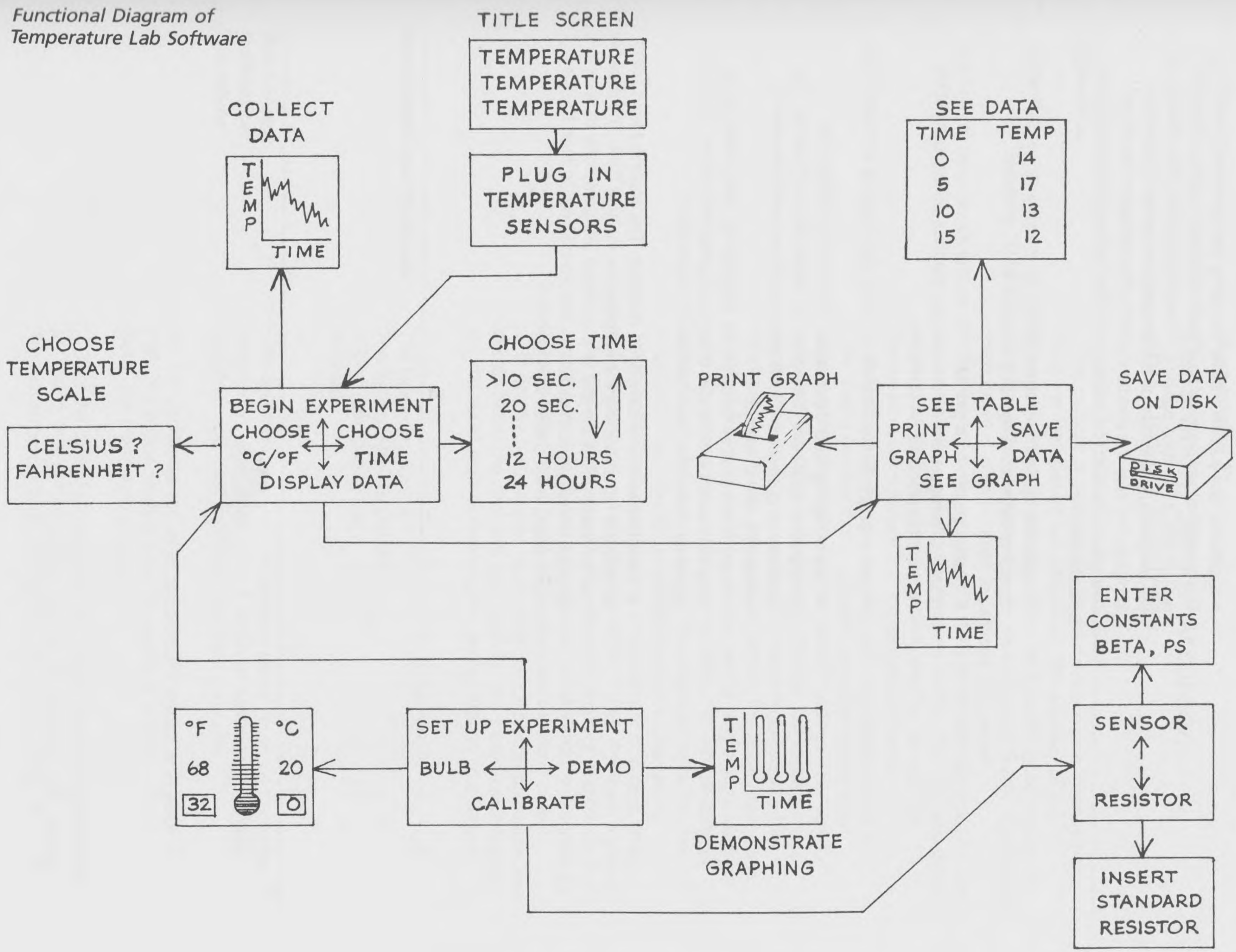
- **Record temperatures between −5°C and 45°C by using the temperature sensor with the blue trim.** When the BULB option is selected from the menu, an alcohol bulb thermometer appears on the screen accompanied by temperature scales on either side—one for degrees Fahrenheit and one for degrees Celsius. The current temperature of the sensor is shown both by the level of alcohol of the bulb thermometer and by digital temperature readings in white numerals. By pressing the F3 key, current temperatures are recorded below the current temperature readings to provide data for a table or graph.

- **Demonstrate how changes in temperature over time can be represented graphically.** In this demonstration an image of a red alcohol bulb thermometer moves from left to right across the screen and copies itself every five seconds. Each copy freezes the value of a temperature at the moment of its creation. After about a 20-second time interval there are four thermometers on the screen. These thermometers slowly fade away leaving a histogram. The histogram in turn fades away while 121 data points representing 121 temperatures collected during the 20-second time interval appear on the screen.

- **Set up an experiment to measure 121 temperatures as a function of time.** The user chooses a display in either °C or °F. In addition, the user chooses from a menu of 16 total time durations between 10 seconds and 24 hours. The temperatures are displayed in a graph as they are recorded. Once the experiment is complete the user can see a display of the temperatures in table form, print the graph, or store the data on a diskette.

- **Record dual temperatures.** A second temperature sensor with orange trim can be obtained as a Temperature Lab accessory. If two sensors are used, the blue temperature sensor is plugged into the left (blue) paddle input of the interface and the orange sensor into the right (orange) paddle input. In the temperature vs. time experiments, temperatures from both sensors can be recorded simultaneously and displayed graphically as measurements are made. Numerical data for both sensors can then be displayed on the data table, transferred to a disk file, or printed out as a graph. Users with color television sets or monitors should note that a blue trace appears on the graph for data obtained using the blue sensor and orange trace for data obtained from the orange sensor.

Functional Diagram of Temperature Lab Software



- **Calibrate the paddle inputs by using the standard resistor.** This routine allows users to do a rapid calibration using a standard resistor and a standard adjustor, if needed, to better the accuracy of the temperature readings of the temperature sensor. Calibration improves the way the paddle inputs to the computer transform changes in the electrical resistance of the temperature sensor into paddle readings.

- **Calibrate the temperature sensor** by entering sensor calibration constants determined by using a special BASIC program.

- **Dump graphs to a printer.** This routine allows users to print out graphs of temperature vs. time on any graphics printer compatible with the Commodore 64 Computer.

- **See a graph** of temperature vs. time after running an experiment.

- **See a highlighted data table.** This routine displays the temperature data taken for up to 121 values for each sensor. The corresponding elapsed time at which each temperature value is collected is also displayed.

  Every few entries in the table are highlighted. Users wanting to keep permanent records can enter the highlighted values into data summary sheets like those included in Appendix F.

- **Save temperature data on a diskette.** This routine allows users to create a file containing the temperature vs. time data. The data file can be read in from the disk and analyzed using any one of several popular languages such as BASIC. (Details on how to read the file using BASIC are included in Appendix E.)

Appendix D
Calibration, Sensor Accuracy, and Timing Accuracy

Calibration

The purpose of calibration is to get more accurate measurements using the Temperature Lab equipment. The accuracy of the temperature readings without calibration is usually good enough for all of the projects suggested in the Experimenter's Guide. To complete them, there is often no need to calibrate your sensor.

If you enjoy doing projects with the best possible accuracy, or have a special need to measure temperatures within 1°C, then you should follow the calibration procedures developed for use with the Temperature Lab Software and the temperature sensor.

The first, which is quick and easy, uses a standard resistor to determine more about how a specific computer paddle input translates electrical resistances into paddle readings. The "resistor" calibration procedure is described in Chapter 1. It should correct temperature readings to within 2°C. However, because of the characteristics of some temperature sensors, the resistor calibration does not always improve the accuracy of the temperature readings.

To insure temperatures accurate to within l°C, a more complex calibration procedure is necessary. This procedure calibrates the response of each specific temperature sensor to changes in temperature. If you are designing an experiment or project which requires temperatures accurate to within 1°C, or if you are a person who likes to do things with the maximum accuracy possible, or if you simply want to learn about the process of calibration, you should try the complete "sensor" calibration procedure described below.

To get the best possible results from the calibration procedure, you should follow the directions very carefully. You should use a crushed ice and water mixture that is tightly packed around your sensor.

Equipment and Materials

The Laboratory Station
The Temperature Lab Diskette
A large cake pan or tray
Ice Water

The Sensor Calibration Procedure

To determine how your temperature sensor responds to changes in temperature when attached to a particular paddle input of your computer, you must find three calibration constants.

PS: The paddle reading when the standard resistor is in place.
P(ϕ): The paddle reading when the sensor is at 0°C.
Beta: The thermistor constant.

Once the calibration constants for a given sensor and paddle input are found, they can be entered into the Temperature Lab Software. The calibration constants can be found by: (1) recording the paddle

value when the standard resistor is in the paddle input, (2) recording it again when the sensor is in the ice water, and (3) finally, recording the paddle reading when the sensor is in room temperature water.

If the paddle values of the sensor at room temperature and the standard resistor are determined, then the thermistor constant Beta is given by the following equation:

$$[\text{Beta} = [\log R_O - \log R_R] / (1/273) - (1/273 + t_R)]$$

where t_R is the room temperature in °C.
R_R is the sensor resistance at room temperature.
R_O is the sensor resistance at 0°C.
log R is the natural logarithm of the resistance.

These resistances can be found from the corresponding paddle readings P_R and P_0 by the equations:

$R \cong 150\,(P/P_S)^{1.14}$ for $P < P_S$

$R \cong 1.26\,(P - P_S) + 150$ for $P \geq P_S$

where P_S is the paddle value when the standard resistor is plugged in.

You can get the paddle values needed for sensor calibration and the results of the calculation of the calibration constants by running the CALIBRATE program included on the Temperature Lab Diskette. If you wish to see this program, simply enter the command LIST after you have loaded it.

To set up the sensor calibration:

1. Insert the Temperature Lab Diskette into the disk drive.
2. Unplug the interface if necessary. Load the program by entering the command LOAD "CALIBRATE",8 and press the RETURN key.
3. Type the command RUN and enter a paddle number of 2 when asked.
4. Plug your interface into control port 2 of your computer.
5. Plug the standard resistor into the appropriate paddle input. Calibration of the left (blue) paddle input is required (and that of the right (orange) paddle input is optional) whenever the Temperature Lab Software is used for recording data. If the sensor adjustor is needed for correct temperature readings, insert it between the standard resistor or temperature sensor and the interface during the calibration procedure.

To calibrate:

1. Prepare a container with water at about room temperature.
2. Prepare a second container filled with crushed ice with a small amount of water at the bottom of it.
3. Place the containers in a large cake pan or tray.
4. Insert the Temperature Lab Diskette in the disk drive.
5. Load the calibration program by typing the command LOAD"CALIBRATE",8 and pressing the RETURN key.
6. Type the command RUN and press the RETURN key.
7. Follow the programmed instructions on the screen to calibrate the blue sensor in the left (blue) paddle input.
8. Copy the calibration constants corresponding to the paddle inputs you used into the table below.

CALIBRATION TABLE

INTERFACE PADDLE INPUT	PADDLE #	PS	P(Ø)	BETA
LEFT (PORT 2)	2			
RIGHT (PORT 2)	4			

TYPICAL VALUES:
PS=155 P(Ø)=181.5 BETA=4194

If you plan to use a second orange sensor in the right paddle input, you should calibrate it as well. To do this, repeat the steps above, this time entering a paddle number of 4 when asked.

What to do with Beta, P(Ø), and PS.
To use the new values of Beta and P(Ø) in the Temperature Lab Software, you should do the following:

1. Unplug the interface from the control port, if necessary.
2. Load the Temperature Lab Software from your working diskette by typing the command LOAD"*",8 and pressing the RETURN key.
3. When READY appears on the screen, type the command RUN.
4. Call up the main menu. Choose the CALIBRATE option by pushing the joystick down (↓).
5. Choose the SENSOR option by pushing the joystick up (↑).
6. Follow the instructions on the screen using the joystick to choose the values of Beta and P(Ø) you entered in the table above.

You should enter the values of PS for each sensor input of interest in the table above for your own information. You do not need to enter the PS values into the Temperature Lab Program because they were recorded when you calibrated using the standard resistor.

Limitations on the Accuracy of Temperature Values
The paddle inputs on the Commodore 64 Computer were not originally designed for accurate measurements of the paddle dial settings. Even when a paddle dial is left untouched or the temperature of a sensor is not changing, the corresponding paddle values may fluctuate up and down about some average value. You have probably already noticed these fluctuations. Temperature readings sometimes go up and down by a degree Celsius when the temperature is right between two possible values.

The actual temperature of a sensor is related to its resistance at that temperature. The relationship between paddle readings and the input resistances of a sensor is not linear. Approximate equations are used to determine R from each paddle reading (see above). These equations may not be quite accurate on all Commodore 64 Computers.

Another limitation on the accuracy of the temperature values is that the temperature sensor thermistor constant, Beta, and the paddle value P(ϕ) with the standard resistor in place ,may not be the same as the typical values used in the sample programs. The deviation of Beta and P(ϕ) from typical values can lead to a 2°C or 3°C error. Better values for Beta and P(ϕ) can be obtained by calibrating the sensor, but the accuracy with which Beta and P(ϕ) can be determined is also limited by the fluctuations in the paddle readings used to find the new values of Beta and P(ϕ).

A final limitation on the accuracy occurs at high temperatures where the temperature sensor does not respond as much to changes in temperature as it does at lower temperatures. Typically, above 35°C, the temperature reading is only accurate to 2.0°C, even after the sensor calibration procedure has taken place.

The limitations on the accuracy of the temperature sensor readings do not matter in many experiments. For example, in most of the projects described in Chapter 3, either temperature differences or the shape of temperature vs. time graphs were of most interest, and not the exact values of temperature.

In summary, if you want 1°C accuracy, you should do the following:

1. Hope that the paddle values for your computer don't fluctuate too much.
2. Hope that the relationship between resistance and paddle value for your computer is not to different from that for a typical Commodore 64 Computer.
3. Design your project to work, if possible, at the low end of the temperature range (−5°C to 30°C).
4. Calibrate your temperature sensor when it is plugged into the paddle input you plan to use in your experiments by following the procedure outlined in this appendix.

Timing Accuracy

The Commodore 64 has an internal 60 Hertz timing signal. This signal is used as a clock to keep track of time intervals when temperatures are monitored. The Commodore 64 times are accurate to better than one percent for all time intervals. For intervals of one hour or more, the computer clock runs a bit slow. The actual time for an experiment is about four-tenths of one percent longer than the indicated time. This means that the actual elapsed time in a 24–hour experiment will be about 5 minutes longer than 24 hours.

The accuracy of the Commodore 64 clock is good enough for almost all the experiments you can think of to do with the Temperature Lab.

Note: An experiment actually begins when the joystick button is released after being pushed. Users testing their timing accuracy should take this into account.

Appendix E

Temperature Lab Programs in BASIC

Programming your own experiments allows you to tailor the data collection and analysis to your own needs. This appendix is a must for those who program.

To use this appendix you should know how to read, enter, and write BASIC programs which contain relatively simple mathematical equations.

The temperature sensor is substituted for the left game paddle when attached to the left (blue) paddle input of the Science Discovery Series Interface. The sensor substitutes for the right paddle when attached to the right (orange) paddle input. The numbers representing the dial setting on a paddle or numbers relating to the temperature of a sensor can be called using any of the computer languages available for the Commodore 64 Computer including BASIC, Logo, Assembler, Forth, Pascal, and FORTRAN.

Several relatively short programs have been developed in BASIC as examples of how temperature data can be obtained from paddle readings. Readers familiar with different versions of BASIC or with other languages will have little difficulty converting the sample programs to those languages.

The short programs are intended primarily to serve as examples of Temperature Lab programming techniques. Elements of these programs can be incorporated into more extensive programs written by users to do special experiments and data analyses.

The programs discussed below allow you to use BASIC to:

1. Read paddle values.
2. Compute temperature in degrees Celsius from a paddle value.
3. Convert temperatures from degrees Celsius to degrees Fahrenheit.

Loading the BASIC Programs from the Temperature Lab Diskette

The short BASIC programs described in this Appendix are included on the Temperature Lab Diskette.

To load a program:

1. Insert the Temperature Lab Diskette in the disk drive.
2. Be sure the interface is unplugged from the control port.
3. When the READY prompt appears, enter the command LOAD followed by the program name in quotation marks followed by a comma and the number 8 to indicate the disk drive is being used. For example, to load the program called READ PDL, enter the command LOAD "READ PDL",8. After the program you want has loaded and the READY prompt appears, it can be listed or run using the LIST or RUN command.

Reading Paddle Values with BASIC

When a game paddle is plugged into the computer, a number between 0 and 255 representing its setting, is stored in the computer's RAM. As paddle dials are turned, these numbers change.

To experiment with reading the paddle inputs, you can plug the interface, as usual, into control port 2. Next, the temperature sensor (and the sensor adjustor, if needed) should be plugged into the left (blue) paddle input. If you have game paddles, you can plug them into the computer instead of the interface and sensor.

To read the value of paddle 2 continuously, follow the procedures described in the section above to load the BASIC program named READ PDL from your Temperature Lab diskette.

Note: Details on how to read paddles from a BASIC program are included on pages 346 and 347 of the Commodore 64 Programmer's Reference Guide.

Run the program by entering the RUN command and pressing the RETURN key. Watch the screen. As you warm up the sensor between your fingers or turn a left paddle dial from right to left, the paddle values should go down. To stop the program, press the RUN/STOP key.

The paddle number is 2 in the program above. The paddle number used in a program indicates which control port, 1 or 2, and which paddle input, left or right, is being used.

For example, to display the values corresponding to the right paddle in control port 2, or a temperaure sensor attached to the orange input of the interface, simply modify line 120 to read the paddle 4 value instead of the paddle 2 value in the program. You can also modify the program to call on paddles 1 and 3 if you wish to plug the interface into control port 1.

Try modifying the program above to read paddle 4 with the temperature sensor in the orange right paddle input.

Computing Temperatures in Celsius From Paddle Values

The Temperature Lab Temperature Sensor consists of a thermistor mounted in a moisture proof wand. To compute the temperature in degrees Celsius associated with a given paddle value the following equation should be used:

Insert Fahrenheit Celsius equation

You can calculate temperatures from paddle readings which are within a few degrees Celsius of the actual temperatures by using the typical values for Beta, P(Ø), and PS. If you want to improve the accuracy to within 1°C you should follow the calibration procedures outlined in Appendix D and substitute the calibrated values for Beta, P(Ø), and PS.

The program PDL TO TEMP on the Temperature Lab Diskette uses the logarithm function LOG, for continuous display on the screen of temperatures in degrees Celsius. You can load and run the program PDL TO TEMP. Press the RUN/STOP key to interrupt the program.

By adding a new line in the program to convert the temperature to degrees Fahrenheit, you can also calculate your temperatures in Fahrenheit from the paddle readings.

To test this program we suggest that you plug the interface into control port 2 with the temperature sensor in the left (blue) paddle input, and run the program. If the "typical" equation is accurate, then placing the sensor in a container with lots of ice and a bit of water should cause a value of 0°C to be displayed on the screen.

Converting Temperatures from °C to °F Using BASIC

The equation for changing the temperature scale from Celsius to Fahrenheit is given by

$$t(°F) = (9/5)t(°C) + 32$$

The program to convert from degrees Celsius to degrees Fahrenheit can be loaded from the Temperature Lab Diskette under the name "C to F".

The program can be modified to allow you to practice converting from degrees Fahrenheit to degress Celsius by changing line 40 to

```
TC = (5/9) * (TF—32)
```

and replacing TC with TF and TF with TC throughout the program.

Appendix F
Saving and Printing Data

Keeping a permanent record of your data and graphs is an important part of a scientific investigation. Such records can be used later for data analysis and the presentation of results.

There are three ways that data and graphs can be saved more permanently. These are:

1. Printing an image of the graph resulting from any temperature vs. time experiment using a graphics printer compatible with the Commodore 64 Computer.
2. Saving the temperatures in the data table on a disk and retrieving the information with a BASIC program
3. Copying data and plotting graphs by hand using the special Table/Graphs reprinted at the end of this Appendix.

Printing Graphs

After an experiment in which a graph of temperature vs. time has been collected a graph can be printed out by users having a graphics printer. To call on the PRINT GRAPH option:

1. Press the F3 key as soon as a graph has been created as the result of an experiment.
2. When the menu screen appears push the joytstick down (↓) to select the DISPLAY DATA option.
3. When the next menu (the DISPLAY menu) appears, push the joystick to the left (←) to select the PRINT GRAPH option. The graph should reappear on the screen.
4. Turn the printer on. If it has been used to print out other information since being turned on, then turn it off and on again to clear out unwanted printer control information.
5. Press the F3 key to begin printing.

Saving and Retrieving Data

The SAVE DATA option in the Temperature Lab Software allows you to save the temperature vs. time data on a disk file. The advantage of saving data on a disk file is that you can write your own programs to retrieve, analyze, or display it in a number of different ways depending on the nature of your experiment. For example, if your are monitoring the weather you may want to print out the high, the low, and the mean temperature for a 24 hour period. You may also want to calculate the heating or cooling degree days. In other experiments, you may want to determine other statistical values such as the standard deviation.

Saving Data

After you have directed the computer to collect data for temperature vs. time, you can save a data file by following the instructions below:

1. When the temperature vs. time graph is complete, choose the DISPLAY DATA option by pushing the joystick down (↓).
2. Another menu will appear on the screen. Choose the SAVE DATA option on this menu by pushing the joystick to the left (←).
3. When you are requested to enter a file, enter a number between 0 and 9 by pushing the joystick up or down.
4. Insert a formatted data disk or leave your Temperature Lab working diskette in the drive.

d 5. When the F3 key is pressed, a file named TEMP<n>.DAT where <n> is the number you entered, will be stored on your TEMPERATURE disk.

The Data File Format

The first entry in the file represents the number of temperature sensors being read during the experiment. The second number represents the number of temperatures collected from each sensor. The third entry in the file is a string signifying the temperature scale and consists of the word "CELSIUS" or "FAHRENHEIT". The fourth entry is the total time chosen for the experiment, and the fifth entry is a string signifying the time unit used (seconds, minutes, or hours). Finally, all of the blue temperature sensor readings are listed sequentially, and, if the orange sensor is plugged in, all of the orange temperature sensor readings are listed sequentially.

Retrieving Data

A BASIC program named READ DATA has been written in BASIC to allow you to read your temperature data and display it on the screen. You are invited to modify it to include any data analyses of interest to you. READ DATA is stored in the on the Temperature Lab Diskette. To call on your data file and display its contents, you should:

1. Insert your Temperature Lab diskette into the disk drive.
2. Load and run the program READ DATA by entering the command LOAD"READ DATA",8 and pressing the RETURN key.
3. Enter the command RUN and press the RETURN key.
4. Insert your data disk with the temperature data file on it into the drive if it is different than your working Temperature Lab Diskette.
5. Enter the file name into the program when it is requested. For example, if you want to display your file number 1, enter the string TEMP1.DAT and press the RETURN key. You should see the data displayed on the screen. To slow down the data display as it scrolls by on the screen, you can hold down the CTRL key.

Recording Highlighted Numbers from the Data Table

When data are reçorded for a temperature experiment, a group of highlighted numbers is displayed when you choose the SEE TABLE option from the menu. These highlighted are the values selected for entry in the data table. They show a representative sample of all the data taken during the experiment.

These values can be entered in a table leaving just enough spaces for the total number of highlighted numbers you choose for your observation or experiment. Then, the values can be plotted on the corresponding graph below the table. The graphs are drawn so that each data point lies along one of the vertical lines of the graph.

Making a Table and a Graph from a Sample Table/Graph

With the sample table/graphs in this Appendix, you can easily create the specific tables and graphs you need to record and analyze the data you get when you do Temperature Lab observations and experiments.

There are six types of graphs. The choice of time determines which type you choose. Table F–1 shows the type of graph for each choice of Total Time.

To use the Samples, follow the instructions below:

1. Look at Table F–1 to find the graph–type you need for the x–axis you chose when the data was recorded.
2. Xerox the graph–type you chose.
3. Enter the highlighted times and temperature values in the data table.
4. Fill in the numbers indicated in Table F–1 for your x–axis below the marks on the x–axis of the graph.
5. Plot each temperature value in order on the graph.

TABLE F-1: Summary of Information Needed to Complete a TABLE and GRAPH

X-Axis Choice	*Graph Type*	*Times in Data Table and Graph Axis*
10 seconds	1	0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 seconds
20 seconds	1	0, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20 seconds
30 seconds	2	0, 5, 10, 15, 20, 25, 30 seconds
1 minute	2	0, 10, 20, 30, 40, 50, 60 seconds
2 minutes	3	0, 20, 40, 60, 80, 100, 120 seconds
3 minutes	1	0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0 minutes
5 minutes	4	0, 1, 2, 3, 4, 5 minutes
10 minutes	4	0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 minutes
20 minutes	4	0, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20 minutes
30 minutes	2	0, 5, 10, 15, 20, 25, 30 minutes
1 hour	2	0, 10, 20, 30, 40, 50, 60 minutes
2 hours	5	0, 20, 40, 60, 80, 100, 120 minutes
3 hours	2	0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0 hours
6 hours	2	0, 1, 2, 3, 4, 5, 6 hours
12 hours	6	0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12 hours
24 hours	6	0, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24 hours

TYPE 1 10, 20 SEC. - 3 MIN.

INVESTIGATOR ______________________________

TRIAL NUMBER ____________ DATE ____________

DESCRIPTION OF PROJECT ____________________

____

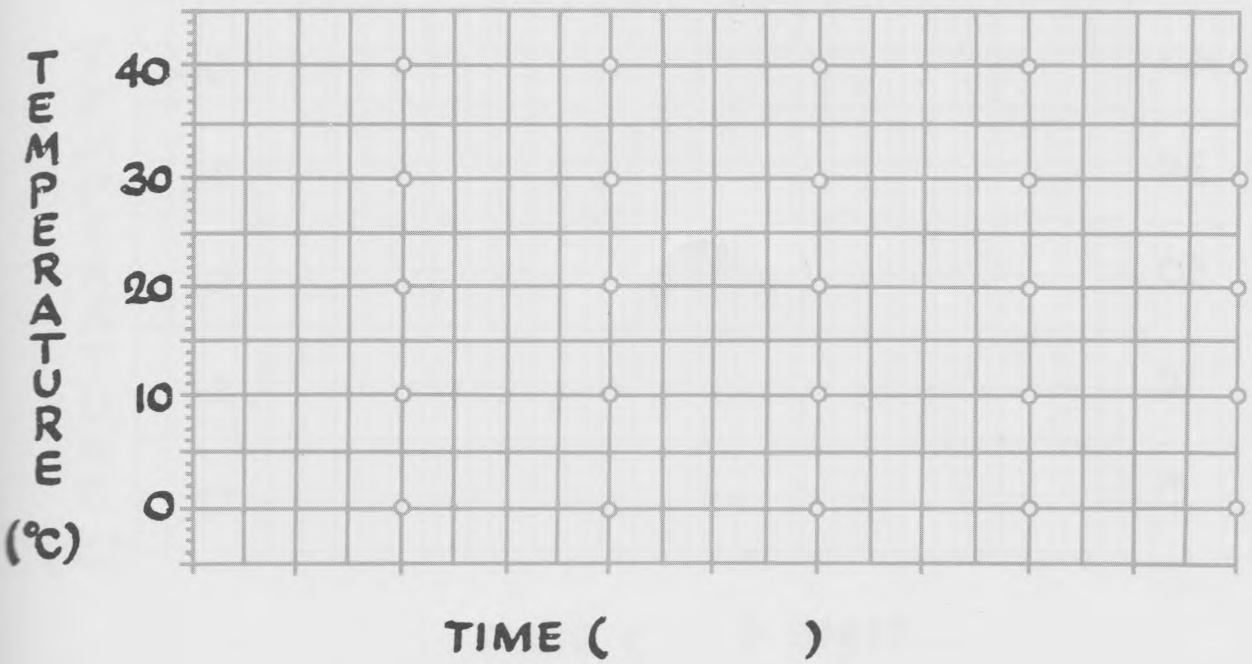
____

DATA TABLE (Highlighted Numbers)

TIME (SCREEN)	TIME (GRAPH)	TEMP. (°C)

TIME (SCREEN)	TIME (GRAPH)	TEMP. (°C)

GRAPH OF TEMPERATURE VS. TIME



TYPE 2 30 SEC.-1,30 MIN.-1,3,6 HRS.

INVESTIGATOR ____________________

TRIAL NUMBER __________ DATE __________

DESCRIPTION OF PROJECT ____________________

____

____

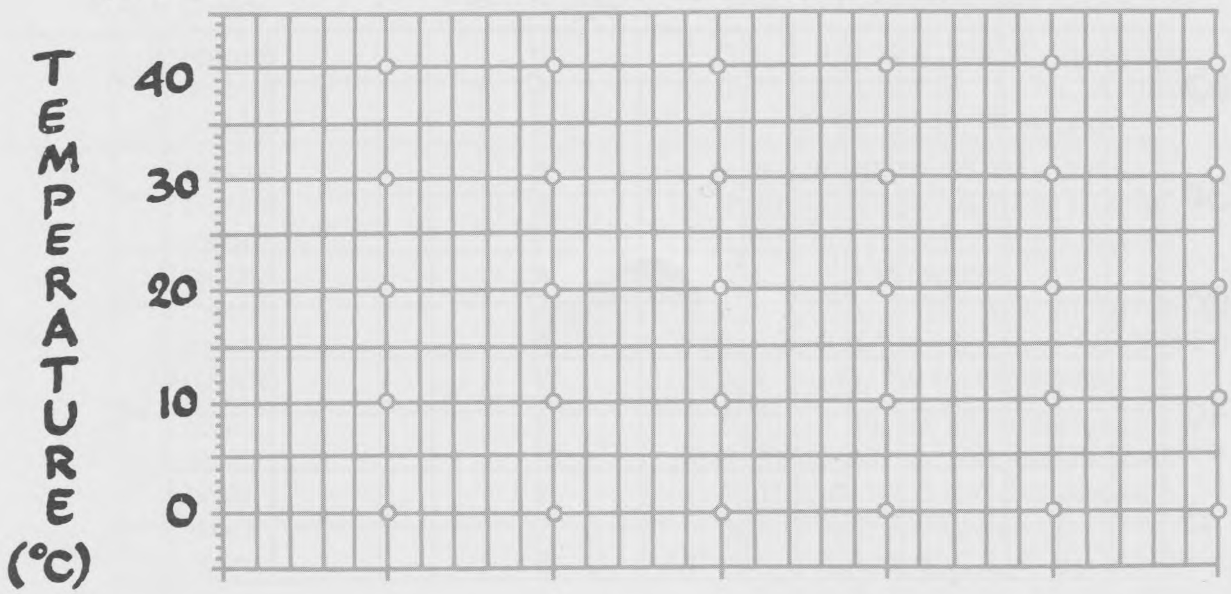
DATA TABLE (Highlighted Numbers)

TIME (SCREEN)	TIME (GRAPH)	TEMP. (°C)

TIME (SCREEN)	TIME (GRAPH)	TEMP. (°C)

TIME (SCREEN)	TIME (GRAPH)	TEMP. (°C)

GRAPH OF TEMPERATURE VS. TIME



TIME (   )

TYPE 3 2 MINUTES

INVESTIGATOR ______________________

TRIAL NUMBER __________ DATE __________

DESCRIPTION OF PROJECT ______________________

____

____

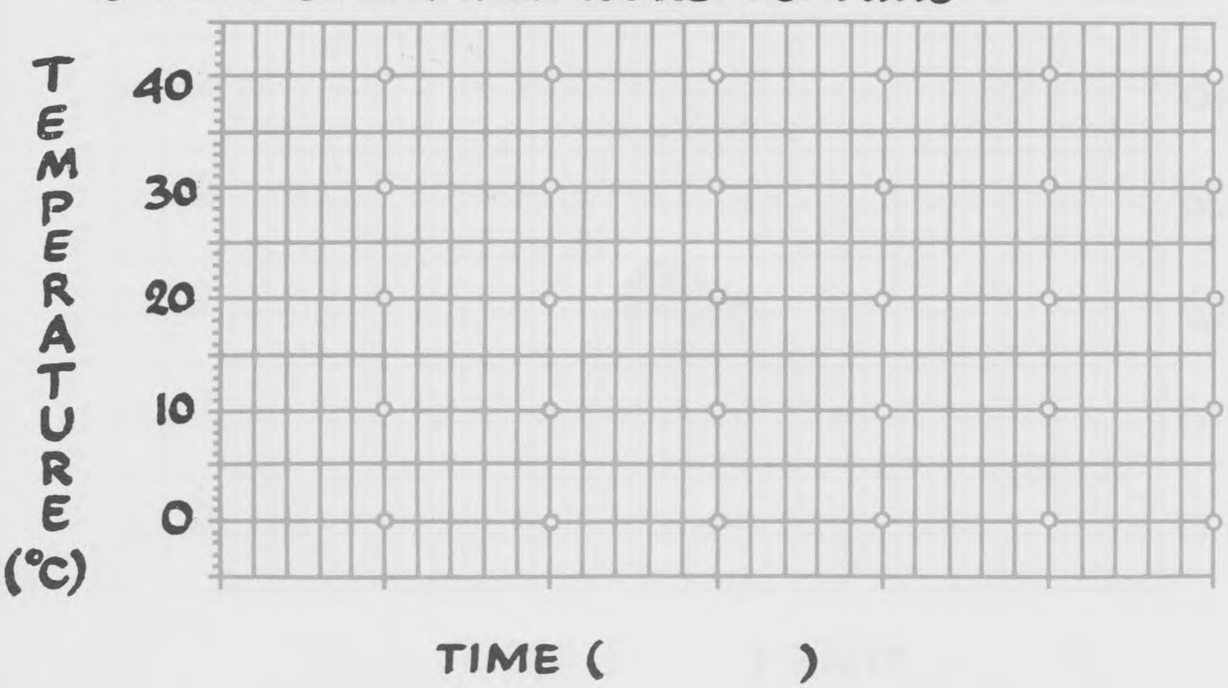
DATA TABLE (Highlighted Numbers)

TIME (SCREEN)	TIME (GRAPH)	TEMP. (°C)

TIME (SCREEN)	TIME (GRAPH)	TEMP. (°C)

TIME (SCREEN)	TIME (GRAPH)	TEMP. (°C)

GRAPH OF TEMPERATURE VS. TIME



TYPE 4 5, 10, 20 MINUTES

INVESTIGATOR ______________________

TRIAL NUMBER ____________ DATE ____________

DESCRIPTION OF PROJECT ______________________

____

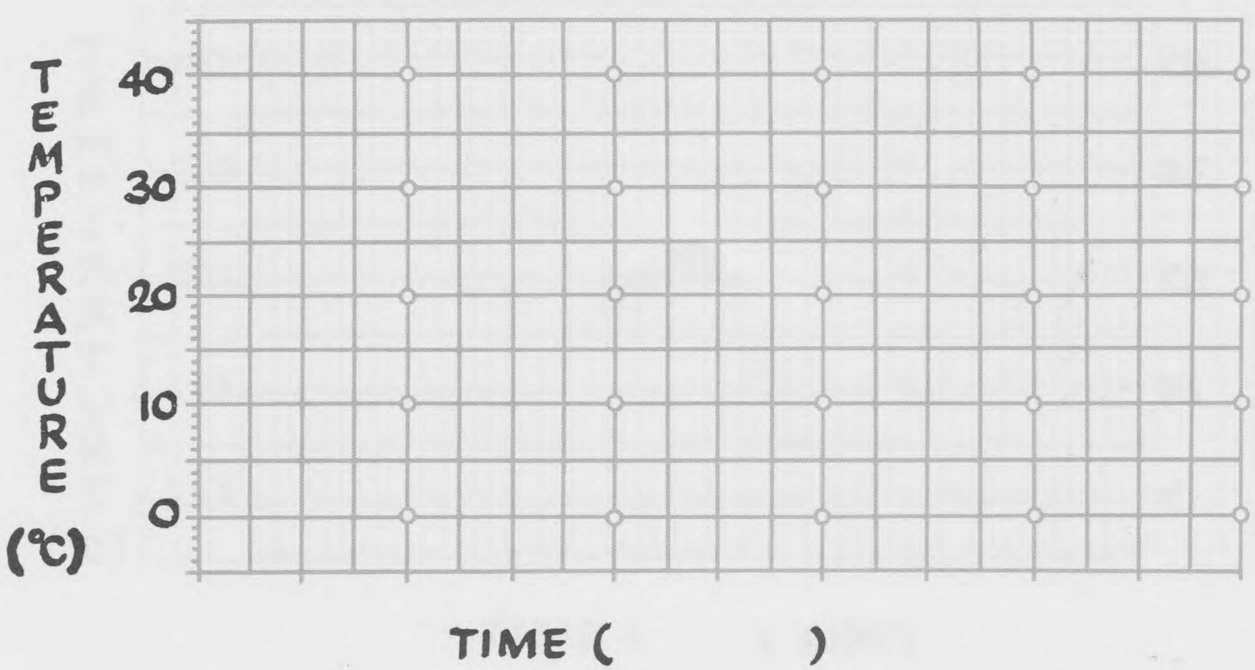
____

DATA TABLE (Highlighted Numbers)

TIME (SCREEN)	TIME (GRAPH)	TEMP. (°C)

TIME (SCREEN)	TIME (GRAPH)	TEMP. (°C)

GRAPH OF TEMPERATURE VS. TIME



TYPE 5 2 HOURS

INVESTIGATOR ______________________________

TRIAL NUMBER ______________ DATE ____________

DESCRIPTION OF PROJECT ____________________

____

____

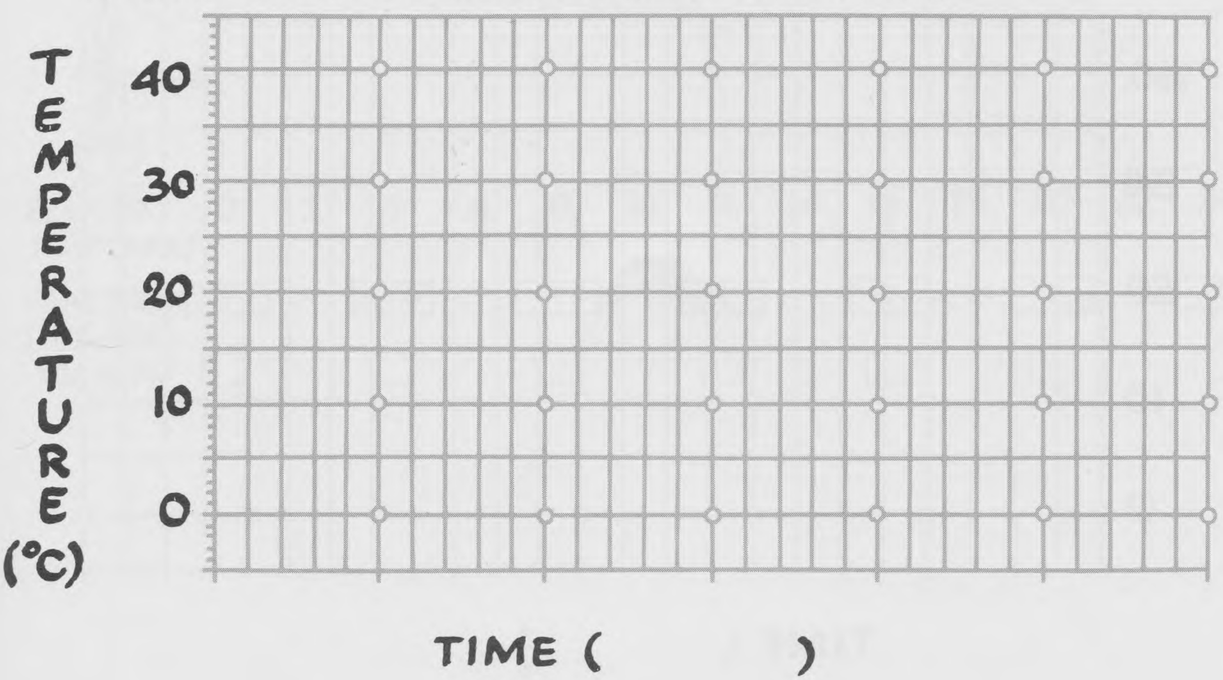
DATA TABLE (Highlighted Numbers)

TIME (SCREEN)	TIME (GRAPH)	TEMP. (°C)

TIME (SCREEN)	TIME (GRAPH)	TEMP. (°C)

TIME (SCREEN)	TIME (GRAPH)	TEMP. (°C)

GRAPH OF TEMPERATURE VS. TIME



TYPE 6 12, 24 HOURS

INVESTIGATOR ____________________

TRIAL NUMBER ____________ DATE ____________

DESCRIPTION OF PROJECT ____________________

____

____

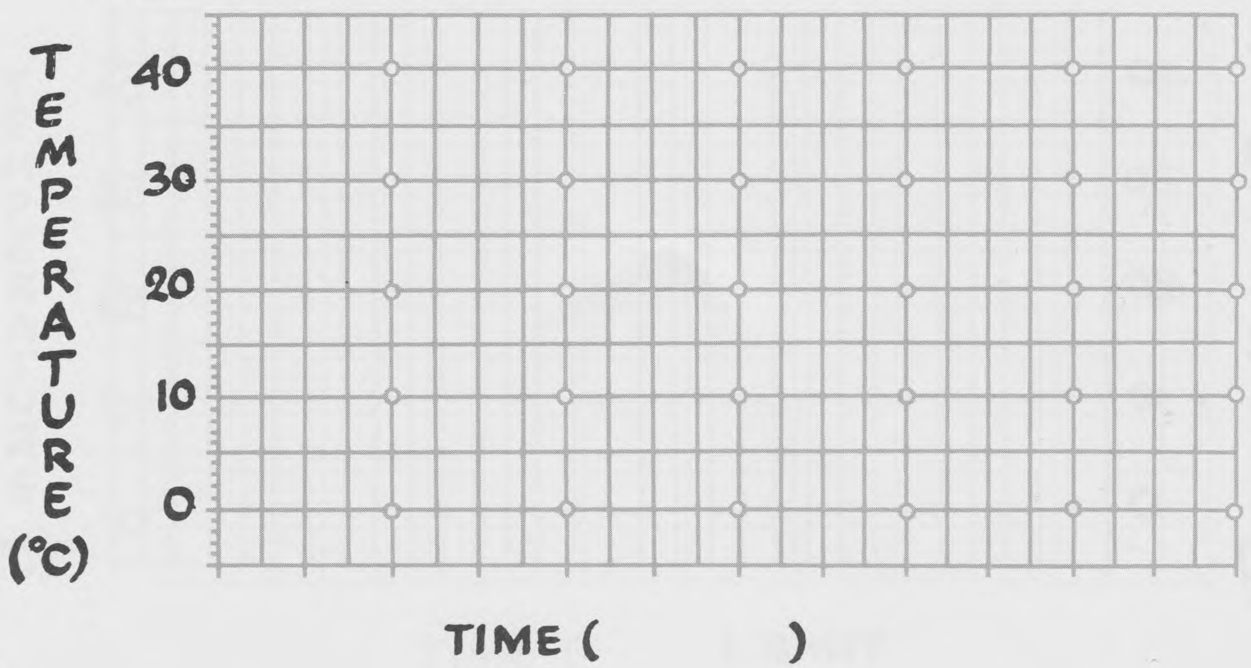
DATA TABLE (Highlighted Numbers)

TIME (SCREEN)	TIME (GRAPH)	TEMP. (°C)

TIME (SCREEN)	TIME (GRAPH)	TEMP (°C)

TIME (SCREEN)	TIME (GRAPH)	TEMP. (°C)

GRAPH OF TEMPERATURE VS. TIME



DAILY TEMPERATURE LOG

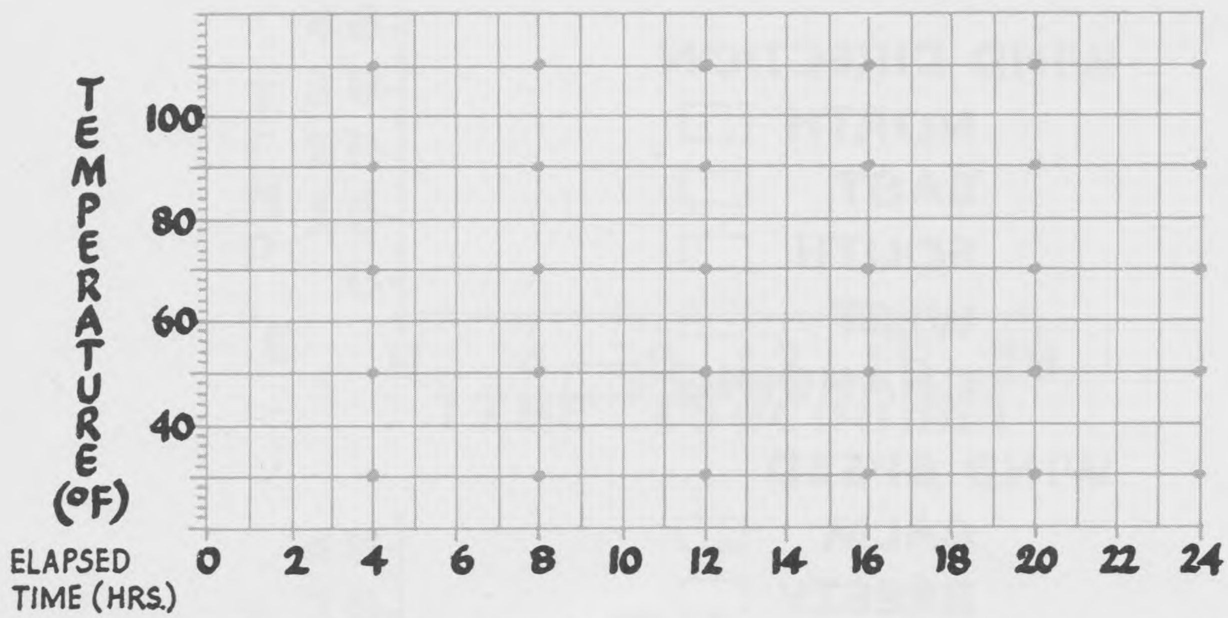
INVESTIGATOR **DATE**

STARTING TIME (HOUR:MIN.) **AM** ☐ **PM** ☐

ELAPSED TIME (MIN.)	ELAPSED TIME (HR.)	REAL TIME	TEMP. (°F)
0	0:00		
60	1:00		
120	2:00		
180	3:00		
240	4:00		
300	5:00		
360	6:00		
420	7:00		
480	8:00		
540	9:00		
600	10:00		
660	11:00		
720	12:00		

ELAPSED TIME (MIN.)	ELAPSED TIME (HR.)	REAL TIME	TEMP. (°F)
780	13:00		
840	14:00		
900	15:00		
960	16:00		
1020	17:00		
1080	18:00		
1140	19:00		
1200	20:00		
1260	21:00		
1320	22:00		
1380	23:00		
1440	24:00		

GRAPH OF TEMPERATURE V.S. TIME



REAL TIME (HRS.-MIN.) [:] [:] [:] [:] [:] [:] [:]

AM OR PM ☐ ☐ ☐ ☐ ☐ ☐ ☐

DAILY WEATHER LOG

OBSERVER ____________________ DATE __________

LOCATION ______________ STARTING TIME ________

DAY'S WEATHER:

CLEAR ☐

PARTLY CLOUDY ☐

PRECIPITATION

RAIN ☐

SNOW ☐

OTHER ______________

TIME ______________

WIND DIRECTION

NORTH ☐

EAST ☐

SOUTH ☐

WEST ☐

CHANGING ☐

WIND SPEED

CALM ☐

BREEZY ☐

WINDY ☐

REMARKS ____

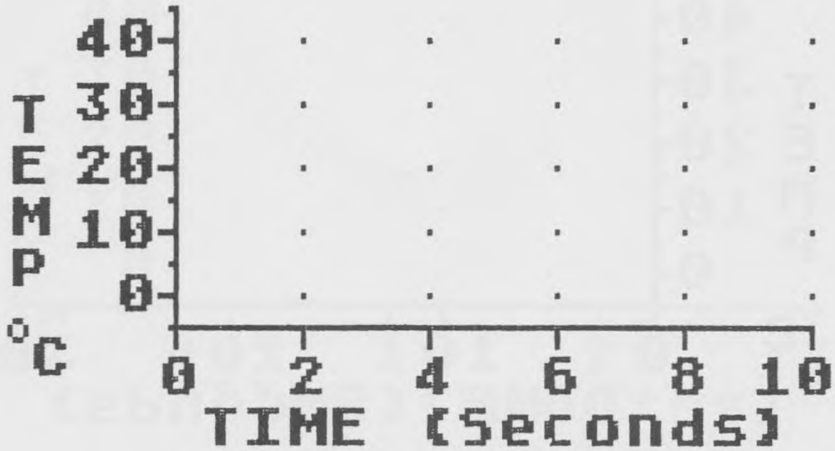
____

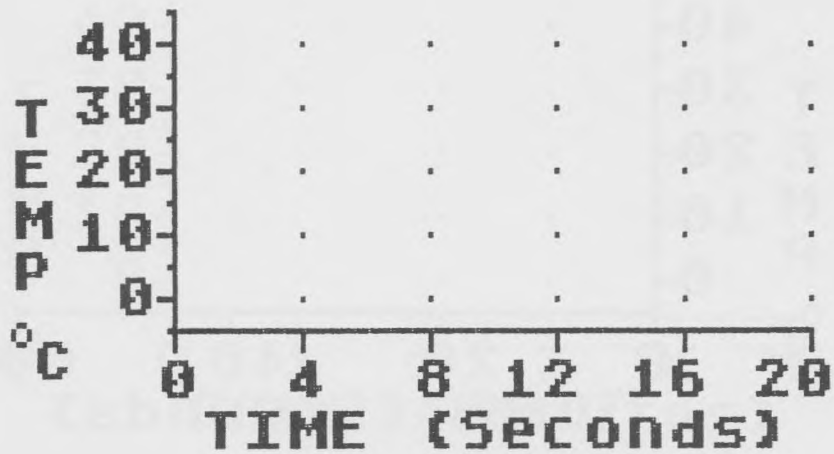
____

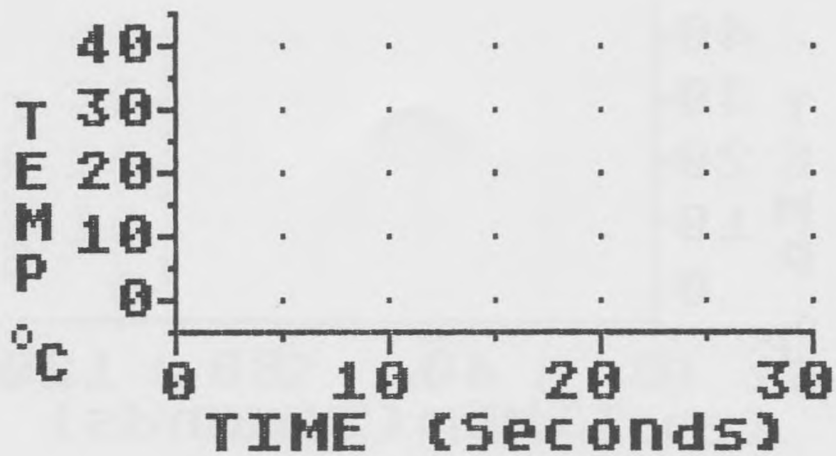
____

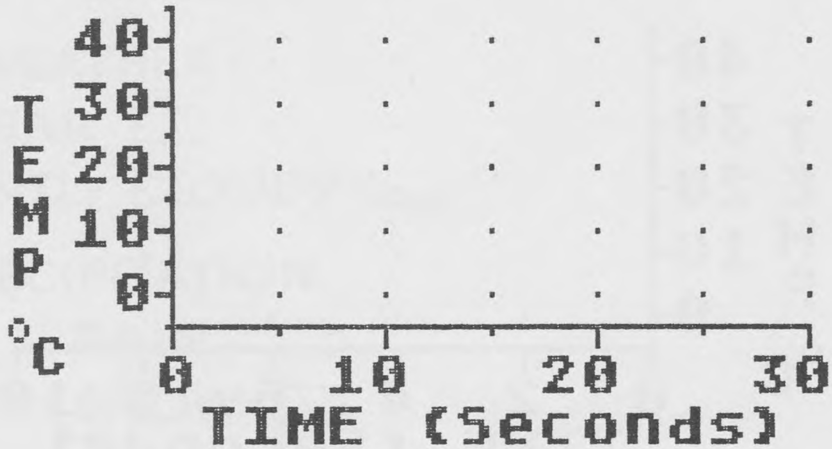
____

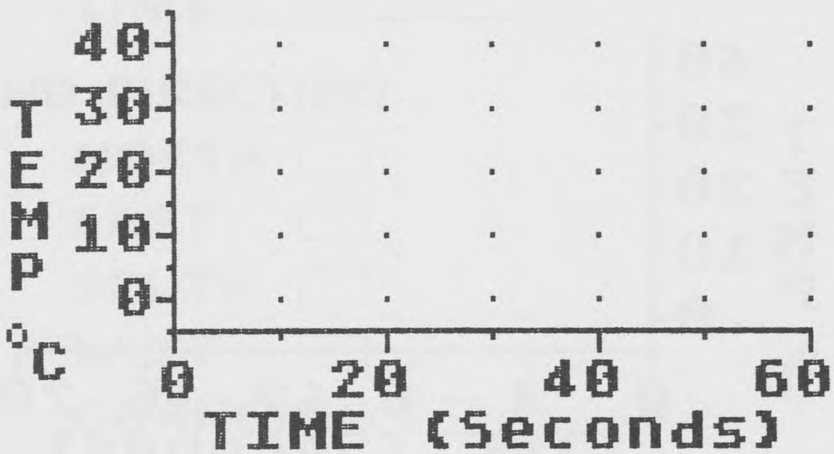
SCIENCE DISCOVERY SERIES™ SOFTWARE GRAPHS

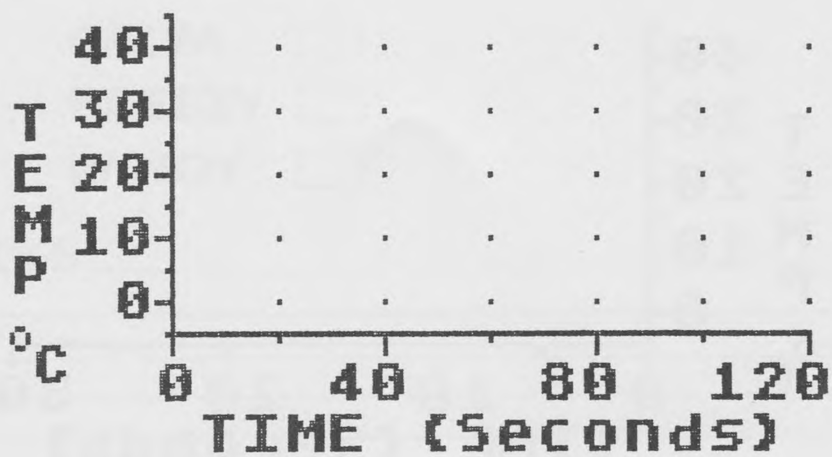




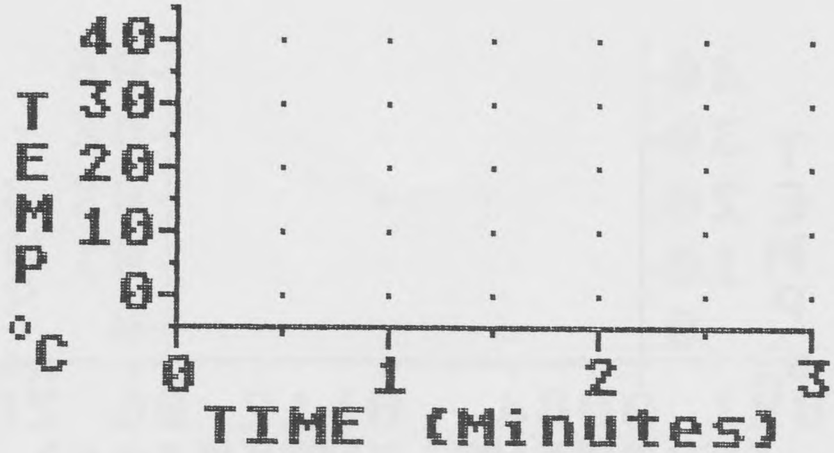


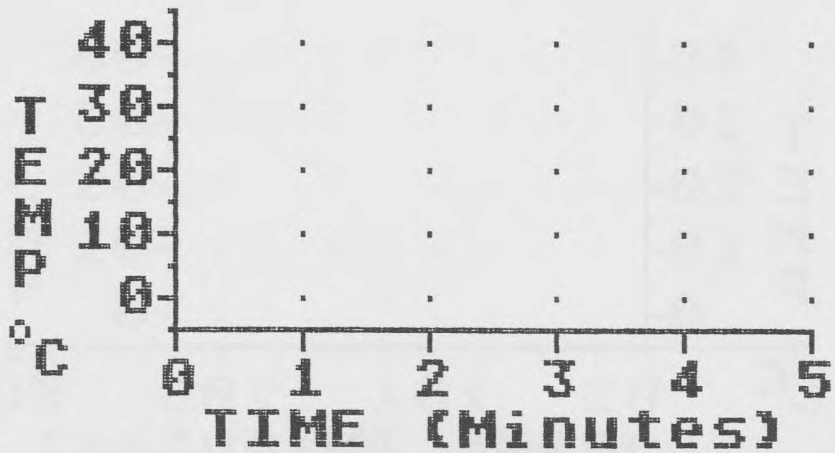

40
30
20
10
0
TEMP °C
0
10
20
30
TIME (Seconds)

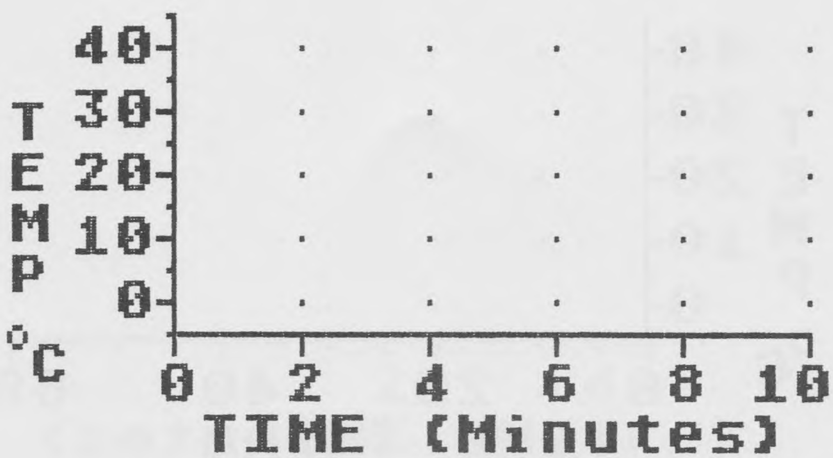

40
30
20
10
0
TEMP °C
0
20
40
60
TIME (Seconds)

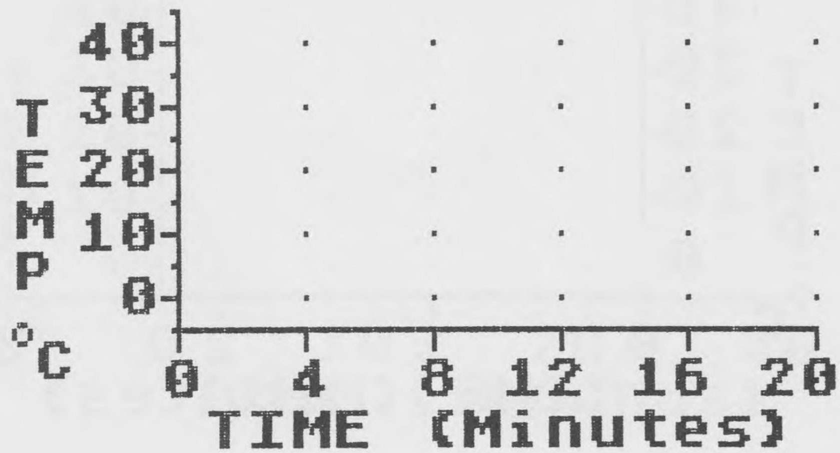

40
30
20
10
0
TEMP °C
0
40
80
120
TIME (Seconds)

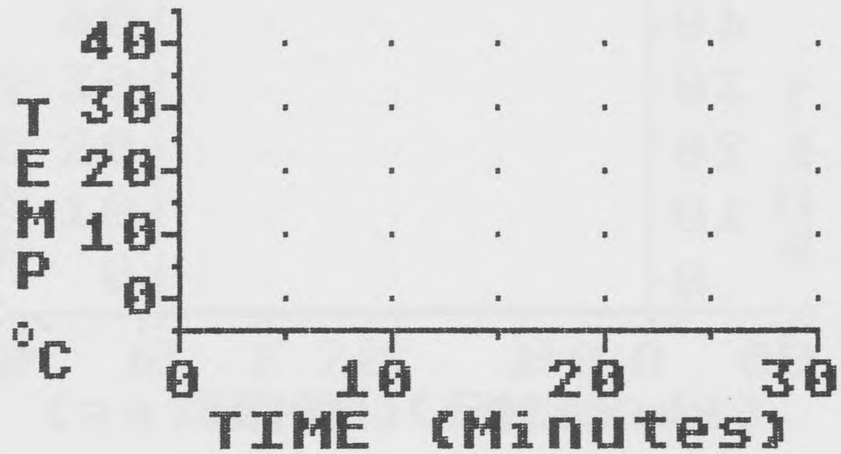
SCIENCE DISCOVERY SERIES™ SOFTWARE GRAPHS

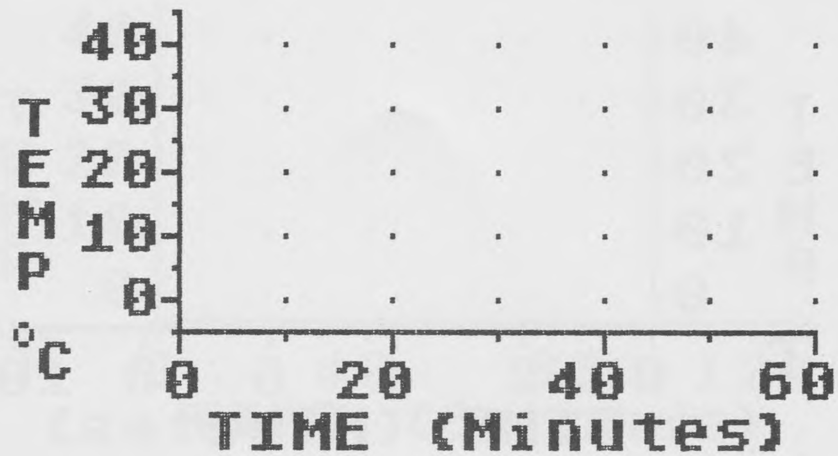


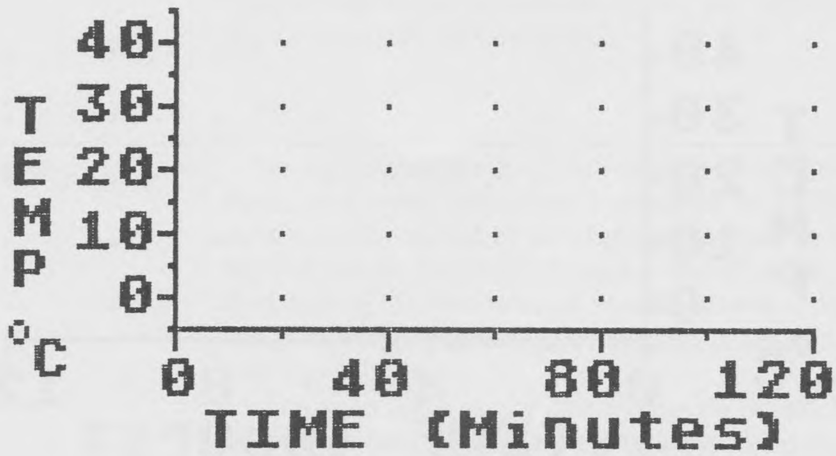


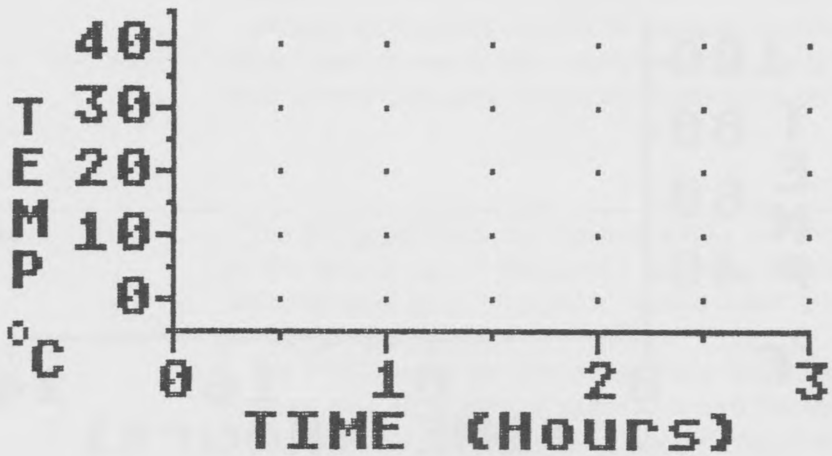


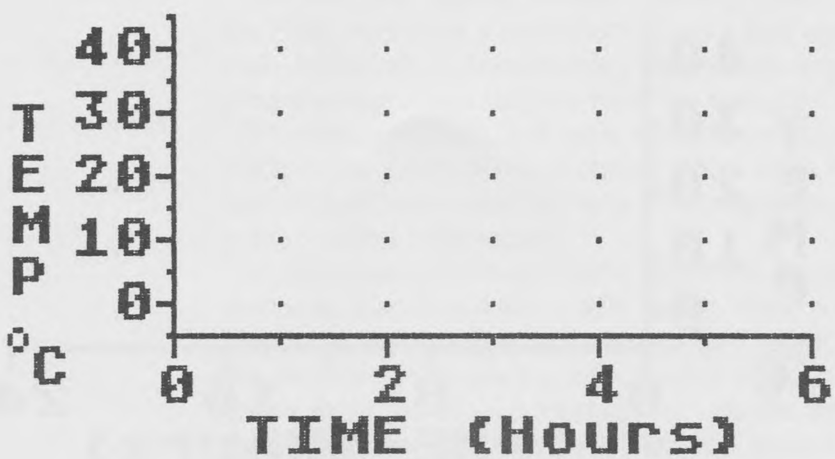

40
30
20
10
0
TEMP °C
0
4
8
12
16
20
TIME (Minutes)

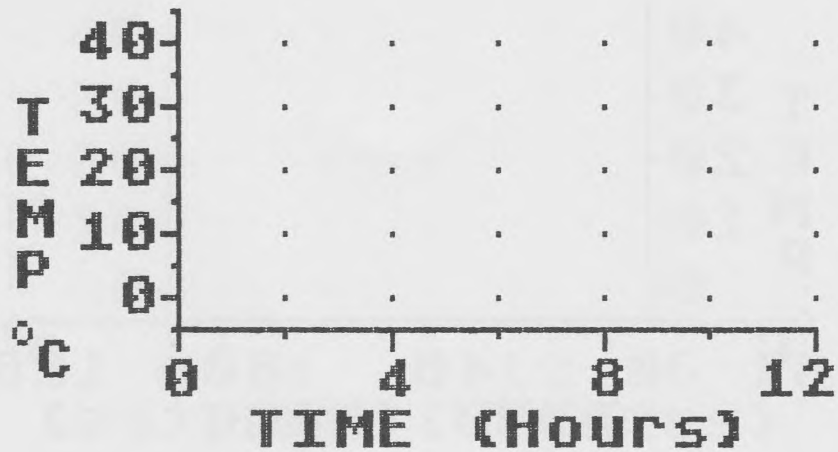

40
30
20
10
0
TEMP °C
0
10
20
30
TIME (Minutes)

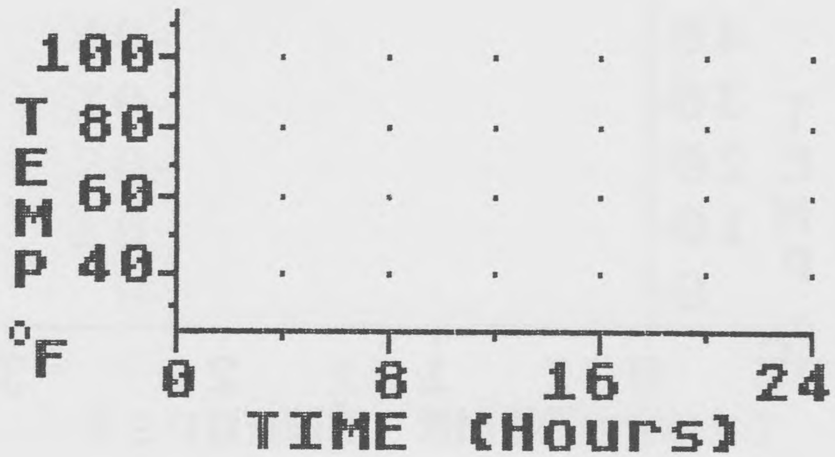

40
30
20
10
0
TEMP °C
0
20
40
60
TIME (Minutes)

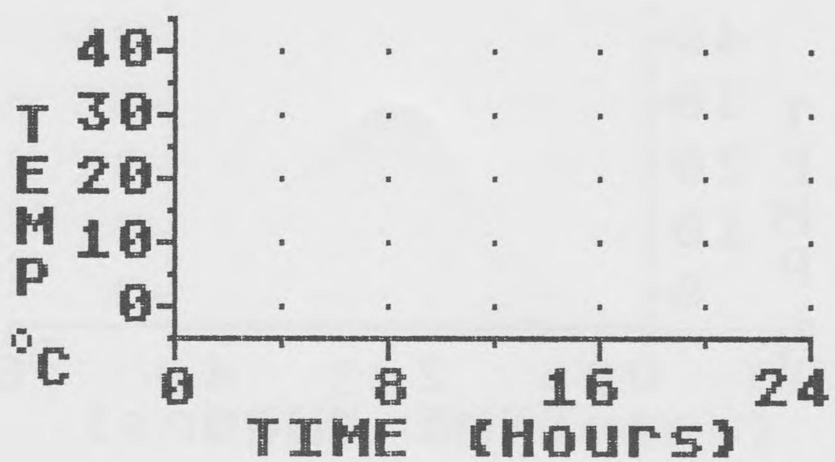

TEMP °C
40
30
20
10
0
0
40
80
120
TIME (Minutes)


TEMP °C
40
30
20
10
0
0
1
2
3
TIME (Hours)


TEMP °C
40
30
20
10
0
0
2
4
6
TIME (Hours)


40
30
20
10
0
TEMP °C
0
4
8
12
TIME (Hours)


100
80
60
40
TEMP °F
0
8
16
24
TIME (Hours)


40
30
20
10
0
TEMP °C
0
8
16
24
TIME (Hours)

Appendix G
The Science Discovery Series Interface

The Science Discovery Series Interface can be plugged into control port 2 on the left side of the Commodore 64 Computer. The interface is used in place of a joystick or paddle. It has phonojack inputs which can be used to connect sensors, lights, and other devices directly to any Commodore 64 Computer.

The PADDLE Inputs

The top row of inputs are left (blue) and right (orange) PADDLE inputs. Any sensor which has a resistance to the flow of electrical current similar to that of an Apple paddle can be connected to the PADDLE inputs. The PADDLE input is known as an analog input. The Temperature Lab Temperature Sensors, several types of light sensors, and a special microphone are examples of sensors that can be used with the PADDLE inputs.

In order to use a sensor as a measuring device, the computer must be programmed to calculate the quantity being measured from the computer paddle reading. More details about how to do this type of calculation for the temperature sensor are included in Appendix E.

Detailed instructions on how to translate paddle readings from other types of sensors into scientific measurments will be included in each Science Discovery Series Lab containing a sensor.

The PTRIG Inputs

The left (green) and right (yellow) PTRIG or Paddle Trigger inputs are on the second row of the Science Discovery Series Interface. They are ordinarily used by a computer to receive information from the buttons on the game paddles.

The PTRIG inputs are known as binary inputs (*binary* means two) because they allow the computer to record the fact that something is 'on' or 'off'. For example, the inputs can record whether or not a paddle button is being pushed.

The two most popular Science Discovery Series devices used with the PTRIG inputs are a push–button and a light sensor. The push–button allows users to start experiments which are under program control at a distance from the computer.

Physicists, engineers, and other scientists are interested in studying the speed at which different objects move. To do these studies, a special Light Sensor attached to a PTRIG input can be used as part of a device called a photogate.

A photogate consists of a light, which can be powered by a computer, placed opposite a light sensor. When a moving object breaks the beam of light shining on a light sensor, a timer program in the computer starts. As the object passes out of the light beam, the continuity of the beam is reestablished and the timer program halts. In this way, times of less than 1/1000 of a second can be measured, and the speed of moving objects can be determined.

A Science Discovery Series photogate can also be set up to read bar code like those on supermarket items.

Details on how to use the PTRIG inputs and photogates are included in the Experimenter's Guides that come with other Science Discovery Series Labs.

The CONTROL Outputs

Some versions of the Science Discovery Series Interface for the Commodore 64 have two extra outputs in the third row. These brown and purple phonojack inputs are actually inputs normally used when a joystick is moved up and down. By entering some simple program statements in the computer, the up and down joystick inputs can be redefined as outputs which are under the programmer's control. A small electrical signal (0 volts or +5 volts) can be sent out along either the left or the right control outputs.

A CONTROL output signal can be used to turn a low-power light on and off under computer control. By using the computer signal to trigger a strobe light circuit, a high-intensity light can be turned off and on.

The CONTROL outputs can be connected to a special relay device that will allow the user to turn household electrical devices on and off. The CONTROL outputs can even be used to control a small robot.

Since the PTRIG inputs can also be redefined as CONTROL outputs, users can have as many as four CONTROL outputs on each interface.

Instructions on how to program the CONTROL outputs are included in appropriate Science Discovery series guides.

The POWER Outputs

The two red outputs in the last row on the interface allow to share the +5–volt power supply with the computer. Using either of the power outputs, low–power lights used with photogates, small electrical circuits, and other devices requiring no more the 5 volts can be operated.

Users must be careful not to attach lights or devices that draw more electrical current then the computer can provide to the POWER outputs. Programs in RAM memory of the computer may be ruined if too much electrical current is drawn.

Appendix H
Trouble–Shooting Guide

I. Problems with Temperature Values

Symptom	*Possible Cause*	*Remedy*
Temperature sensor only reads −5°C when temperature being measured is known to be higher.	Interface not connected to control port 2.	Connect interface to control port 2.
	Interface connection is loose so red light at bottom of interface not on.	Push 9–pin connector firmly into control port.
	Temperature sensor not plugged into blue paddle input.	Plug in temperature sensor.
	Temperature sensor connection is loose.	Plug temperature sensor in more firmly.
	Broken connection inside interface or interface cable.	Replace interface.
	Broken connection inside temperature sensor.	Replace temperature sensor.
Temperature sensor only reads 45°C when temperature being measured is known to be lower.	Water leaking into sensor.	Dry out sensor for a day or so and reseal with epoxy or replace sensor.
	Sensor has a short circuit.	Replace temperature sensor.
Temperature readings about 10° too high or too low.	Sensor adjustor not in place when needed causing temperature readings about 10° too high.	Plug the temperature sensor into the sensor adjustor
	Sensor adjustor in place when it isn't needed causing tenperature readings about 10° too low.	Remove sensor adjustor from the end of the temperature sensor.
	Adjustor not in place when it isn't needed during calibration.	Put adjustor at end of standard resistor and recalibrate using the "resistor" method.
	Adjustor in place when not needed during calibration.	Remove adjustor from end of standard resistor and recalibrate using the "resistor" method

I. Problems with Temperature Values (Continued)

Temperature sensor and thermometer readings not within 2°C or 3°C of each other.	Thermometer has glass tube pulled away from backing and reads incorrectly.	Use another household thermometer for comparison or order a new thermometer (see attached order form).
	Defective temperature sensor.	Replace temperature sensor.
	Temperature sensor has an abnomally low or high thermistor constant, Beta.	Calibrate sensor using the Resistor method (Ch 1) or the Sensor method (Appendix D), or replace sensor.
	Defective electrical components in Apple paddle inputs leading to paddle reading much different than 155 when sensor is in ice water.	Send computer to a repair facility to check computer paddle input circuits.

II. Problems with Software

Symptom	***Possible Cause***	***Remedy***
Strange symbols on the screen, program not functioning properly.	Something went wrong while program was running.	Restart computer by turning it off and on, unplug interface, reload software.
	Defective Temperature Lab Software Diskette.	Make a new working diskette from the original Temperature Lab Diskette or replace diskette (see attached order form).
	Computer is out of order.	Contact computer service facility.
Fuzz on screen.	Printer or other radiofrequency interference (RFI) source affecting TV reception of signals.	Turn off RFI source.
Can't move past "Plug in Sensors" instruction screen.	Interface not properly attached to control port 2	Plug in interface and check for firm connection.
	Blue temperature sensor not plugged in.	Plug temperature sensor into blue input and check connection.
	Blue temperature sensor connector broken.	Replace temperature sensor.

II. Problems with Software (Continued)

Disk will not load.	Defective disk.	Make a new working diskette from the original Temperature Lab Diskette or replace diskette (see attached order form).
	Disk drive not connected properly.	Check 1541 disk drive Manual for drive connection instructions.
Program stops before returning to main menu from BULB or CALIBRATE option.	Defective disk drive or computer.	Contact computer service facility for repair.
	Temperature Lab Diskette no longer in drive.	Re–insert Temperature Lab Diskette and restart the program by turning the computer off and on, unplugging interface, and reloading software.

III. Problems with Printing Graphs

Symptoms	***Possible Cause***	***Remedy***
Software "freezes" and printer does not respond when key is pressed to begin.	Printer is not compatible with C-64 graphics output.	Use a C-64 compatible graphics printer.
	Printer is not plugged in.	Plug in printer and reload program.
	Printer is not turned on.	Turn on printer and reload program.
	Printer is not on line.	Press printer on–line button and reload program.
	Printer is not connected properly.	Check connections and reload program.
	Printer is out of paper.	Put paper in printer and reload program.
	Paper is jammed in printer.	Remove paper jam, put new paper in printer, and restart program.
Printer prints out strange symbols.	Unwanted control codes in printer buffer.	Turn printer and computer off and on again. Restart program.

IV. Problems with Saving Data

Symptom	*Possible Cause*	*Remedy*
Disk Error #26 on screen.	Write protect label on disk.	Remove write protect label, reinsert disk in drive, and press red joystick button to return to menu.
Other disk errors mentioned on screen.	Disk not in drive.	Insert disk in drive.
	Drive not properly connected.	Check drive connection and press red joystick button.
	Drive door not closed properly.	Close drive door, press red joystick button to return to menu.
	Disk not formatted.	Format and name disk.
	Too many files stored on disk.	Delete old files from disk or format a new disk using the 1541 BACKUP Program.
Disk Error #63 on screen.	File by same name already on disk.	Press red joystick button to return to SAVE DATA option and create new file.

INDEX

Temperature Lab
C-64 Series
Accessories Order Form & Price List

Commodore 64 Standard Resistor (34130) . . . . . . $ 1.95
The standard Resistor is placed in the left or right paddle (if you have a second sensor) input during the "Resistor Calibration" procedure. This resistor has a 150K OHM value.

Commodore 64 Temperature Lab Diskette (33630) $15.00

Blue Temperature Lab Sensor (33730). $15.00

Orange Temperature Lab Sensor (34230) $15.00
(OPTIONAL) This electronic sensor allows users to monitor two temperatures at once, when used with the blue Temperature Lab Sensor and Software. It is identical to the blue Sensor included in the lab except its phono plug is color-coded orange to match the temperature trace on the screen graph and right paddle input to the interface.

Temperature Lab Manual (33530). $15.00

Temperature Lab Thermometer (33930) . . . . $ 1.95

Commodore 64 Sensor Adjustor (34330) . . . . $ 1.95
Some of the early C-64's have different paddle inputs. If your temperatures are reading consistently off by about 5°C, you need to put adjustors between your sensors and the interface.

Science Discovery Series Interface (33830) $50.00
The Interface is used by all the Labs in the Science Discovery Series.™

These items are available only from Creative Technology, Inc. To order any of them items, you must have submitted a registered warranty card within 90 days of your original purchase. Complete the order form and mail with check or money order to:

CREATIVE TECHNOLOGY, INC.
P. O. BOX 1009
CARLISLE, PA 17013

Ship To:

(Name) ______________________

(Address) ______________________

(City) ______ (State) ______ (Zip) ______

(Phone) ______________________

Qty.	Item	Code	Price	Total

Mail with check or money order to:
Creative Technology, Inc.
P. O. Box 1009
Carlisle, PA 17013

Subtotal ______
6% Tax for PA Residents ______
Grand Total ______

WARRANTY REGISTRATION CARD

Product Name: ______
Product Number: ______
Serial Number: ______

Name: ______
Address: ______
City: ______ State: ______ Zip: ______
Date Purchased: ______
Purchased From: ______
City/State: ______
Type of Store: Computer Store ____ Software Store ____ Book Store ____ Mail Order ____
Other ____
Your Age: under 20 ____ 21-25 ____ 26-35 ____ 36-45 ____ over 45 ____
Number of Children: ____ Ages (if applicable) ____
Computer Model: ____ Peripherals: disk drive(s) ____ cassette player ____
color monitor ____ B&W monitor ____ other ____
Your Favorite Computer Magazines: ______

TO OBTAIN THE WARRANTY OFFERED, PLEASE RETURN THIS CARD WITHIN TEN (10) DAYS OF PURCHASE

Warranty and Support offered to original purchaser only.

Attach
Postage
Here

Hayden Software Company
600 Suffolk Street
Lowell, MA 01854

Interface and resistor made in Taiwan, R.O.C. All other parts made in U.S.A.

HAYDEN SOFTWARE
HAYDEN SOFTWARE COMPANY, INC.
600 SUFFOLK STREET
LOWELL, MA 01854 1-800-343-1218
IN MA., CALL (617) 937-0200

33509-00
33530-00
33522-00