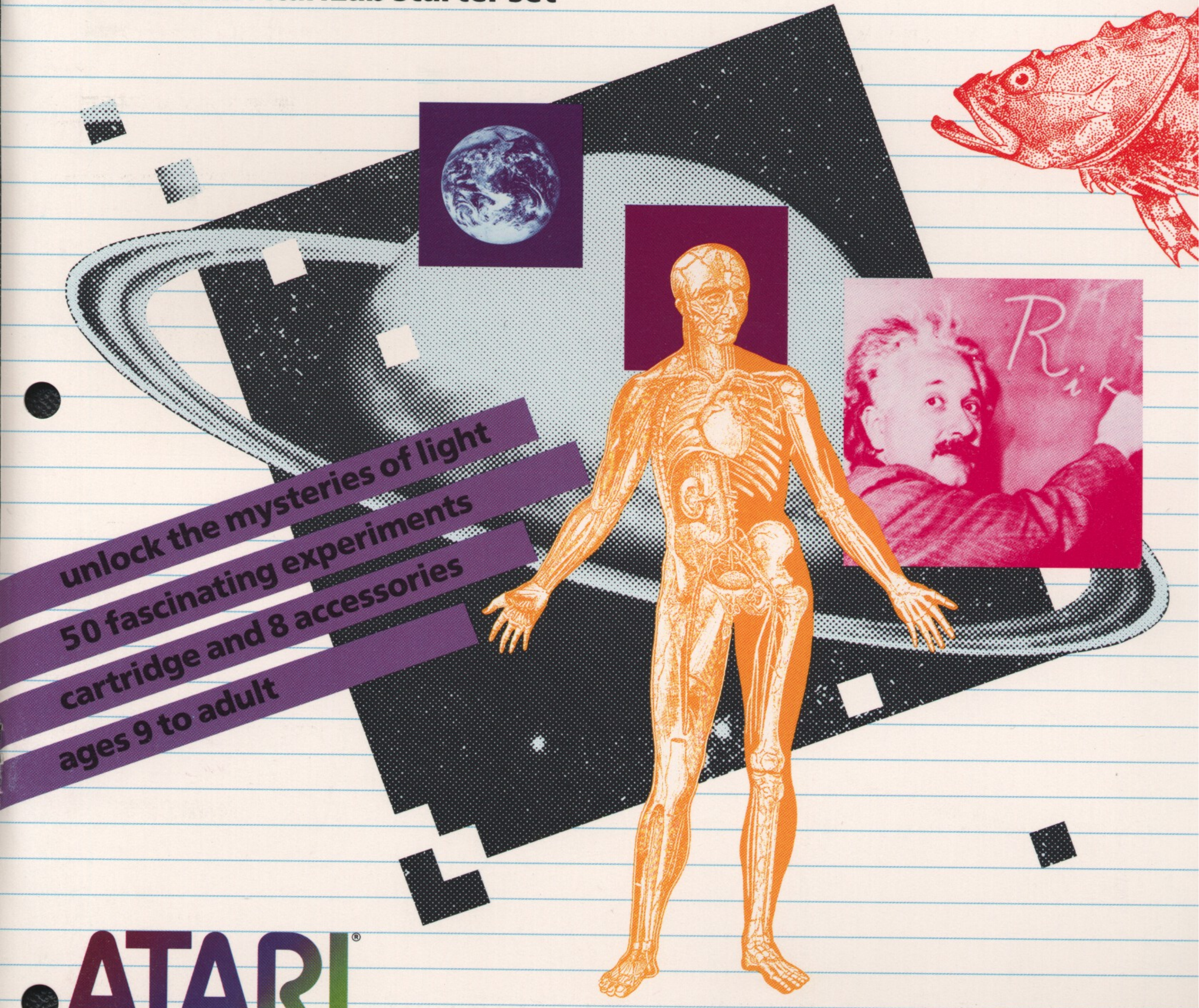
AtariLab™* light module

a science series for *Atari* computers to use with AtariLab starter set



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ATARILAB™ SCIENCE SERIES

LIGHT MODULE
EXPERIMENTER'S GUIDE

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Preface

Oh Light Supreme, that art so far exalted Above our mortal ken!

The Divine Comedy, Dante

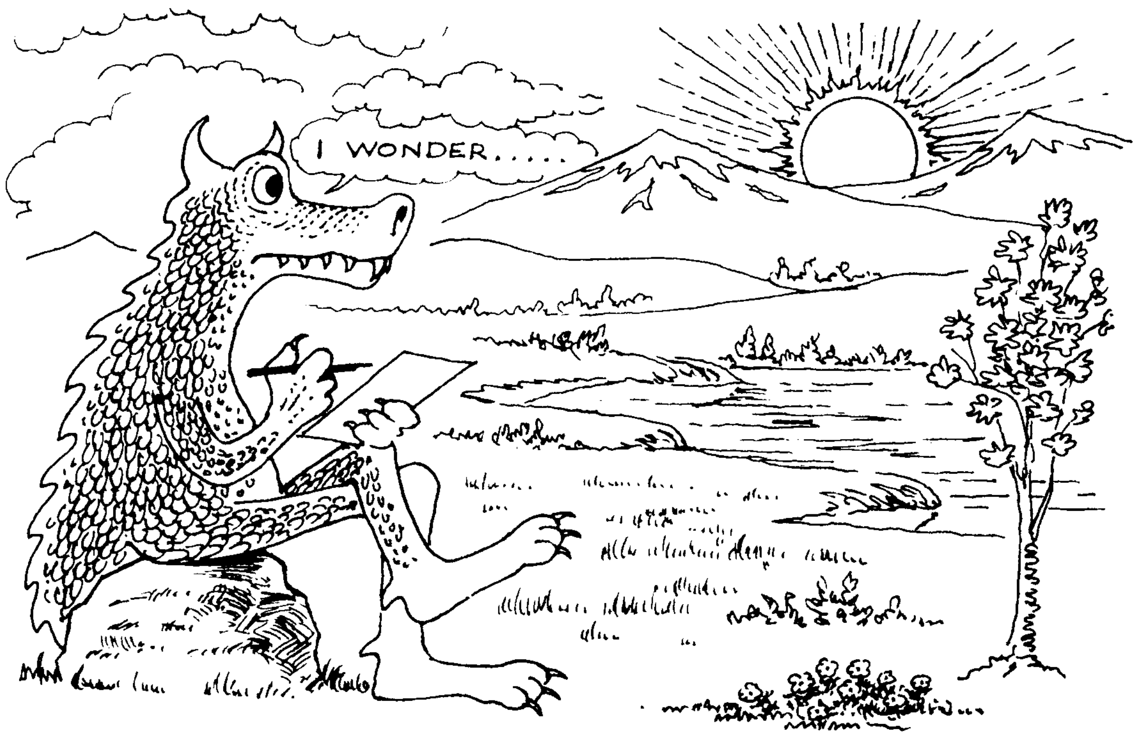
Light is the source of all life on earth. Without light nothing would grow—there would be no food. Without light we would see nothing. Everything that we see creates, reflects, or absorbs light.

Light has been an inspiration for poets and an endless source of fascination for scientists. The warm glow of the setting sun and the cool light of fireflies on a hot summer evening can be the start of exciting adventures in art and science.

Thinking about light and the world around us raises many questions: What is light and how can we talk about it? How does light help us understand the nature of the objects we look at and touch every day? What is color? Why is the sky blue? Why are some things red and others green or yellow?

With the AtariLab Light Module, you will be able to answer some of these questions by doing experiments that reveal some of the special qualities of light. You can explore some of the ways scientists use light as a tool to find out more about chemical reactions, the size of small objects, and the growth of bacteria. The projects suggested in the AtariLab Light Module involve the use of simple everyday items, such as the dirt in your backyard, to discover how light can help us better understand the world in which we live.

Using the AtariLab Light Module should open your eyes to a new world of scientific discovery.



CHAPTER 1
Light and its Measurement

The beholding of the light is itself a more excellent and fairer thing than all the uses of it.
Francis Bacon

Introduction

Light is so familiar that we usually take it for granted. But, knowing more about what scientists have learned about light and its behavior will help you understand observations that can be made with an AtariLab Light Module.

Light, like heat, is a type of energy. In the AtariLab Temperature Module, we explained the relationship between heat energy and the movement of atoms and molecules. Unlike heat energy, light energy is not associated with the motion of atoms or molecules. Instead, light is a form of energy known as **electromagnetic radiation.** Other types of electromagnetic energy are radio waves which carry radio and television signals, the microwaves used in cooking, medical x-rays, and the gamma rays given off by radioactive materials.

Of the many types of electromagnetic radiation, light is the only abundant type bombarding the earth that can pass easily through the atmosphere. Over millions of years, humans and other animals have developed sensors that can detect the presence of light. These sensors are eyes, and with them we "see" light. Since radio waves and other types of electromagnetic radiation are invisible, light is a very special form of electromagnetic radiation.

Light—Waves or Particles?

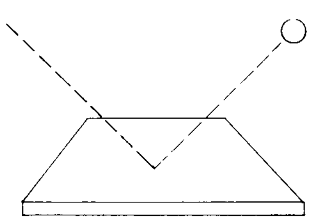


Figure 1–1. *A ball bouncing off a hard surface.*

In the seventeenth century, scientists argued about whether light energy behaved like tiny particles moving through space or like the waves that travel along the surface of a pond after a rock is dropped. There is evidence to support both views. Light reflects from the surface of a mirror in the same way that a rubber ball glances off a smooth hard surface. This suggests that light behaves like tiny particles. On the other hand, an electron contained in an atom or molecule can vibrate back and forth when light passes it in much the same way that a cork bounces up and down as a water wave passes by.

At present, scientists believe that light can best be described as tiny bundles of energy that act like waves in some situations and particles in other situations. The wave-particles associated with light and other types of electromagnetic radiation are known as **photons.**

Figure 1–2. *The AtariLab dragon making a piece of rope behave somewhat like a photon of light.*

Creating a Model of a Photon

What is a photon like? By using a three-foot long piece of rope or heavy string we can create a simplified model of some aspects of a photon. First, let a piece of string or rope hang down from your hand. Give it energy by shaking it back and forth rapidly until you see a wave pattern forming as shown in Figure 1–2.

As you shake your string or rope, try to imagine it traveling through space at the incredible speed of 186,000 miles in one second. Light travels more than 300,000 times faster than the fastest jet, and it can travel the 24,000 miles around the earth in about an eighth of a second! (Figure 1–3)

Figure 1–3. *A 'string' model of a photon of light traveling at the speed of light. In reality, the dragon could not travel with the photon as no material objects can travel at the speed of light in empty space.*

What is Color?

When photons enter our eyes we see colors. A rainbow contains all the basic colors—red, orange, yellow, green, blue and violet. When we see colors, we are actually seeing photons which have different wavelengths and carry different amounts of energy.

Scientists have discovered that violet photons which carry the most energy have the shortest wavelengths. Red photons are the least energetic and have the longest wavelengths.

To see the difference between a violet photon and a red photon, you can use the string or rope again. First, shake the string or rope as rapidly as possible. Use lots of energy! Next, shake the string or rope back and forth much more slowly.

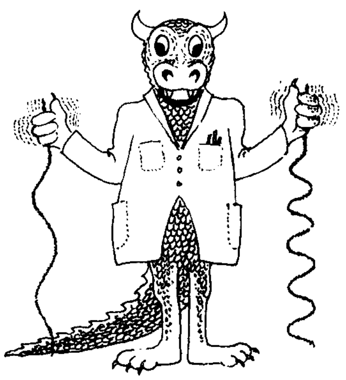


Figure 1–4. *The AtariLab Dragon creating string models of photons of light having two different wavelengths.*

You should notice that when you shake the string with lots of energy, you produce many short waves. This is a model of a violet photon. By using less energy, you produce a model of a red photon that has longer waves. The distance between one wave and the next is called a wavelength. Light having different wavelengths is seen as different colors. (Figure 1–4)

The string model or picture of light developed in this Experimenter's Guide can help us to understand the results of many experiments that can be done with the AtariLab Light Module. These results can, in turn, help us understand more about both natural and man-made phenomena. We hope you enjoy the projects suggested in this manual, invent dozens of your own projects, and learn more about this fascinating form of energy called light.

The AtariLab Module Equipment

The Experimenter's Guide

The Experimenter's Guide contains suggestions for observations and experiments which reveal more about the nature of light. Projects that use light as a tool to learn more about objects in the natural world are included. In addition, there are guidelines on how to write BASIC and Logo programs to record, analyze and display data on light levels.

This guide is a continuation of the *AtariLab Starter Set Manual and Temperature Module Project Guide* which introduced you to the process of scientific investigation and the use of the AtariLab Temperature Module.

The Light Module Cartridge

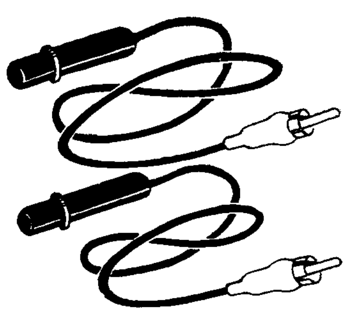
This cartridge contains the programs needed to make observations and perform experiments using the Light Sensor and the Light Assembly. With the programs you can turn your computer into a light meter. The screen of your television set or monitor shows the relative light level displayed on a light meter and also in numerical form.

You can gather data on the changes of light level in two ways. You can choose to gather the data yourself and display your findings on a graph or you can have the computer collect your data automatically. You can also look at your most recent graph again, examine the data in a table, print out your graph, or save your data on a disk. A description of the features of the Light Module Cartridge are included in Appendix B.

The Light Sensor

The Light Sensor, a resistor that changes its value when light shines on it, is attached to a wire and plug. It is capable of sensing amounts of light energy as low as 1/20 of a foot-candle up to about 1 foot-candle. The **foot-candle** is a measurement of light energy. It is explained in Project One.

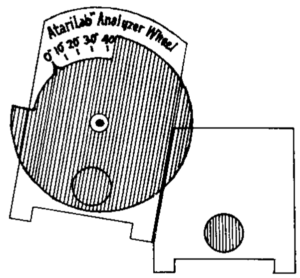
The Light Sensor plugs into the right (orange) paddle input of the AtariLab Interface.



Light Sensor and Light Assembly.

The Light Assembly

The AtariLab Light Assembly consists of a cable with a small light bulb attached to one end. It is used for projects involving the absorption and scattering of light. Different types of materials can be placed between the Light Assembly and the Light Sensor. Since the light gets its power from the computer, it can be plugged into either of the red power inputs of the AtariLab Interface. It can also be plugged into the brown and purple control inputs of the AtariLab Interface and be turned off or on under computer control.



Analyzer Wheel and Polarizer.

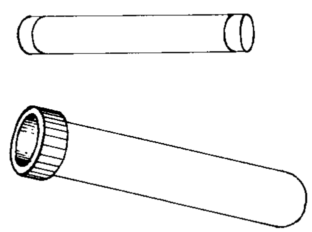
The Analyzer Wheel and Polarizer

These two specially mounted pieces of polaroid filters work in the same way as polaroid sunglasses. The wheel has degrees of angles marked from -10 to 100°. As you turn the wheel, you can use the Light Sensor to measure the amount of light coming through the Polarizer and Analyzer Wheel at each of the possible angles. The Polarizer and Analyzer Wheel fit conveniently in the slots at the top of the Light Stand.

The Test Tube

The plastic test tube can be used to hold a number of common liquids that can absorb and scatter light. It comes with a screw-on plastic lid. The test tube fits into the top hole on the Light Stand.

Warning: This test tube is not intended to hold organic solvents such as acetone (nail polish remover). It can be used for all of the projects described in this manual, but it will dissolve in the presence of certain solvents.



Light Stick and test tube.

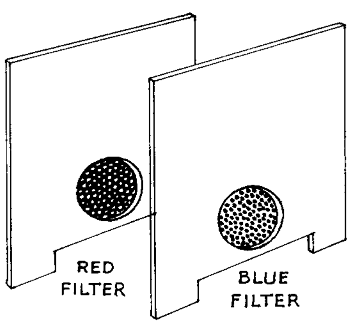
The AtariLab Light Stick

The light stick is a flexible plastic tube that fits inside the test tube. It contains chemicals that give off light when they mix together.

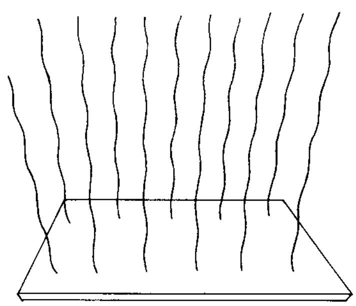
Note: *Handle the light stick with care until you are ready to use it. Bending it could cause the chemicals to mix, react, and give off all their light before you are ready to do an experiment.*

Light Filters

Red and blue plastic films used to block out unwanted colors of light are included. These colored films are mounted in special holders that can be placed in the slots at the top of the Light Stand. The filters are used in the study of colors and light absorption.

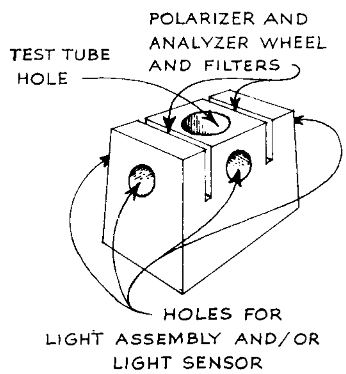


Glow Panel.



The Glow Panel

The glow panel is a piece of vinyl coated with phosphorescent paint. The paint can store light energy and then give it off as a yellowish green light. The AtariLab Light Module can measure the amount of light energy given off by the glow panel as time passes.



Light Stand

The AtariLab Light Stand

The Light Stand is a small hollow plastic box with slots at the top and holes at the top and sides. The slots hold the Polarizer and Analyzer Wheel, the glow panel and filters for the study of light emission, absorption and scattering. The holes are used for the Light Assembly, the test tube and the AtariLab Light Stick.

Checking Your Equipment

Before doing any projects you should be sure that your AtariLab Light Module equipment, AtariLab Interface, and computer system are working correctly.

To test the components, you should record several light levels. To do this, collect the following items to use with your computer system:

Light Module Cartridge
AtariLab Interface
Light Sensor
Light Assembly
Polarizer
Analyzer Wheel

Checking the Cartridge and Light Sensor

The first step in checking the Cartridge and Light Sensor is to set up the ATARI Laboratory Station as follows:

1. Set up the ATARI Computer and television set or monitor.
2. Insert the Light Module Cartridge into your computer.
3. Turn on the computer and television set or monitor. You should now see the title screen for the Light Module Cartridge.
4. Decide whether you want keyboard or joystick control. If you prefer joystick control, plug a joystick into controller jack 1.
5. To begin, press any key or the red joystick button.
6. Plug the AtariLab Interface into controller jack 2.
7. Plug the AtariLab Light Sensor into the right (orange) paddle input of the AtariLab Interface.
8. Press any key or the red joystick button to see the main menu options for the Light Module Cartridge.

The next step in checking the Cartridge and Light Sensor is to use the LIGHT METER option and measure some light in the room you are in. To measure the amount of light, follow the instructions below:

1. Push the ← key or the joystick left to select the LIGHT METER option (There is no need to press **CTRL** to use an arrow key). You should see a picture of a light meter on the screen.

The light level is indicated by the length of a yellow bar extending across the screen inside the meter. The bar turns red whenever the light is too bright or too dim to be recorded by the Light Sensor. Numbers showing the amount of light energy measured as %LIGHT appear to the right of the meter.

2. Point the Light Sensor toward a window, the television screen, or a light. Cover the Light Sensor with your hand. On the screen, you should see the light level shown on the light meter go up and down.
3. To record a light level measurement on the screen, press the **START** button. You are able to record up to three light level measurements on the screen at one time.

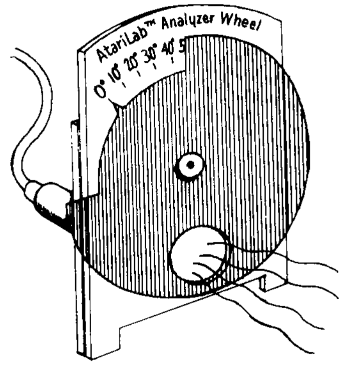
Checking the Light Assembly

1. If you have turned your computer off, turn it on again.
2. Plug the AtariLab Interface into controller jack 2.
3. Plug the Light Assembly into one of the red power inputs in the AtariLab Interface. The light should turn on.

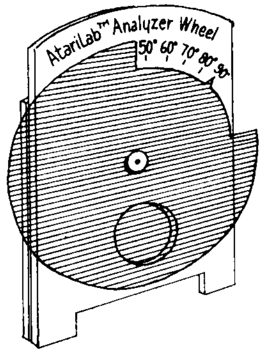
Checking the Polarizer and the Analyzer Wheel

1. Plug the Light Assembly into one of the red power inputs of the AtariLab Interface and make sure the light is on.
2. Set the Analyzer Wheel at 0° and line up the cardboard holder of the Analyzer Wheel with the Polarizer.
3. Hold the Light Assembly behind and against the gray portion of the Analyzer Wheel and the Polarizer as shown below. You should see the light shining through the gray portion of the Analyzer Wheel and the Polarizer without any change in the color of the light.
4. Rotate the Analyzer Wheel until the Polarizer has turned through a 90 ° angle. Now, place the Analyzer Wheel on top of the Polarizer.
5. Hold the light from the Light Assembly behind and against the gray portion of the Analyzer Wheel and Polarizer. You should see only a small amount of purple light pass through the two filters.

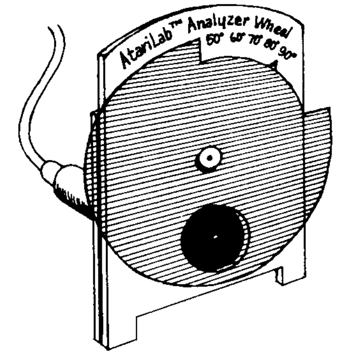
If you are having trouble getting light meter readings, or are having problems with the Cartridge, the Light Assembly, the Light Sensor, or the Analyzer Wheel and Polarizer, consult the Trouble-Shooting Guide in Appendix F.



The Analyzer Wheel, set at 0°, is lined up with the Polarizer. Light is passing through them.



The Analyzer Wheel at 90° with Polarizer.



The Analyzer Wheel at 90° with Polarizer. Only a small amount of light can come through.

Does Your Refrigerator Light Really Turn Off?

For some extra fun, you can move your computer next to the refrigerator and place the Light Sensor inside! When the light is on you should have 100 %LIGHT or more on the meter on the screen. Now close the door gently on the Sensor wire. Does your refrigerator light really go off when the door is closed?

Tips for Experimenters

Before beginning the projects in this manual, you should read this section. It will help you get better results from your experiments.

Getting Started

You should reread the section on getting started at the beginning of Chapter 2 in the *AtariLab Starter Set Manual and Temperature Module Project Guide*. The major tips in that section include:

1. How to keep a laboratory notebook.
2. A reminder to read all the way through a project before starting it.
3. A warning that all liquids involved in an experiment should be kept away from the computer and AtariLab Interface.
4. Advice on the use of extender cables in cases where the Sensor needs to be far away from the computer.

Taking Accurate Measurements

One of the biggest challenges in doing experiments with light is getting rid of all the light that you don't want to measure. You need to be certain you are measuring only the light from the source you are using for the experiment. For example, if you are using the Light Sensor to observe the light from a candle, you don't want light through window or from an electric light to interfere with the light from the candle.

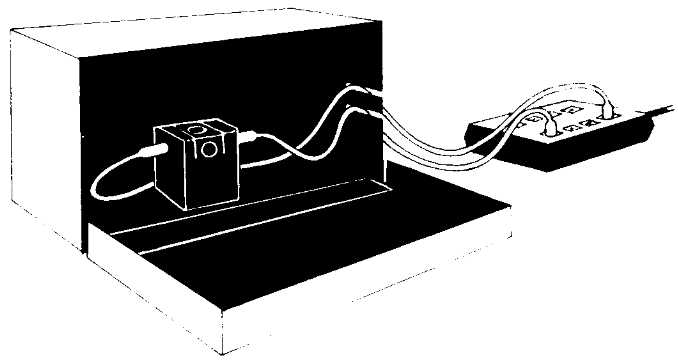
The ways to get rid of light that you don't want depend on the project you are doing. Some of these methods are:

1. Placing a black cloth over the Light Sensor and the Light Assembly when they are used in the Light Stand.
2. Placing the Light Stand, Light Assembly, Light Sensor, and whatever other materials are needed for an experiment inside a shoe box lined with black construction paper. We call this an **Experiment Box**. The construction paper should be taped or glued on to both the bottom and top of the box and the top should be hinged to the bottom. Slots should be cut in the sides of the box for the Light Sensor and Light Assembly cables. An Experiment Box is shown below.

Warning: NEVER place a burning candle in a box of this sort!

3. Working in the evening, in a windowless room, covering all windows with blankets or black cloth, turning off the room lights, or pointing the Light Sensor away from the TV screen during measurements.
4. Using extender cables and doing your projects in a dark closet.

Note: *The last three methods allow you to move the Light Sensor, Light Assembly, and Light Stand more freely.*



An Experiment Box made using a shoe box and black construction paper.

Calibrating the Light Sensor

To get better experimental results, you should calibrate the Light Sensor. Instructions for calibration will be found in Project Two later in this chapter. Calibration involves exposing your Light Sensor to the brightest light it will see in the project you plan to do. This measurement becomes the 100 %LIGHT level. All other light levels you measure should then be less than 100%.

Repeating Experiments

A well-designed experiment usually gives results that are similar when the experiment is done again following the same steps. You may want to repeat an experiment several times to get the best results. If you do this, be sure you are taking the measurements in exactly the same way.

In a good experiment, when two sets of measurements are taken in the same way, you should be able to draw the same conclusions from each set of results.

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 TV set or monitor plugged in correctly?
- Is the Cartridge inserted correctly?
- Is the AtariLab Interface inserted in controller jack 2?
- Is the Light Sensor inserted correctly in the right (orange) paddle input?
- If you are using the Light Assembly, is it inserted in one of the red power inputs on the Interface?
- Did you make any changes in the recommended procedures? Do these changes affect the results of your experiments?
- Did you check the Trouble-Shooting Guide in Appendix F?

If your problems appear to be caused by a bad Sensor, Light Assembly, AtariLab Interface, or Cartridge, consult your dealer.

CHAPTER 1: Project One

Measuring Light— The Foot–candle

Having learned to read, Abe read all the books he could lay his hands on . . . . Books lighted lamps in the dark rooms of his gloomy hours.
Carl Sandburg

Abraham Lincoln, as a boy growing up in Kentucky and Indiana, had less than a year of formal education. After spending his days chopping wood and doing his other chores, Abe spent many long evenings educating himself. Legend has it that he did this by reading a small collection of books over and over again by fire and candle light.

Before electricity, the most common source of light for any indoor or evening activity was the candle. People read, wrote, played games, and sewed by candlelight. When a unit of measurement was needed to express the amount of light a person could see, the candle was the obvious starting point. Just as inches and feet are used to express the measurement of length and height, the foot–candle is a unit that expresses the amount of light a person sees. It is measured at a distance of one foot from a candle. In this first activity, you will learn how to measure light in foot–candles with your AtariLab Light Module.

Purposes

- To observe the amount of light you can see at a distance of one foot from a candle.
- To find out how many foot–candles correspond to 100 %LIGHT for your AtariLab Light Sensor and your computer.

Equipment and Materials

An ATARI Laboratory Station with the AtariLab Light Module items
A dark draft–free room
A short fat candle about 2 inches high and 1-inch in diameter (sold in supermarkets and variety stores under the name votive candle)
Matches
A large china or glass plate (not plastic)
4 or 5 thin books
A ruler
A piece of string about 3 feet long
A 3–foot long space on a clean table top

More About Light

When you look at a white light or the yellow flame of a candle, you are looking at a combination of photons of different wavelengths which you see as different colors. Your eyes respond best to yellow and green photons. Because of this special response, a candle flame appears yellow even though more of its light energy consists of photons which you would see as red.

The sensitivity of the AtariLab Light Sensor to different colors of light is very similar to that of a typical human eye. It, too, is most responsive to yellow and green light. When you or the Light Sensor "see," only part of the light energy given off by a light source is detected.

The AtariLab Unit of Light— The Light Level

Historically, all measurements of light level were compared to that of a candle at a distance of one foot. The candle you are using probably does not give off exactly the same amount of light energy as the official candle used when Abraham Lincoln was president of the United States. The original foot-candle was defined in 1860 by the London Gas Act to be the illumination one foot away from a candle made of sperm whale oil. The standard sperm whale oil candle weighed one-sixth of a pound and had to burn its wax at a rate of 120 grains an hour. (One grain is one seven thousandths of a pound.)

Because the old sperm whale candles did not always give off a steady light, the modern foot-candle is defined by the amount of light given off by the glow of a platinum wire of a particular shape and size when an electric current is run through it.

There are several popular measuring units used by scientists to measure light. Some of these are the foot-candle, the watt, and the lumen. Each of these units expresses the measurement of light in a different way. The lumen, for example, describes total light energy. For the AtariLab Light Module, we have chosen a unit we call "light level" or "%LIGHT".

Light level is represented by a number between 0 and 100. It is defined as the relative percentage (%) of light that can be detected by the AtariLab Light Sensor. Our light level or %LIGHT unit can be compared most easily to the foot-candle. By completing the project below, you can determine how many foot-candles it takes to get a reading of 100 %LIGHT with your Atari Laboratory Station.

Warning: This project requires adult supervision! The burning candle should always be placed on a china or glass plate or other surface that will not catch fire if the candle is tipped over. The candle should be lit with care and then kept away from any material such as paper or cloth that might catch fire. The candle should be blown out as soon as a project is completed.

Observing the Light Level of a Candle

Do you think you could do all your reading by candlelight? Pretend you are Abe Lincoln! Just for fun, see how well you can read by candlelight in an otherwise dark room. Unless you have a room with no windows, you should wait until evening to make this first observation.

Setting Up and Making the Observation

1. Take the necessary materials into a room that can be darkened. If you need to screen out light from the windows, you can hang blankets over them.
2. Place the candle in the middle of the plate and put the plate on the table.
3. Light the candle.
4. Turn off the lights in the room.
5. Hold a book about 12 inches away from the candle. Can you read the book?
6. While still reading the book, move the book away from the candle.
7. Find the farthest distance from the candle where you can still read the print comfortably. Mark the distance by placing the book at that location.
8. Turn on the lights.
9. BLOW OUT THE CANDLE IMMEDIATELY, BUT DON'T MOVE IT!
10. Measure the distance from the candle to the book. Write your answer below:

_______ inches

Finding the Least Number of Foot-candles Necessary for Reading

Less and less light reaches an object as the distance between the object and the light source increases. The amount of light energy which reaches an object from a small light source decreases very quickly with distance. For example, if your book is two feet away from the candle. it gets only 1/4 the amount of light it would receive at a distance of one foot from the candle. If your book is three feet away from the candle, it will receive only one-ninth (1/9) the amount of light it would receive at one foot from the candle. You can see this illustrated in Figure 1.1-1.

By using the table below, you can find how many foot-candles you need to read comfortably by candlelight. On the table below, find the distance you just measured and the number of foot-candles at that distance will be on the right.

Exploring How Your ATARI Laboratory Station Responds to Light

How many foot-candles are needed to give a reading of 100 %LIGHT? Each candle, Light Sensor, and ATARI Computer is slightly different. One way to find out how your equipment responds to light is to measure how far away your candle has to be from the Light Sensor to get a light level of 100 %LIGHT.

Table 1.1–1. *The Number of Foot-candles of Light as the Distance from a Source Increases.*

Distance (inches)	Foot-candles
4	9.00
5	5.76
6	4.00
7	2.94
8	2.25
9	1.78
10	1.44
11	1.19
12	1.00
13	0.85
14	0.73
15	0.64
16	0.56
17	0.50
18	0.44
19	0.40
20	0.36
21	0.33
22	0.30
23	0.27
24	0.25
25	0.23
26	0.21
27	0.20
28	0.18
29	0.17
30	0.16

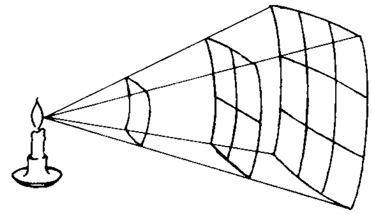


Figure 1.1–1. *Light energy spreads out as it moves away from the source.*

Setting Up and Taking the Measurement

1. Find a room that can be darkened completely and is free of drafts so the candle will burn steadily.
2. Set up the ATARI Laboratory Station (See Appendix A).
3. Place the Light Sensor in any one of the side holes in the Light Stand.
4. Choose the LIGHT METER option (See Appendix A). You should see a picture of a light meter on the television or monitor screen.
5. Put the china or glass plate on the table directly opposite the Light Stand.
6. Place the candle in the middle of the china or glass plate and light it.
7. By looking closely, find the brightest part of the candle flame. DO NOT TOUCH THE FLAME!
8. Using your ruler, measure the distance from the plate to the brightest part of the candle flame. (Figure 1.1–2)

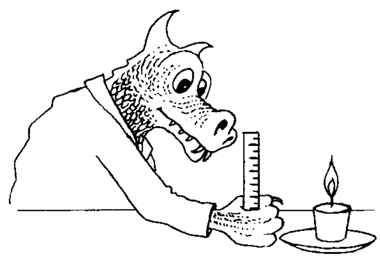


Figure 1.1–2. *The AtariLab Dragon measuring the distance between the plate and the brightest part of the flame.*

9. Now measure the distance from the table top to the hole holding the Light Sensor in the Light Stand. (Figure 1.1–3)

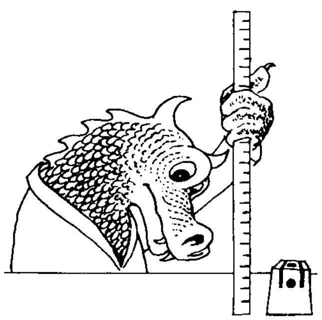


Figure 1.1–3. *The AtariLab Dragon measuring the distance from the table top to the hole in the Light Stand holding the Light Sensor.*

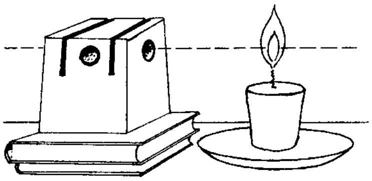


Figure 1.1–4. *Adjusting the Light Sensor and candle to the same height.*

10. The brightest part of the candle flame and the Light Sensor should be about the same distance from the table top. Adjust the differences in height by placing some thin books or notebooks under the plate and Light Stand until the Light Sensor and the flame are the same distance from the table top. See Figure 1.1–4.
11. Turn off the lights and darken the room.
12. Slowly move the candle away from the Light Stand. Try to keep the candle directly opposite the Light Sensor. The band inside the light meter will be red before you move the candle, and the number to the right of the meter will be >100%. As you move the candle away, you will see the yellow band fill the light meter on the screen and the numbers to the right of the meter will change. Adjust the candle so that the numerical readout indicates 100 %LIGHT and the ">" sign no longer appears. (Figure 1.1–5)

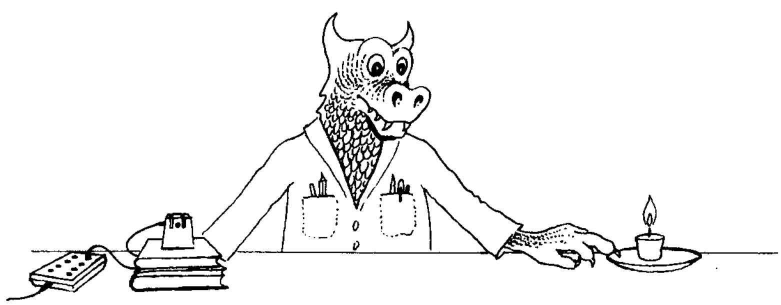


Figure 1.1–5. *Moving the candle away from the Light Sensor.*

13. Carefully move the candle from side to side, and back and forth, to be sure it is in line with the Light Sensor. The Light Sensor will give its highest reading when it is in line with the candle.
14. Turn on the lights.
15. BLOW OUT THE CANDLE IMMEDIATELY, BUT DON'T MOVE IT.
16. Carefully measure the distance in inches between the Light Sensor and the wick of the candle. You may want to stretch a string between the Light Stand and the candle wick and then measure the length of the string. (Figure 1.1–6)

Figure 1.1–6. *Measuring the distance between the candle wick and the Light Sensor.*

17. The distance is:

    ______inches.

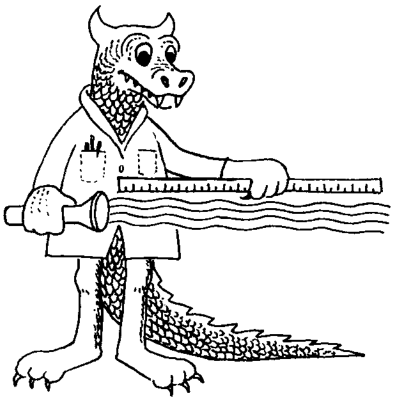
18. By using Table 1.1-1 again, you can find the number of foot-candles which correspond to 100 %LIGHT for the distance you just measured and record your finding below:

    ______foot-candles.

Standard Calibration

The measurement you just made allows you to determine how many foot-candles correspond to 100 %LIGHT for Standard Calibration for your AtariLab Light Sensor and computer. Because each computer and Light Sensor are slightly different, your measurement will probably not be the same as that of other people also using the AtariLab Light Module. We found that three-tenths of a foot-candle (0.3 foot-candles) corresponded to 100 %LIGHT. Your measurement is probably different.

In the next project you will learn more about Standard Calibration and how to use it in the other AtariLab Light Module projects.



CHAPTER 1: Project Two

Calibrating Your Light Sensor

I have measured out my life in coffee spoons.
T.S. Eliot

Since the measuring device has been constructed by the observer . . . we have to remember that what we observe is not nature in itself but nature exposed to our method of questioning.
Werner Karl Heisenberg

Can you remember the last time you looked at a clock in your home and realized that it gained or lost time every day? A clock measures time in seconds, minutes and hours. Ideally, when a clock is made, its internal workings are set to record seconds, minutes and hours at the same rate that a standard clock in the United States National Bureau of Standards records them. When the clock in your home is fast or slow, it has to be corrected so that it will run at a rate that is closer to that of the standard clock again. This procedure is called calibration.

In general, calibration involves adjusting a measuring instrument so its readings are as close as possible to those of a standard. Calibration is an important scientific activity because measurements should always be as accurate as possible. In this project, you will learn about calibration by learning to calibrate the AtariLab Light Sensor.

Purposes

- To learn more about the process of calibration.
- To learn how to calibrate the ATARI Laboratory Station to measure light levels. Remember, the light level is the percent of light energy that can be detected by the AtariLab Light Sensor.

Equipment and Materials

An ATARI Laboratory Station with the AtariLab Light Module items
A piece of white paper

Calibrating the Light Sensor

If you don't calibrate your Light Sensor after loading your Cartridge or after pressing the **RESET** button, all your light measurements will be recorded using a Standard Calibration provided with the Light Module Cartridge.

Calibration of the AtariLab Light Sensor involves choosing the light level that will be interpreted by the computer as 100 %LIGHT. The scale used to measure %LIGHT can be adjusted for each experiment.

When you calibrate the Light Sensor, the CALIBRATE SENSOR option will not allow calibration if the light level is too low or too high.

Although you can calibrate at light levels that are not in the best range, a message will appear on the TV or monitor screen suggesting that you adjust the light level. The messages you will see on the calibration screen are shown below in Table 1.2-1.

Table 1.2-1. *Calibration Screen Messages.*

Message	*Calibration Possible?*
TOO BRIGHT REDUCE LIGHT LEVEL	no
FOR MORE PRECISION REDUCE LIGHT LEVEL	yes
GOOD LIGHT LEVEL	yes
FOR MORE RANGE INCREASE LIGHT LEVEL	yes
TOO DIM INCREASE LIGHT LEVEL	no

Calibrating the Sensor at Different Light Levels

Calibration is adjusting a measurement against a standard. In AtariLab Light Sensor calibration, you find a new standard each time you do an experiment. The new standard corresponds to the brightest light level you can expect to find in each experiment or observation you do. It becomes the 100 %LIGHT level. All your further measurements for the project will be compared to this new standard.

For proper calibration, the amount of light the Light Sensor receives should be adjusted until the message "GOOD LIGHT LEVEL" appears on the screen. The light from the AtariLab Light Assembly is usually too bright for the Light Sensor. You can reduce the amount of light by following the suggestions in Appendix A under the heading "Reduce the Light Level at the Sensor" or by using one of the methods suggested earlier in this project.

Calibrating with a Bright Light Source

Let's try a calibration at a light level brighter than the 100 %LIGHT in the Standard Calibration.

Setting Up the Calibration

1. Set up the ATARI Laboratory Station (See Appendix A).
2. Set up the AtariLab Light Stand with the Light Sensor and Light Assembly (See Appendix A). To do this, insert the Light Sensor in one of the Light Stand holes behind a filter slot. Put the Light Assembly into the hole in the Light Stand opposite the Light Sensor.

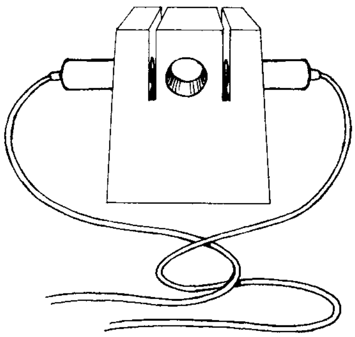


Figure 1.2–1. *The Light Stand with the Light Assembly and Light Sensor inserted facing each other.*

Calibrating the Light Sensor

Ordinarily, to calibrate the Light Sensor you can follow the instructions in Appendix A under the heading "Calibrate the Light Sensor." In this case we need to calibrate the Sensor for bright light conditions. If the ATARI Laboratory Station is set up, these instructions are as follows:

1. Press any key or the red joystick button to see the MAIN MENU options.
2. Choose the CALIBRATE SENSOR option by pressing the → key or moving the joystick to the right.

Note: *The AtariLab Light Assembly, when mounted in the Light Stand without any filters between it and the Light Sensor, is usually too bright. There will probably be a message on the television or monitor screen stating "TOO BRIGHT REDUCE LIGHT LEVEL."*

3. If necessary, reduce the light detected by the Sensor until the message states "FOR MORE PRECISION REDUCE *LIGHT LEVEL.*"
4. Continue with the calibration by pressing the **START** key.
5. Wait about 3 seconds for the MAIN MENU to reappear.
6. When the MAIN MENU reappears, choose the LIGHT METER option by pressing the ← key or pushing the joystick to the left. If the light level reaching the Light Sensor has not been changed since calibration, you should see a reading of 100 %LIGHT on the television or monitor screen.
7. If your Light Meter reading is not 100 %LIGHT, calibrate again by repeating steps 1 through 6.

Measuring Light Level Using Standard Calibration

What happens when you use Standard Calibration and slowly decrease the amount of light shining on the Light Sensor? Let's try it.

1. Set up the ATARI Laboratory Station. (See Appendix A.)
2. Press any key or the red joystick button until you see the Main Menu displayed on the television or monitor screen.
3. Choose the LIGHT METER option (See Appendix A.)
4. Adjust the light level at the Light Sensor until the reading to the right of the meter is 100 %LIGHT. If the reading is too large (>100 %LIGHT) or too small (a number which is less than 100 %LIGHT):

- To increase the light level at the Light Sensor, point the Sensor toward a light.
- To decrease the light level at the Light Sensor, cover the Sensor with your hand or dim the light in the room.

5. Try covering and uncovering the Sensor slowly several times using your hand and notice how the %LIGHT readings jump down as you cover the Light Sensor.

You should have noticed that the %LIGHT readings did not go down smoothly from 100% to 99% to 98% and so on. This is because the computer is not very sensitive to changes in light levels near 100 %LIGHT at the Standard Calibration.

Observing the Jumps in Light Meter Readings

In order to observe the jumps in light level more carefully, you can watch the changes in %LIGHT readings on the LIGHT METER screen as the Light Sensor is slowly covered. To do this, follow the instructions below:

1. Slowly cover the Light Sensor until the next lower value of %LIGHT appears on the screen.
2. Press the **START** button to record this measurement of %LIGHT.
3. Repeat steps 1 and 2 until you have recorded three measurements for %LIGHT.
4. Record these measurements for the first three light levels that are less than 100 %LIGHT at Standard Calibration below:
   %LIGHT
   ______
   ______
   ______

Your light level readings using the Standard Calibration, should be 97%, 94%, and 91%.

5. Block out all the light from the Light Sensor by covering it completely with your hand or the piece of folded paper. What is the %LIGHT reading on Light Meter?
   ______ %LIGHT

As you block more and more light from the Sensor, you will see that below about 67 %LIGHT, the %LIGHT readings decrease by 1% at a time. However, the Sensor cannot detect any more changes in light level below 13% of the original level of 100%. You already saw in step 9 above that when you block all light from reaching the Sensor, the %LIGHT level is < 13%. The sign "<" stands for "less than" which means that the light level is below 13%. At low light levels the meter will always indicate < 13%.

Table C-1 in Appendix C lists all possible %LIGHT levels at the Standard Calibration.

If the light is brighter than that needed for 100 %LIGHT at Standard Calibration, the reading on the meter will simply be > 100%. The sign ">" stands for "greater than" so the symbol "> 100%" means the reading is above 100%.

Some Observations About Calibration at Different Light Levels

Now that you've calibrated, let's see how well the computer can record changes in the amount of light detected by the Sensor using the new calibration. Let's make the same observation we did for the Standard Calibration and investigate what happens when we slowly decrease the amount of light. To do this:

1. Take the Light Sensor out of the Light Stand.
2. Cover the Sensor with your hand or a folded piece of paper until the light meter on the screen reads 100 %LIGHT again.
3. Continue to slowly cover the Sensor until the next lower measurement of %LIGHT appears on the screen.
4. Press **START** to record this measurement of %LIGHT.
5. Repeat steps 3 and 4 until you have recorded three measurements for %LIGHT.
6. Enter the measurements for the first three recorded light levels that are lower than 100 %LIGHT (for a Light Sensor calibrated at a light level brighter than Standard Calibration) below:

   %LIGHT

   ______

   ______

   ______

7. Block all the light coming in to the the Light Sensor by covering it completely. Record the lowest %LIGHT reading:

   ______ %LIGHT.

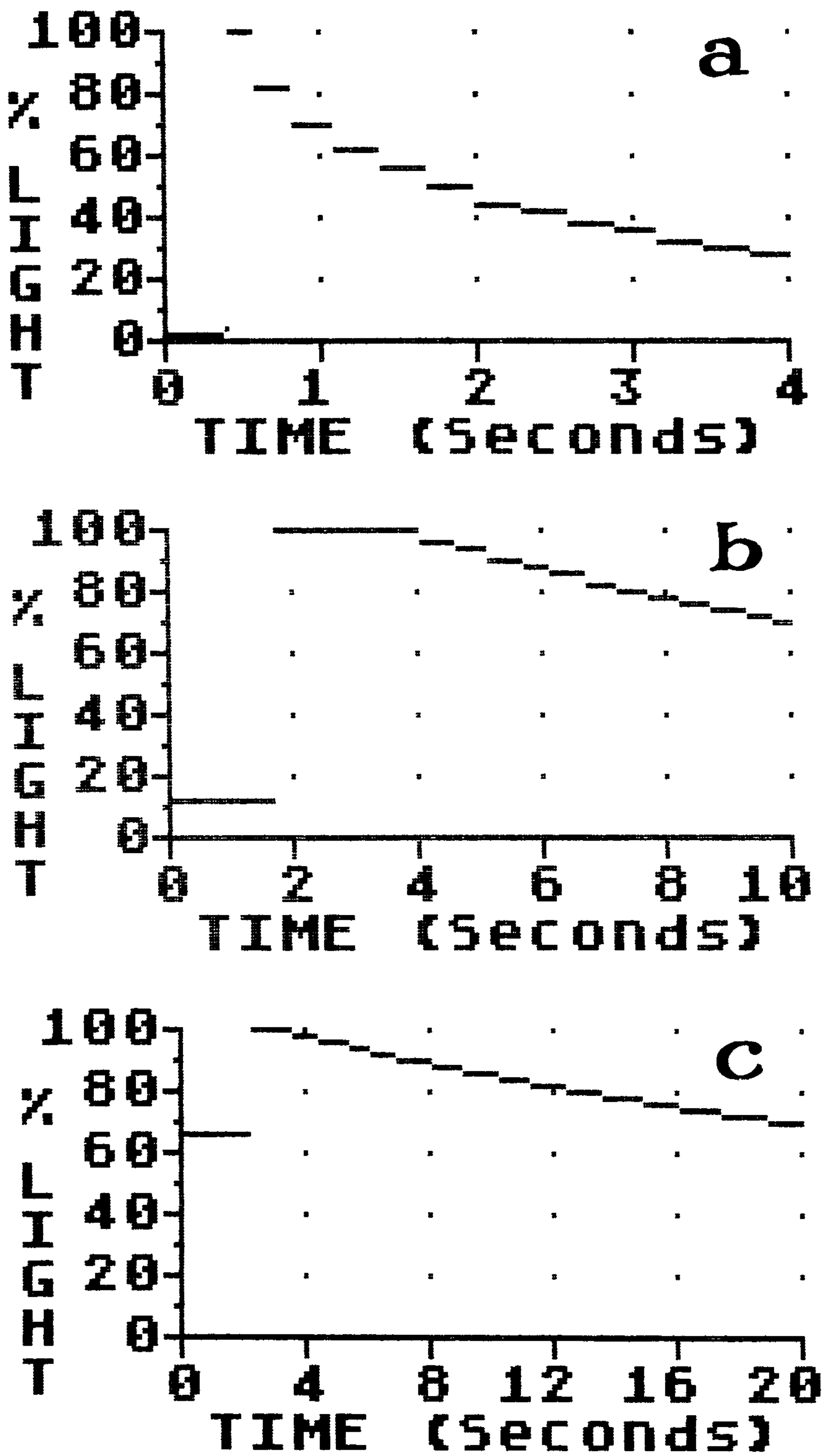
You should notice that calibration with a brighter light causes the %LIGHT readings to decrease in even bigger jumps, but the smallest %LIGHT that can be recorded is smaller than 13%.

Table C-2 in Appendix C lists light levels for calibration at the brightest and dimmest light possible. You can compare your findings with the table. However, unless you have taken your measurements at the brightest possible light level corresponding to 100 %LIGHT your results will be different than the values listed in the table.

If you repeat the calibration process for a light that is dimmer than that used for Standard Calibration the light readings will decrease in smaller jumps, but the smallest %LIGHT that can be recorded is 13% or more.

The jumps are shown in Figure 1.2-2 below. Notice that the brightest calibration has the most jumps while the dimmest calibration has no jumps.

Figure 1.2–2. *Graphs representing data taken at three different calibrations as the light from the AtariLab Glow Panel decreases (a) brightest, (b) standard, and (c) dimmest.*



Summary

Each light experiment will require a different calibration. If the brightest light used in an experiment is too bright to be recorded using Standard Calibration, you will have to calibrate for the brighter light. In this case the jumps between recorded light levels will be larger and will reduce the accuracy of your measurements.

If the brightest light used in an experiment is too dim, then the range from 100 %LIGHT to the smallest %LIGHT that can be recorded will be small. This small range will limit the amount of light level change that can be recorded.

It is best, whenever possible, to do experiments in which you can achieve the "GOOD LIGHT LEVEL" message for calibration. This can be done by using the methods listed in Appendix A.

CHAPTER 1: Project Three

How Fast Does Your Light Sensor Respond to Changes in Light Level?

Hurry up please, it's time.
T.S. Eliot

Most AtariLab Light Module experiments focus on measuring the changes in the light level falling upon the AtariLab Light Sensor. Your Sensor measures rapid changes in light level. Suppose you suddenly turn off the lights. How quickly would the Light Sensor actually record the changes in light level? In order to do experiments that measure changes in the amount of light correctly and accurately, you must know the speed at which your AtariLab Light Sensor reponds to these changes.

The term **response time** has a special meaning for scientists and engineers. For the purpose of our experiments with light, we will understand response time to mean the time it takes a reading from the Light Sensor to reach its final value after a light is turned off or on suddenly.

Purposes

- To measure how quickly the Light Sensor responds to sudden changes in light level.
- To learn more about what affects the response time of the Light Sensor.

Equipment and Materials

An ATARI Laboratory Station with the AtariLab Light Module items

Measuring Response Time

You have probably noticed when using the Light Meter on your TV or monitor that the light level display changes very rapidly when the Light Sensor is covered suddenly.

Let's try a simple measurement of response time. To do this you can expose the Light Sensor to 100 %LIGHT using the standard calibration, and then suddenly block the light source you are using. How long would it take the Sensor to record the new light level?

Setting up the Measurement

1. Set up the ATARI Laboratory Station with the Light Module.
2. Use the Standard Calibration. If you have already calibrated the Sensor, press **RESET** to return to Standard Calibration. Next, press any key or the red joystick button twice to return to the Main Menu.

3. Choose the SET UP EXPERIMENT option (See Appendix A).
4. Choose an X AXIS of 4 seconds (See Appendix A). To do this, press the ← key or move the joystick to the right to choose the CHOOSE X AXIS option. When the X axis choices appear on the screen, press the ↓ key or move the joystick down until the 4-second scale is highlighted and then press the **ESC** key or red button on the joystick.
5. Select a light source that gives a reading of about 100 %LIGHT. You may want to go back to the LIGHT METER option and test the brightness of different sources. If you do this, you will have to repeat steps 1 through 5 above.
6. After selecting your light source, put the Sensor near the palm of your hand. Get ready to cover the Sensor quickly.
7. Begin a Light vs. Time Experiment (See Appendix A) by choosing the BEGIN EXPERIMENT option by pressing the ↑ key or pushing the joystick up.
8. When the graph appears, press any key or the red joystick button to begin recording light data.
9. Quickly cover the Light Sensor.

Recording Your Results

When the graph is completed after 4 seconds, you should examine it carefully. Did the light level seem to decrease immediately? If not, what was the response time of your Light Sensor to a sudden decrease in light level? That is, how long did it take after the Sensor was shielded from light for the light level to fall to its final level?

Note: *You may want to review the use of AtariLab graphs by rereading Project Two on "Graphing How Temperatures Change over Time" from the* Temperature Module Project Guide.

The easiest way to find the time needed for the light level to decrease to its final value is to look at the data table. The times recorded in the data table are shown in 60ths of a second. In a 4-second graph, a light level is recorded each 2/60ths of a second. By scanning the data table, you can find the time when the final light level was first recorded and when a 100 %LIGHT reading was last recorded. Since the response time is the difference in time between 100 %LIGHT and the time the final value first appeared, simply subtract the time when the 100 %LIGHT was last recorded from the time when the final %LIGHT value was reached. To do this follow the directions below:

1. Press **ESC** or the red button on the joystick to go to the DISPLAY DATA menu.
2. Press the ↑ key or push the joystick up to see the data table.

3. Look at the data table to find the last time in 60ths of a second that the Light Sensor read close to 100 %LIGHT. If necessary, press any key or the red joystick button to scan through the data table. Record the time below:

   ______ 60ths of a second.

4. Look at the data table a second time to find the first time that the Sensor read its final value. Record the time below:

   ______ 60ths of a second.

5. Subtract the time in step 3 from the time in step 4. Then record the result below:

   The response time is ______ 60ths of a second.

The response time is somewhat different for each AtariLab Light Sensor. Our Light Sensors had a response ranging from 8/60ths of a second to 50/60ths of a second.

Further Suggestions for Measuring Response Time

Response Time from Dark to Light

You just measured the response time of Light Sensor at the Standard Calibration when light was cut off from the Sensor. That is, you measured response time from light to dark. This time is often called the **fall time**.

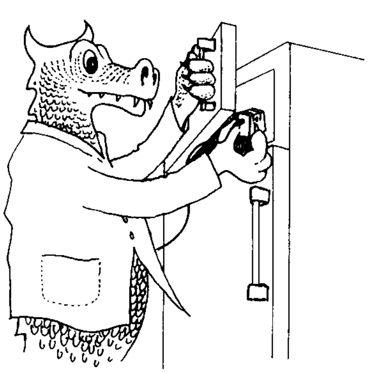
What if you measured the response time of the Sensor from darkness to light instead? This time is often called the **rise time**.

Try measuring the rise time. Is it different than the fall time? The same steps listed above in the section titled "Measuring Response Time" can be used. This time, start with your palm covering the Light Sensor and then quickly uncover it.

Follow the steps listed in the section titled "Recording Your Results." This time, when you look at the data table, write in the time at which final light level was first recorded, then write in the last time at which the first light level was recorded.

Is the rise time different than the fall time? We found that the rise time was much faster—about two or three-60ths of a second.

There are other observations you can make to see what may affect the response time of the Sensor. For example, what if you calibrate the Light Sensor to a much higher light level, then measure fall time? Will the response time of the Sensor change?



Other Response Time Projects

There are other meaurements you might want to try. Does the response time change with temperature? You can try putting your Light Sensor in the freezing compartment of your refrigerator for a while. What happens to the response time if the Light Sensor has been calibrated for a dimmer light?

Conclusions

If you measured the fall time and rise time for your Light Sensor, you should have found that the fall time is longest. This fall time, or light-to-darkness response time, is important to remember as you do other projects in Chapters 2 and 3 of this manual. Changes in light level that are more rapid than the response time of the Light Sensor cannot be measured. For example, a measurement of camera flash time will appear to be longer than it really is because the Light Sensor cannot respond quickly enough to record the flash properly.

CHAPTER 2

Projects That Help Us Learn About Light

The difference is as great between the optics seeing and the objects seen.

Alexander Pope, *Moral Essays*

Introduction

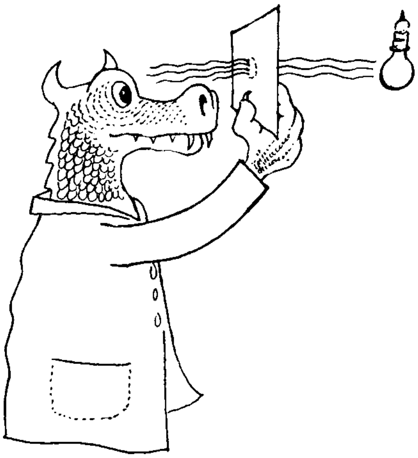
One of the best ways to learn more about both light and the natural world is to observe what happens when light passes through materials. Light can shine on anything—a piece of paper, the air in the Earth's atmosphere, or the lenses in a pair of polaroid sunglasses.

By shining light on an object, we can measure how much of it is reflected, how much is scattered by an object, and how much is absorbed by the atoms and molecules that make up the object.

What we learn from these experiments with light depends upon our point of view. If we know about the object, then studying what happens to light shining on it can tell us more about some special properties of light. On the other hand, if we know something about the nature of light, then shining light on an object can tell us more about the nature of the object.

How is light absorbed by molecules of a gas or layers of a solid material? What special property of light allows polaroid sunglasses to block out reflected sunlight? What happens to photons of different wavelengths when they pass atoms and molecules? How does understanding what happen to photons encountering air molecules help us explain why the sky is blue and sunsets are red?

In this chapter of the Experimenter's Guide, you can explore, and perhaps answer many of the questions for yourself.



CHAPTER 2: Project One

Paper Filters—A Tool for Understanding How Light Passes Through Materials

But soft, what light through yonder window breaks?
William Shakespeare, *Romeo and Juliet*

If you shine a beam of light on a piece of plain white paper, what do you see? You should see a spot of reflected light that is the same color as the light. You should also see a spot of transmitted light that has passed through the layer of paper. You can make these observations yourself by shining light from the AtariLab Light Assembly on a piece of paper.

In this project, you will learn more about how light is transmitted when passing through layers of matter. The AtariLab Light Module can be used to measure the amount of light passing through as many as ten pieces of paper.

By studying the results of your observations, you will understand more about the nature of paper and why certain things such as clouds, salt, and sugar appear white.

Purpose

- To observe how light levels decrease when light passes through layers of material.
- To learn more about the structure of paper.
- To understand why certain substances appear white.

Equipment and Materials

An ATARI Laboratory Station with the AtariLab Light Module items
A piece of plain white paper, 8 1/2″ by 11″
An Experiment Box or a dark room
Cellophane tape

Looking at the Structure of Paper

Take a large sheet of white paper and hold it up to a window or bright light so you can see light shining through it. No matter how even and smooth paper appears when lying on a table, it will appear uneven when held up to light. This is because most paper is made up of a tangled mat of long thin wood fibers pressed together.

The paper appears uneven in the light because more light passes through the paper in some places than others. How much difference is there in the amount of transmitted light shining through different parts of the paper? You will need to answer this question before you can understand the results of measurements made using many layers of paper.

Measuring Differences in the Levels of Transmitted Light

Let's measure differences in the amount of light passing through a piece of paper. The paper can be placed in a filter slot between the Light Assembly and the Light Sensor. Then it can be moved from from side to side in the filter slot.

Setting Up and Making the Observation

1. Set up the ATARI Laboratory Station (See Appendix A) and then set up the AtariLab Light Stand with the Light Sensor and Light Assembly. (See Appendix A.)
2. Shield the Light Sensor from stray light when you perform the calibration or take any data. To do this, place the Light Stand, Light Sensor, and Light Assembly in an Experiment Box or a darkened room.
3. Cut the piece of white paper into about 16 strips of approximately 1-inch by 1 1/2 inches.
4. Reduce the light level at the Light Sensor by placing about 3 or 4 strips of paper in the filter slot next to the Light Assembly.
5. Choose the CALIBRATE option on the Main Menu.
6. While looking at the TV or monitor screen, increase or decrease the number of paper strips in the filter slot until the message "GOOD LIGHT LEVEL" appears. Do not press the **START** key yet.
7. Tape the paper strips you used to reduce the light level firmly to the Light Stand.
8. Press the **START** key to calibrate, and then choose the LIGHT METER option. (See Appendix A.)
9. Place a single strip of paper in the other filter slot next to the Light Sensor.
10. Slowly move the paper strip from side to side in the filter slot. Watch the %LIGHT value to the right of the light meter. Be sure that stray light is still shielded from the Sensor as you do this.
11. When the reading of %LIGHT is the lowest, press **START** to record it.
12. Continue moving the paper strip from side to side, and press **START** again when the %LIGHT reading is the highest.
13. Record the lowest and highest %LIGHT readings for light shining through your paper below:

    Lowest %LIGHT ______
    Highest %LIGHT ______

As you will soon see, it is helpful to know the average value of the %LIGHT transmitted through a strip of paper. The average is found by adding the lowest %LIGHT light value to the highest %LIGHT value and dividing by 2. For example, if the lowest value is 70 %LIGHT and the highest value is 80 %LIGHT then the average value is:

$$(70\ \%LIGHT + 80\ \%LIGHT) \div 2 = 75\ \%LIGHT$$

Do the calculation using the results of your measurements and enter the result below:

Average %LIGHT ______

Ideas About How Light Passes Through a Material

When a particle of light passes near an atom or molecule in a layer of material several things can happen to it. It can pass by the atom or molecule and continue on. It can be absorbed by an atom or molecule for a very short time before a new photon is shot out. If this happens we say the photon of light has been reflected or **scattered** into a new direction. Finally, the particle of light can be absorbed by the material. In this case the light energy is changed into heat energy so that the atoms and molecules in the material move more rapidly. The relationship between heat energy and the motion of atoms and molecules is explained more fully in the *Temperature Module Project Guide.*

The likelihood or probability that a photon of light will be transmitted through a layer of material depends on the nature of the material. Some materials absorb light energy easily. Other materials reflect or scatter a large number of the light photons that shine on them. For example, black objects are absorbers of light energy, white objects reflect light easily, and light passes through clear objects easily. Light that passes through a material is known as **transmitted** light. Usually, some photons in a beam of transmitted light pass straight through the material. Other transmitted photons have been scattered or reflected, but they are still traveling in the same general direction as the original beam of light.

Think about the results of the measurement you just made on the %LIGHT passing through a single sheet of paper. Some light is reflected back to your eyes, making the paper appear white, but most of the light is transmitted. This is surprising. If paper transmits most of the light shining on it, why isn't it clear? We will discuss the reasons for this later when we return to the question of what paper is made of.

How Light Passes Through Layers of Material

Developing a Hypothesis

What happens if you shine light through two layers of paper instead of one? Three layers? Four layers? And so on? If you found that 75 %LIGHT was transmitted through the first sheet of paper, this could mean that of the thousands of photons of light passing through the piece of paper, the average of 75 out of every 100 particles passed through the paper. Then you might think: If 75% of the light photons pass through the first layer of paper, perhaps only 75% of those passing through the first layer will pass through the second layer, and so on.

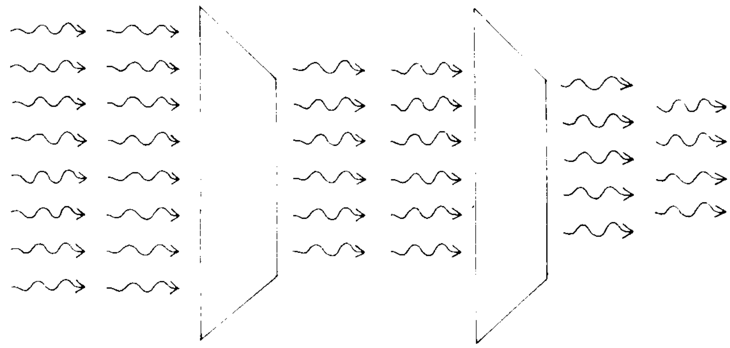


Figure 2.1–1. *Light photons passing through one paper filter and then a second paper filter.*

We could state a general hypothesis about how light passes through several layers of material as follows:

> *The same fraction of light passes through each sucessive layer of material.*

Let's test the hypothesis with layers of paper.

Note: *You may want to review how to formulate a hypothesis by reading the section "Doing Science With the ATARI Laboratory Station" in the* Temperature Module Project Guide.

Testing the Hypothesis

Can we use this hypothesis to predict the %LIGHT coming through sucessive layers of paper? Let's try it! For example, assume the Sensor is calibrated so that 100 %LIGHT is shining on the Light Sensor when no paper strips are placed in the filter slot next to the Sensor. If the average of 75 %LIGHT passes through one layer, then the predicted light levels shining through other layers can be calculated as shown in the table below.

Table 2.1–1: *Sample Table Summarizing the Predicted %LIGHT Transmitted through Layers of Paper.*

No. of Layers	*Predicted %LIGHT**
0	100
1	.75×100=75
2	.75×75 =56
3	.75×56 =42
4	.75×42 =32
5	.75×32 =24
6	.75×24 =18
7	.75×18 =14
8	.75×14 =11
9	.75×11 = 8
10	.75× 8 = 6

*These predicted values are calculated assuming that the average of 75 %LIGHT passes through a single layer of paper.

With your Sensor calibrated for 100 %LIGHT from your previous observation, you can use the average value for the %LIGHT transmitted that you obtained for one layer of paper to calculate your own predicted values for %LIGHT as light is passed through more layers of paper.

Calculate your predicted values by multiplying as shown in Table 2.2-1 above, or entering and running the BASIC program shown below.

```
10 L=100
20 PRINT "Enter %LIGHT for one filter"
30 INPUT L1
40 FOR I=0 TO 10
50 PRINT "# of Layers=";I;" %LIGHT=";L
60 L=INT(L1/100)*L+0.5)
70 NEXT I
```

Your predicted values for %LIGHT should be entered in Table 2.2-2 below. In the experiment which follows, you will find the measured values by placing more paper filters between the Light Assembly and the Light Sensor. By entering your measured values in the table, you can compare the predicted and measured values.

Table 2.1-2: *Summary of Predicted and Recorded %LIGHT Transmitted through Paper Layers.*

# of Layers	*Predicted %LIGHT**	*Measured %LIGHT*
0		
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

**Predicted values are calculated from the actual measurement of the average amount of light passing through a single layer of paper.*

Setting up and Doing an Experiment

Earlier you noticed that a piece of paper passed more light in some places than in others. Because of this natural variation in the amount of light passing through, the measurements used to test the hypothesis must be made carefully. If you follow the suggested procedures carefully, you should be able to compare your measured results to your predicted results in Table 2.2-2 above.

To record and display the data for %LIGHT transmitted, you can select the DATA POINT # graph. Then press **START** each time another layer of paper is added to the filter slot in the Light Stand.

Let's measure the %LIGHT coming through different layers of paper using the Calibration you completed earlier.

1. Choose the SET UP EXPERIMENT option. (See Appendix A.)
2. Begin a Light vs. DATA POINT # Experiment with DATA POINT #0 at 100 %LIGHT as follows:
   - Choose an X AXIS of DATA POINT #. (See Appendix A.)
   - Choose the BEGIN EXPERIMENT option by pressing the ↑ key or pushing the joystick up. You should see a graph of %LIGHT vs. DATA POINT # with a flickering cursor at DATA POINT #1.
3. Place a strip of paper in the filter slot next to the Light Sensor. After making sure the Light Sensor is shielded from stray light, move the paper strip from side to side slowly until the cursor is about halfway between its highest and lowest point on the screen. Press **START** to record the data point.

Note: *The side to side movement is used to find the average value of %LIGHT transmitted through the piece of paper.*

4. If the value of %LIGHT for DATA POINT #1 is less than 60 %LIGHT, find a piece of thinner paper and cut it into strips. Repeat step 3.
5. Repeat step 3 until all 10 data points have been recorded.
6. Examine your graph. It should be a graph of %LIGHT vs. DATA POINT #.

Note: *If your graph or table reads LOG(%LIGHT) vs. DATA POINT #, press* **START** to return to %LIGHT vs. DATA POINT # mode.

7. Sketch the data points in the graph shown in Figure 2.2-2
8. Press **ESC** or the red joystick button to return to the menu.
9. Finally choose the the SEE TABLE option and copy the numbers for %LIGHT into Table 2.2-2 above under the heading "Measured %LIGHT."

Note: *Because you calibrated, the light reading was 100 %LIGHT at DATA POINT #0.*

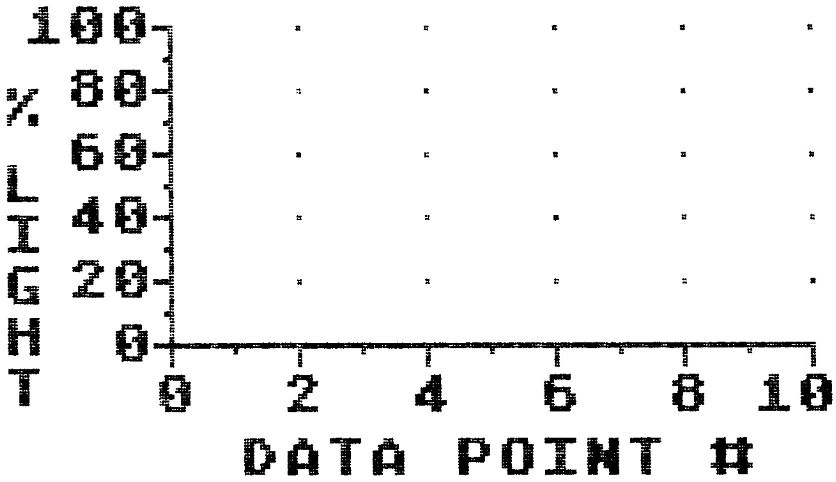


Figure 2.2–2. *Graph of %LIGHT vs. DATA POINT #*

Compare the Measured and the Predicted values for %LIGHT. How well does the hypothesis hold? There will be some variation in your predicted measurements because of the differences in the shape of the wood fibers of each piece of paper. If the values you measured for %LIGHT transmitted are within 5 or 10% of the predicted values, the hypothesis holds fairly well.

More About Paper

The wood fibers in a piece of paper are made of cellulose—a material which is also used in clear cellophane. In fact, if we could examine a single fiber, it would look clear and shiny, rather like a piece of nylon thread.

Although light can pass through both a layer of paper and a layer of glass quite easily, something is different about the light transmitted through paper. We cannot see things through paper as clearly as we can through glass.

Why Isn't Paper Clear?

If single fibers of cellulose are clear why does paper look white instead of clear? When light shines on a clear material such as cellulose, water, or glass we see the surface because, typically, about 4% of the light is reflected each time the light meets a surface. When a beam of light shines on a layer of paper, it bounces from fiber to fiber, sometimes reflecting off the surface of a fiber, sometimes passing through a fiber.

After encounters with many fibers, some light may bounce back from the paper (reflected light) and some of it may pass through the paper (transmitted light). Even the light that passes through the paper has bounced around from fiber to fiber several times. This explains why paper does not look clear.

Why is Paper White?

Why is some paper white and not some other color? The individual cellulose fibers in white paper are clear. Paper is a collection of clear material. The probability that reflection or transmission will take place between a light photon and paper fiber is about the same for photons representing all "colors." Because the individual fibers are clear, a beam of "white" light which is composed of light photons of all colors will be reflected and transmitted as a beam of white light.

Why do things such as snow, clouds, salt and sugar also appear white? Like paper, all of these things are made up of many small particles of clear material. Snow is a collection of tiny ice crystals which have a special six-fold symmetry. Clouds are made up of many tiny water droplets. Sugar and salt consist of little crystals of material which are clear.

Suggestions for Other Projects

What Happens when Oil or Water is Dropped on Paper?

Try dropping some salad or motor oil on a piece of paper. You might also want to pour water over another part of the of paper. Now hold the paper up to a light or a window. You should be able to see throught the paper. Why?

The way oil and water transmit and reflect light is similar to the way paper fibers transmit light. The oil or water fill in the small gaps between the fibers in the paper. There are fewer separate reflecting surfaces and more light is transmitted straight through the paper. Thus, the paper appears relatively clear.

You can repeat the experiments suggested in this project with oily paper and with wet paper, and measure the increase in the light transmission.

CHAPTER 2: Project Two
Polarized Light

There are two ways of spreading light: to be the candle or the mirror that reflects it.
Edith Warton

If you look through one of the lenses on a pair of polaroid sunglasses or through your AtariLab Polarizer what do you see? Try it! Your surroundings probably look gray and dim to you.

Your AtariLab Polarizer and Analyzer Wheel are filters which have a special way of blocking out some of the light coming through them. The lenses in a pair of polaroid sunglasses are also polarizing filters. Polaroid sunglasses are popular because they filter out glaring sunlight that reflects from surfaces.

We refer to light that has passed through a polarizing filter as **polarized light**. In this project, you will learn what polarized light is, what happens when light reflects from surfaces, why polaroid sunglasses are so effective, and how polarized light is used by scientists and engineers as a tool to analyze certain materials.

Purposes

- To measure the amount of light passing through a polarizing filter.
- To learn how to use the AtariLab Polarizer and Analyzer Wheel.
- To learn more about the nature of light.
- To learn more about how light reflects from surfaces.

Equipment and Materials

An ATARI Laboratory Station with the AtariLab Light Module items
An Experiment Box or a dark room
A 3-foot-long piece of heavy string or rope
An ice cream stick
A small piece of aluminum foil

How Much Light Does the Polarizer Eliminate?

Let's answer this question by using the LIGHT METER option to display and record the %LIGHT coming into the Light Sensor before and after the Polarizer has been put in place.

Setting Up and Making the Observation

1. Set up the AtariLab Light Stand with the Light Sensor and Light Assembly. (See Appendix A.)

2. Shield the Light Sensor from stray light (See Appendix A) by placing the Light Stand, Sensor, and Light Assembly in an Experiment Box or a darkened room.
3. Calibrate the Light Sensor. (See Appendix A.) Before calibrating, insert enough paper filters in the filter slot nearest to the Light Assembly to obtain a "GOOD LIGHT LEVEL" on the calibration screen. Tape the paper to the light stand.
4. Choose the LIGHT METER option. (See Appendix A.) If the LIGHT METER does not read 100%, recalibrate the Light Sensor by repeating step 3.
5. Place the Polarizer in the filter slot nearest to the Light Sensor and shield from stray light.
6. Press the **START** button to record the %LIGHT passing through the Polarizer.
7. Enter the recorded value for %LIGHT passing through the AtariLab Polarizer below:

If your results are similar to ours, only about 40–50% of the light energy that the Light Sensor can detect will pass through the Polarizer.

The Analyzer Wheel

Like the Polarizer, the Analyzer Wheel consists of a piece of polaroid film that is mounted so it can fit into the filter slots of the Light Stand. The polarizing filter in the Analyzer Wheel can be rotated through angles between 0° and 90°.

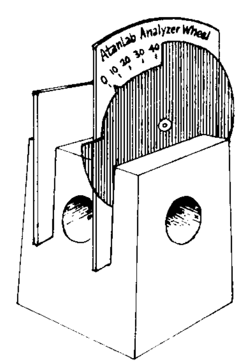


Figure 2.2-1. *Polarizer and Analyzer Wheel inserted in the Light Stand filter slots.*

Some Simple Observations using the Analyzer Wheel

1. Look through the Polarizer. You will see that the objects you are looking at are dim and gray.
2. Take the filter paper, Light Assembly, and Light Sensor out of the Light Stand. Place the Polarizer and Analyzer Wheel in the filter slots on the Light Stand. (Figure 2.2-2)
3. Set the pointer on the Analyzer Wheel to 0°.
4. Pick up the Light Stand and look at your surroundings through the Polarizer and Analyzer. The objects you are looking at should be even dimmer and more gray than they did when you looked through just the Polarizer.

5. Turn the pointer on the Analyzer Wheel to 45° and look through the Polarizer and Analyzer Wheel again. Your surroundings should look much dimmer but still gray.
6. Finally, turn the pointer on the Analyzer to 90° and look through the Polarizer and Analyzer Wheel once more. Your surroundings should be very dim and purple looking.

Polarized Light

The Amount of Light Passing through a Polarizer and Analyzer Depends on the Angle Between Them

The observations you have made looking through just the Polarizer and then through the Polarizer and Analyzer Wheel at several angles are unusual. If you were to look at the light coming through two paper filters, or even the red and blue filters included with the light module, the amount of light passing through would not depend on the angle between the two filters. Because the amount of light passing through the Polarizer and Analyzer Wheel depends on the angular setting on the Wheel, we know that polarized light is somehow different from ordinary light. Let's look at how scientists describe polarized light.

A Description of Polarized Light

Passing light through the AtariLab Polarizer is rather like trying to pass energy from a vibrating string through a picket fence. Both the fence and the Polarizer only allow energy vibrating in one direction to pass through it.

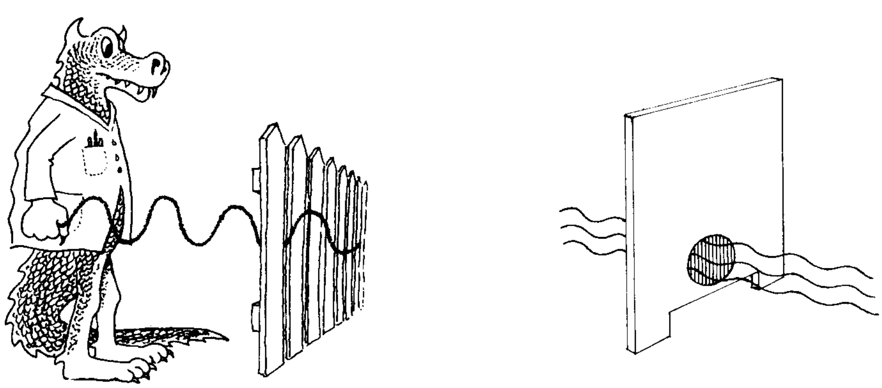


Figure 2.2-3. *A vibrating string trying to pass through a picket fence and a light wave passing through a Polarizer.*

The Importance of the Angle Between the Polarizer and the Analyzer

The polarizing filters used in both the Polarizer and the Analyzer Wheel have long stringy molecules in them. These long molecules are lined up in one direction like pickets along a fence. When the Polarizer is placed correctly in the Light Stand filter slot, most of the molecules lie in an up and down direction.

The direction that the stringy molecules lie in a polarizing filter is known as the **axis of polarization**. The axis of polarization is in the up and down direction when the Polarizer is set properly in the light stand. This axis is also in the up and down direction in the Analyzer Wheel when it is set to 0° and placed properly in a filter slot.

The picket fence model of how a Polarizer and Analyzer Wheel work (Figure 2.2-3) helps explain why the angle between the axis of the Polarizer and the setting on the Analyzer Wheel are so important in determining how much light passes through the two filters.

A beam of light consists of many photons each polarized in a different direction. When this light shines on the Polarizer, only the photons that are polarized in the direction of the axis of the Polarizer pass through it. Only about 50% of light that has not been polarized should pass through a polarizer. Similarly, if the angle set on the Analyzer Wheel is 0° then its molecules also lie in an up and down direction. Most of the light that comes through the Polarizer can also pass through the Analyzer Wheel. If the angle set on the Analyzer Wheel is 90°, the axis of polarization of the Polarizer and the Analyzer Wheel are at right angles to each other. Under these conditions very little light will pass through the Polarizer and Analyzer Wheel combination.

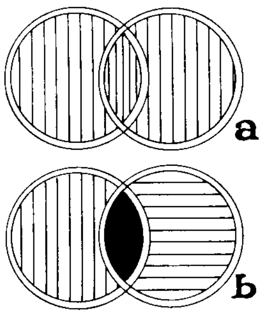


Figure 2.2-5. *The amount of light passing through a Polarizer and Analyzer (a) when their axes of polarization are lined up, and (b) when their axes of polarization are at right angles to each other.*

Measuring the Effect Angle has on Polarized Light

Let's observe how the angle between the Analyzer Wheel and the Polarizer affects the amount of transmitted light.

Setting Up and Making the Observation

1. Set up the AtariLab Light Stand with the Light Sensor and Light Assembly. (See Appendix A.)
2. Shield the Light Sensor from stray light (See Appendix A) by using an experiment box or a darkened room.
3. Place the Polarizer in the filter slot directly in front of the Light Assembly.
4. Place the Analyzer Wheel in the filter slot directly in front of the Light Sensor.
5. Set the angle on the wheel at 0°.
6. Calibrate the Light Sensor. (See Appendix A.) If necessary, place a few layers of white paper in the filter slot next to the Light Assembly until the message "GOOD LIGHT LEVEL" appears on the screen. Tape the paper filters firmly to the light stand.
7. Press **START** to calibrate the Light Sensor.
8. Choose the SET UP EXPERIMENT option. (See Appendix A.)

9. Choose an X AXIS of DATA POINT #. (See Appendix A.)
10. Choose the **START** EXPERIMENT option, and begin a Light vs. DATA POINT # experiment with DATA POINT #0 at 100 %LIGHT. (See Appendix A.)
11. Shield the Sensor from stray light.
12. Set the Analyzer Wheel at 10°.
13. Press **START** to record DATA POINT #1.
14. Increase the angle on the Analyzer Wheel by an additional 10°, shield the sensor from stray light, and press **START** again to record the next DATA POINT #.
15. Repeat step 14 until all ten DATA POINT #'s corresponding to angles between 10° and 100° have been recorded.

Note: *DATA POINT #0 is 0°, DATA POINT #1 is 10°, and so on. DATA POINT #10 is 100°. When the graph is complete, if the axis on the left of the screen should read %LIGHT. If it reads LOG (%LIGHT), press* **START** to display %LIGHT.

16. Press **ESC** or the red joystick button to go to the DISPLAY DATA menu.
17. Choose the SEE TABLE option by pressing the ↑ key or pushing the joystick up and copy the numbers for %LIGHT into Table 2.2-1 below.

Table 2.2-1. *%LIGHT as a Function of the Angle between the Polarizer and Analyzer Wheel axes.*

DATA PT. #	%LIGHT
1	97
2	88
3	75
4	59
5	41
6	25
7	11
8	3
9	0
10	3

18. Finally, transfer the numbers recorded in the table and plot it in the graph shown below.

Note: *Recall that because you calibrated the Light Sensor for 100 %LIGHT with the angle between the Polarizer and the Analyzer Wheel at 0 degees. You can place a %LIGHT of 100 on the DATA POINT #0 spot on the graph.*

Interpreting the Results of Angle Measurements

If your results are like ours, the %LIGHT stays fairly high until the angle increases to about 30° and then it begins to drop off more rapidly. The relationship between angle and %LIGHT was described mathematically by a French army engineer named Etienne Louis Malus who lived from 1775 to 1812. This relationship is known as the **Law of Malus**. The Law of Malus can be used to predict the %LIGHT for each of the degree settings on the Analyzer Wheel. The predictions are plotted on the graph below, and they follow a gentle curve which mathematicians call the cosine squared curve.

Note: *If you have BASIC for your computer, you can enter the program listed below to compute the predicted %LIGHT values using the Law of Malus.*

```
10 DEG
20 FOR A=0 TO 100 STEP 10
30 L=100*COS(A)*COS(A)
40 LIGHT=INT(L+.5)
50 PRINT "A=";A;
60 PRINT " LIGHT=";LIGHT
70 NEXT A
```

You should plot the results of your own measurements on the graph in Figure 2.2-6 also. Since the Polarizer and the Analyzer Wheel are not perfect and are not usually lined up exactly, your data points will not lie right on the predicted locations. However, your curve should have the same gentle shape as the predicted curve.

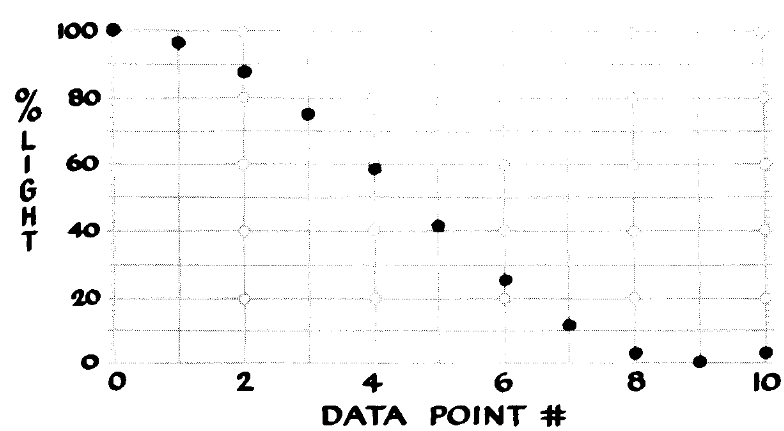


Figure 2.2-6. *Graph of %LIGHT vs. DATA POINT # representing %LIGHT as a function of the angle between the axis of polarization of a polarizer and an analyzer. The %LIGHT values predicted by the Law of Malus are plotted on the graph as black cicles.*

How do Polaroid Sunglasses Work?

You are now ready to think about why Polaroid sunglasses work so well to cut out glare. Wait for a sunny day and look through your upright Polarizer at some reflected light from the surface of water, a mirror, or a shiny car. Next, look at the same light with your Polarizer turned sideways. You should see the Polarizer cut out more of the reflected light when it is upright than when it is on its side. Polaroid sunglasses are special because they cut out reflected light effectively.

Let's develop a hypothesis based on this observation about reflected glare as follows:

Reflected light is at least partially polarized.

Testing the Hypothesis

To test this hypothesis, let's set the Light Assembly and Light Sensor at right angles to each other in the Light Stand. By sticking an ice cream stick covered with a piece of aluminum foil into the test tube hole in the Light Stand, you can reflect light into the Sensor. By placing the Analyzer Wheel in front of the Sensor, we can compare the light level at a 0° setting to that at a 90° setting on the Wheel. If the %LIGHT is significantly different in the two situations, the reflected light is at least partially polarized.

Setting Up and Taking the Measurement

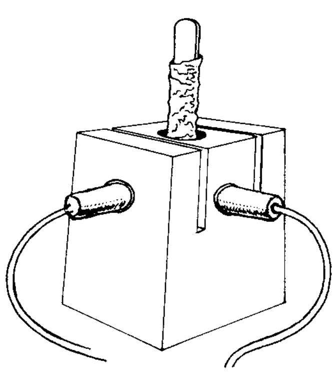


Figure 2.2-7. *Light Sensor and Light Assembly at right angles to each other with the foil wrapped ice cream stick and Analyzer Wheel in place.*

1. Set up the AtariLab Light Stand with the Light Sensor. (See Appendix A.)
2. Insert the Light Assembly in one of the side holes in the Light Stand so it is at an angle of 90° with the Light Sensor.
3. Wrap an ice cream or popsicle stick with a shiny flat piece of aluminum foil and place it in the test tube hole in a diagonal position.
4. Place the Analyzer Wheel in the filter slot next to the Light Sensor. Set the angle to 0°.
5. Choose the LIGHT METER option. (See Appendix A.)
6. Shield the Light Sensor and the Light Stand from stray light. (See Appendix A.)
7. Turn the ice cream stick slowly until you are sure reflected light from it is shining on the Light Sensor. If necessary, use some paper filters in the same slot with the Analyzer Wheel to reduce the %LIGHT reading to 100% or less.
8. Press **START** to record the LIGHT METER reading with the Analyzer Wheel set at 0°. Its axis of polarization is in the up and down direction.
9. Turn the Analyzer Wheel to 90° so the axis of polarization is from side to side or in the horizontal direction. Then press **START** to record the LIGHT METER reading again.

10. Is the relected light from the foil wrapped ice cream stick partially polarized?

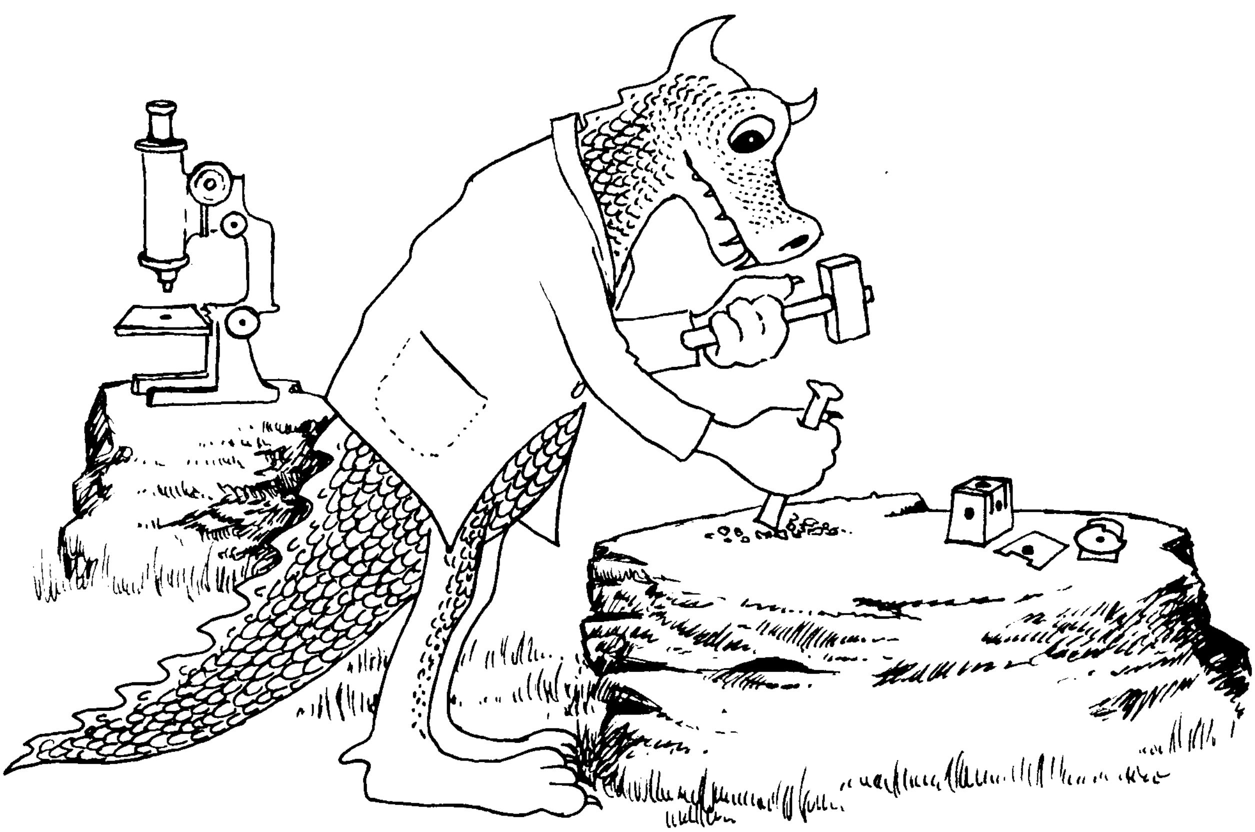
Your answer should be yes. This explains why polaroid sunglasses cut out reflected glare so well!

Some Other Uses for Polarized Light

If you place cellophane or certain clear plastics between the Polarizer and the Analyzer Wheel you can see colors. These colors will change if the material you are looking at is bent or stretched or if the Analyzer Wheel angle is changed.

Scientists can use a Polarizer and Analyzer to measure stress in materials or the thickness of materials. Geologists often look through microscopes at thin pieces of rock placed between two polaroid filters to identify minerals in the rock.

The study of polarized light is one of the best ways to learn about the nature of light itself as well as about other materials.



CHAPTER 2: Project Three
What Sugars Do to Polarized Light

The two noblest things, which are sweetness and light.
Jonathan Swift

In the last project, you learned about the axis of polarization. Some atoms and moclecules can change the axis of polarization of the photons that pass throught them. These materials are called **optically active.** In this project you will explore common sugar as an optically active material.

Purposes

- To measure the rotation of the axis of polarization of light passing through table sugar.
- To understand how measurements of the rotation of the axis of polarization of light can be used to identify materials or the concentration of a given material.

Equipment and Materials

An ATARI Laboratory Station with the AtariLab Light Module items
1/4 cup of table sugar
Hot tap water

Optically Active Materials

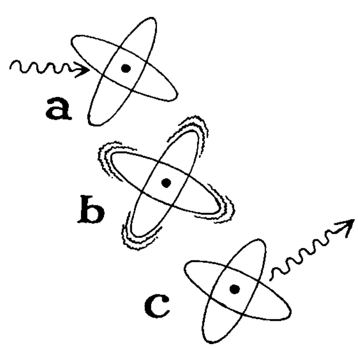


Figure 2.3–1. *An atom absorbing a light photon and emitting another one in a new direction a short time later.*

When light passes through materials, some of its photons are absorbed by the molecules and atoms that make up the material. The material then emits a new photon a short time later.

Some types of molecules can cause the axis of polarization of the light that passes by them to change slightly as the light is absorbed and given off again.

Materials that cause a change in the axis of polarization of light passing through them are called **optically active materials.**

When a beam of light passes through a material it has many encounters with the molecules and atoms in the material. Each encounter can cause a small rotation in the axis of polarization of photons near an atom or molecule. All these small rotations can add up to a rotation through an angle which is large enough to be measured using the AtariLab Light Module.

The final angle of rotation of the axis of polarization of a beam of light depends on two factors—the number of individual atoms or molecules the photons encounter in passing through the material, and how much the rotation in changed in each encounter.

Knowing the angle through which an optically active material rotates polarized light tells us something about the structure of the material. It can also reveal information about the concentration of the optically active material. This means that the study of angular rotation is a valuable tool for identifying substances and measuring how much of the optically active material is present.

Measuring the Angle of Rotation of an Optically Active Material

Ordinary table sugar (sucrose) is an optically active material when dissolved in water. You can see this if you dissolve table sugar in water and then pass polarized light through the mixture. Using the Analyzer Wheel, you can measure the angle that lets the smallest amount of light through. When you make the same measurement for water, taking the difference between the two angles will give you the angle of rotation.

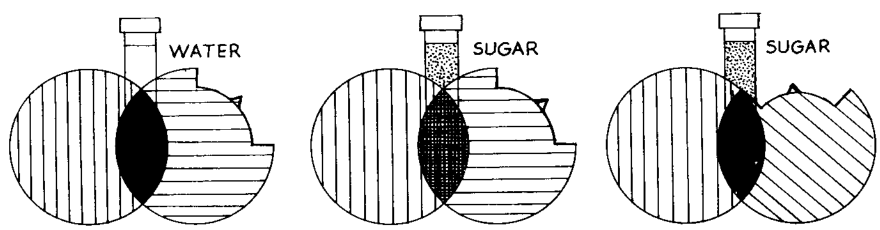


Figure 2.3–2. *Polarized light shining through water and through sugar dissolved in the water. The sugar rotates the axis of the polarized light passing through the test tube so the analyzer must be set at a new angle to screen out the polarized light.*

Setting up and Taking the Measurements

1. Set up the AtariLab Light Stand with the Light Sensor and Light Assembly. (See Appendix A.)
2. Place the Polarizer in the filter slot directly in front of the Light Assembly.
3. Place the Analyzer Wheel in the filter slot directly in front of the Light Sensor.
4. Set the Wheel at an angle of 0°.
5. Fill the test tube with plain water and place it in the hole in the top of the Light Stand.
6. Shield the Light Sensor from stray light. (See Appendix A.)
7. Calibrate the Light Sensor. (See Appendix A.) If necessary, place a few layers of white paper in the filter slot next to the Light Assembly until the message "GOOD LIGHT LEVEL" appears on the screen. Tape the filters firmly to the Stand.
8. Choose the LIGHT METER option.
9. Set the Analyzer Wheel pointer to 90°.

10. Slowly turn the pointer back and forth until the %LIGHT reading on the LIGHT METER is as small as possible.
11. Press **START** to record the %LIGHT. Write down the %LIGHT and the angle setting of the Analyzer Wheel below:

%LIGHT ______
Angle 1______degrees

12. Mix 1/4 cup of table sugar (2 oz.) with 1/2 cup (4 oz.) of hot tap water.

Warning: For safety, the water should not be too hot to touch.

13. Stir the sugar water mixture until the sugar dissolves.
14. Pour the plain water out of the test tube and fill it with the sugar water mixture.
15. Place the test tube with the sugar water mixture in the top hole in the Light Stand.

Note: *To obtain reliable results, a freshly made sugar solution should always be used.*

16. Repeat steps 6–11 above and enter the values you measure for %LIGHT and Analyzer Wheel angle below:

%LIGHT ______
Angle 2______degrees

The angle of rotation is the difference between the angle setting of the Analyzer Wheel when the sugar solution is in the test tube and the angle when the plain water is in the test tube. You subtract Angle 1 from Angle 2 to find the angle of rotation. Record the Angle of rotation below:

Angle of Rotation = Angle 2 - Angle 1 = ______degrees

More About Optical Activity

You should have found that the angle of rotation for the sugar solution is not 0° but about 5° or 6°. Because there is an angle of rotation, you can conclude that ordinary table sugar is optically active. This optical activity is caused by the three-dimensional structure of the sucrose molecules which make up table sugar. The polarized light that is absorbed and given off by these molecules is rotated.

The structure of optically active solids, as well as the shape and concentration of molecules found in optically active liquids, can be explored by measuring angles of rotation. For example, the molecules found in optically active liquids have helical or corkscrew shapes. Materials that are optically active include minerals such as quartz crystals, mica, and most types of sugars including sucrose, glucose, dextrose, and fructose.

The final angle of rotation is the sum of many small angles of rotation. It also depends on the concentration of molecules in a liquid or the thickness of a solid such as quartz or mica.

Since scientists have recorded the angles of rotation for thousands of chemical compounds, measurements of the angle of rotation can be used to help identify unknown compounds. Angle of rotation measurements can also be used to determine the concentration or relative number of optically active molecules in a solution.

Suggestions for Other Optical Activity Experiments

Using Solutions with Different Concentrations of Optically Active Molecules

The amount of rotation of the polarization when light passes through a test tube full of a liquid should depend on the number of optically active molecules in the liquid. If this hypothesis is true, then mixing 1/2 of a test tube of water with 1/2 of a test tube full of the sugar solution you used earlier should give about half the angle of rotation that you measured earlier. Try it!

The Optical Activity of Other Sugars

The angle of rotation can also be measured for other sugars. Fructose is available in powdered and liquid form. You can mix it with water in the same way you mixed the table sugar with water. Light corn syrup, which is availiable at supermarkets, can also be tested. How about using honey, which is a complex mixture of different sugars?

Does the Optical Activity of Sugar Change With Time?

Another interesting project is to measure the angle of rotation of your sugar solution every few hours after it has been made up. Scientists believe that as a sugar solution gets older, the sugar molecules start combining with water molecules to become less optically active.

What Other Substances are Optically Active?

You might develop a hypothesis that all white crystals that dissolve in water are optically active. Why not substitute salt for sugar and repeat all the proceedures recommended in this project? Does the hypothesis hold? Does salt have a measureable angle of rotation? How about measuring the optical activity of some of the sugar substitutes?

CHAPTER 2: Project Four
Reflections from Milk— or Why is the Sky Blue?

Blue skies smiling at me, nothing but blue skies do I see...
Irving Berlin
To a land where the sky is as red as the grass. And the sun as green as the rain.
Sir John Squire

The sky is blue in the daytime. The sun appears to be red when it rises and sets. Why? Since the sky is black and has no sun at night, you might suspect that both the blue light in the sky and the red light from the low sun came originally from the sun. If sunlight usually appears to be white when we see it why, then, does the sky appear red and blue at times?

The light from the sun is being bounced off air molecules as well as fine dust particles found in the earth's atmosphere. When light bounces off particles, it changes direction. This process of light changing direction as it bounces is called **scattering.**

In this project we will develop two hypotheses which, if they work, can help explain why the sky is blue and sunsets are red. These hypotheses are based on guesses about how light might be scattered from small particles, and can be tested with the AtariLab Light Module.

Purposes

- To learn more about how light is scattered from small particles of matter.
- To see how the scattering of light explains the colors observed in the sky.

Equipment and Materials

An ATARI Laboratory Station with the AtariLab Light Module items
An Experiment Box or a dark room
An eyedropper
A few drops of milk

Why is the Sky Bright on a Sunny Day?

Developing a Hypothesis

Since the sky becomes dark every night shortly after the sun sets, we might guess that the bright sky consists of photons of light which come from the sun.

The atmosphere contains tiny particles of dust and many different air molecules—nitrogen, oxygen, water vapor, argon, carbon dioxide and other gases. These particles in the atmosphere are small compared to the wavelengths of light photons. For the purpose of this project, "small" means that a particle has a diameter that is smaller than a wavelength of light.

Small particles found in the atmosphere scatter photons in all directions. So, photons from the sun can approach the earth from any direction.

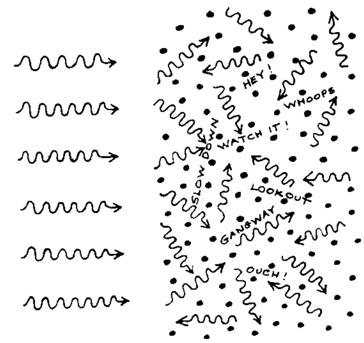


Figure 2.4–1. *Photons scattering in many directions after bouncing off of small particles.*

We can say this in the form of a general hypothesis:

> *Small particles such as molecules or tiny dust particles can scatter light.*

The next step is to figure out how to use the AtariLab Light Module to test this hypothesis.

Testing the Hypothesis that Small Particles Scatter Light

To test the hypothesis using the AtariLab Light Module, we need a source of relatively small particles. You can measure scattered light in two situations. First, you can measure the amount of light scattered into your Light Sensor by a test tube full of clear water. Second, you can add a drop of milk to the water in the test tube and measure the scattered light again.

Milk particles are small compared to the wavelengths of light, and we should expect interesting results from the milk and water mixture.

Setting up and Taking the Measurements

1. Set up the ATARI Laboratory Station. (See Appendix A.)
2. Set up the AtariLab Light Stand with the Light Sensor and Light Assembly. (See Appendix A.)
3. Shield the Light Sensor and Light Stand from stray light. (See Appendix A.)

Note: *Stray light can throw off the results of this observation. Be especially careful to block it out.*

4. Fill the test tube with plain water and place it in the hole in the top of the Light Stand.
5. Calibrate the Light Sensor. (See Appendix A.) If necessary,

add pieces of white paper to the filter slot in front of the Light Assembly until the message "GOOD LIGHT LEVEL" is displayed on the screen. Tape the paper filters to the Light Stand before pressing **START** to calibrate.

6. Choose the LIGHT METER option and Record %LIGHT. (See Appendix A.) If the %LIGHT reading is not 100% repeat step 5.
7. Place the Light Sensor in one of the side holes so it makes a right angle with the Light Assembly.

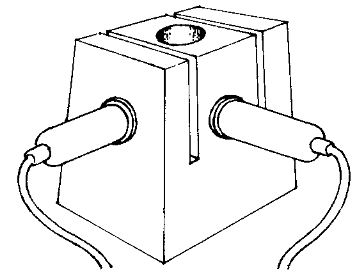


Figure 2.4–2. *The Light Stand with the Light Assembly and the Light Sensor at right angles to each other.*

8. Choose the LIGHT METER option and Record %LIGHT (See Appendix A) by pressing **START**. Enter the light level reading below:

   %LIGHT scattered into the Light Sensor from water in a test tube ______.

Next, the measurement can be repeated with the light being scattered through a mixture of water and a small amount of milk.

9. Add one drop of milk to the water in the test tube. Place the lid on the test tube and shake it gently to mix the milk in with the water.
10. Insert the test tube in the hole in the top of the Light Stand.
12. Repeat steps 5–8 above and enter the scattered light level reading below:

    %LIGHT scattered into the Light Sensor from water and milk in a test tube ______.

Conclusions

You should have observed that much more light scatters into the Light Sensor when milk particles are suspended in the water. This result agrees with our hypothesis that small particles, such as those of milk, nitrogen and oxygen molecules, or fine dust particles could scatter a large amount of light.

In the experiment you just did, many particles of milk were concentrated in a small space. The concentration of particles in the atmosphere is much smaller. But the atmosphere is several miles thick, and the photons from the sun will eventually pass by many of the particles in the atmosphere. Although we cannot be sure without more evidence, it is possible that the bright daytime sky is the result of sunlight scattering from small particles in the atmosphere.

Why is the Sky Blue?

The results of the experiment you just did can be used to help explain why the sky is so bright in the daytime. But, why isn't the sky white like the sun instead of pale blue?

Let's develop another hypothesis about the colors we see in the sky. In order to develop this hypothesis, we need to discuss the nature of the photons from the sun.

White light from the sun is actually a mixture of photons of many different colors or wavelengths. The white light from the sun was first separated in the seventeenth century by Isaac Newton, one of the greatest scientists who ever lived. Newton used a wedge-shaped piece of glass called a prism to separate the white light into its component colors.

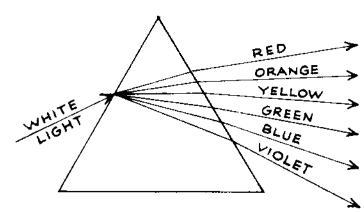


Figure 2.4–3. *A prism separating a beam of light into different colors.*

Since sunlight consists of many different colors, one possible explanation for the blue color of the sky is that blue light scatters more than other light when it encounters small particles. Let's develop a general hypothesis that states what we've just discussed:

> *When a beam of light encounters small particles the photons with shorter wavelengths (purple or blue light) scatter more than those of longer wavelengths (orange or red light).*

If this hypothesis works, we might expect the sky to be purple. However, the human eye and the AtariLab Light Sensor cannot detect purple light very well. Let's test the hypothesis and see if we can use it to explain why the sky is blue.

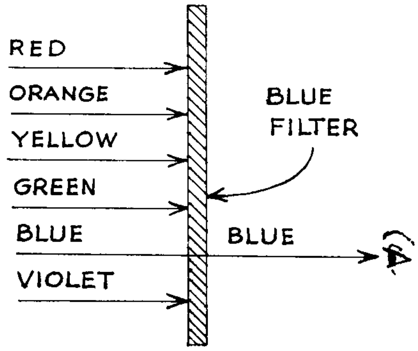


Figure 2.4–4. *Drawing showing a color filter that eliminates all colors of light except one.*

Testing the Hypothesis

We could test this hypothesis by using the AtariLab Light Module to record how much blue light is scattered by a test tube containing milk and water and then recording how much red light is scattered in passing through the same mixture.

The easiest way to obtain red and blue light is to use filters in front of the Light Assembly. A filter of a certain color will absorb all other colors. Blue and red filters have been included in the AtariLab Light Module. When the blue filter is placed in front of the Light Assembly all the light except the blue light is absorbed by the filter. If the red filter is used, all the light except the red light is absorbed by the filter.

By using a colored filter in the Light Stand, we can compare the amount of scattered light to the amount of light transmitted through the mixture of water and milk.

Making the Observation

1. Using the water and milk mixture in the test tube, set up the Light Stand with the Light Assembly and the Light Sensor.
2. Place the blue filter in the filter slot next to the Light Assembly.
3. Repeat steps 5–8 in the section "Why the Sky is Bright on a Sunny Day."
4. Record the light level below:

   %LIGHT scattered into the Light Sensor from a test tube of water and milk (blue light) ______.

5. Remove the blue filter and place the red filter in the filter slot in front of the Light Assembly.
6. Now repeat steps 5–8 in the section "Why the Sky is Bright on a Sunny Day."
7. Record the light level below:

   %LIGHT scattered into the Light Sensor from a test tube of water and milk (red light) ______.

8. Summarize all the results you have recorded in this project in Table 2.4–1 below.

Table 2.4–1. *Summary of %LIGHT Scattered from Water and Milk*

Material	*Light Color*	*%LIGHT*
Water	White	______
Water/Milk	White	______
Water/Milk	Blue	______
Water/Milk	Red	______

Conclusions about Scattering Colored Light

Why the Sky is Blue—One More Explanation

You should have observed that relatively more blue light scattered than red light. This agrees with our second hypothesis that blue light will scatter more than red light from small particles like those in milk or fine dust in the atmosphere.

Some of the red light was scattered, and then, when the white light from the sun is scattered, all of the different colors of light come into our eyes—a bit of red, more yellow and green and even more blue and purple. By the time we take into account the fact that our eyes don't see purple very well, the sky appears light blue from the mixture of colors our eyes *can* see.

Why Sunsets are Red

Your results should also allow you to explain why sunrises and sunsets are red. When the sun is low in the sky it's light passes through much more of the Earth's atmosphere than when it is high in the sky. Most of the purple, blue and green light are scattered out of the suns direct rays when the sun is low. This leaves the yellow, orange, and red light in the rays. That is why the sun appears red at sunrise and sunset or when a person views the sun during a dust storm or when smoke from a fire fills the air.. It is always fascinating to watch the sun gradually turn yellow, orange, and then red as it rises or sets.

A Final Word

We would have to do many more experiments to be convinced that only dust particles in the atmosphere cause scattering or the color effects we have just analyzed. There are many different kinds of molecules in the atmosphere, including some not common in your laboratory, such as a special form of oxygen called ozone. We can't trap enough of these particles in the AtariLab test tube to observe any scattered light from them. We are not able to determine whether any types of air molecules contribute to the scattering of sunlight. This is a topic for another investigation that cannot be done easily using the AtariLab Light Module.

CHAPTER 3
Using Light as a Tool to Learn about Other Things

We often discover what will do, by finding out what will not do, and probably he who never made a mistake will never make a discovery.
Samuel Smiles

Introduction

One of the most exciting aspects of making scientific observations is that they can be applied in almost every situation. What we discover about how matter behaves in distant galaxies applies equally well to matter in our own backyards. The observation of light from the planets, stars, and distant galaxies is the most most common method of learning about the universe.

Although the AtariLab Light Sensor is not sensitive enough to study distant stars and planets, it can be pointed towards the heavens for the study of energy from the sun, reflected light from the moon, and solar eclipses.

The light photons that carry information to us from the vast regions of outer space have the same properties as photons we use in our own laboratories here on Earth to learn about the natural world close to home. We can use light in different ways to tell us about the world in which we live. The light created by fireflies or by phosphorescent chemicals carries messages to us about chemical reactions. The light transmitted through a test tube full of backyard dirt can tell us about the size and shape of the dirt particles. If the test tube contains living yeast cells, measuring changes in the level of light passing through a test tube containing sugar, water and yeast can tell us about the growth patterns of the yeast cells.

The projects suggested in this chapter represent a few of the hundreds, perhaps thousands, of projects that you can do with the AtariLab Light Module as you begin to explore your immediate surroundings and then our solar system.

About Doing the Projects in This Chapter

When a scientist embarks on a new project, there are no specific instructions on how to proceed. Often many hours are spent perfecting a measuring technique, reading articles about the research of others, or figuring out why an unexpected result is obtained. Scientists are frustrated at times, but there is nothing more exciting to a reseach scientist than finally achieving new understanding, or, even better, making a significant new discovery about the natural world.

Taking accurate measurements, and then making new discoveries based on laboratory observations usually require what many scientists call **fiddling**. Fiddling is what young children do quite naturally when they play: It is doing something over and over again in different ways.

In Chapters 1 and 2, you were given specific instructions on how to do the observations and experiments. In this chapter, you are the scientist. Using all that you have learned about doing science with the AtariLab Starter Set and now the Light Module, you can make up some of your own procedures, and do your own observations and experiments after being presented with a problem. You can see what fiddling means by reading about some observations we made with the AtariLab Light Module in our laboratory.

Fiddling to Catch Moonbeams

Scientific discovery always begins with a question. Ours was: How much moonlight is absorbed by the Earth's atmosphere as a full moon moves through the sky on a clear night?

To begin our project, we had to find a window facing south with no trees or other obstructions in front of it. Then we had to wait for one of the few nights each month when the moon was full so we could capture as much moonlight as possible. Next, the night had to be clear. Finally, we had to wait until the moon was far enough above the horizon to avoid stray light from the town of Carlisle. Since the Moon rises an hour later every night, we found ourselves staying up later and later to do our fiddling.

The reflected sunlight bouncing off the Moon seems bright to our eyes. The pupil of the human eye opens up in dim light so the eye can gather more light. The AtariLab Light Sensor has no pupil, and we found that it could just barely respond to moonlight.

As we tried to gather more moonlight, we began fiddling in earnest. We made "reflecting telescope mirrors" by lining kitchen bowls with aluminum foil; we taped the Sensor to the bottom of a white toilet paper roll; we tried poking the Sensor through the bottom of a styrofoam coffee cup; and, finally, we focused the light from the Moon on the Light Sensor with a small magnifying glass. The styrofoam cup and the magnifying glass show the most promise, but our fiddling is not over. Some month in the middle of the night, we hope to experience the joy of making measurements of light transmission through the Earth's atmosphere with a homemade AtariLab "Telescope."

More about Fiddling

Intelligent fiddling and problem-solving is one of the hallmarks of experimental science. Several of the projects that follow will test your ingenuity. With your understanding of the behavior of light and the skill you have already developed in using the Light Module equipment, you should enjoy working on any one of the projects in this chapter that catch your fancy.

CHAPTER 3: Project One

How Big Are the Dirt Particles in Your Yard?

Dirt from your yard probably consists mainly of small chunks of various minerals chipped away from larger rocks by natural processes. Other debris is usually mixed in with the mineral grains. It is not unusual to find pollen, dead insect parts, traces of salt, decaying plant matter, and other debris in a sample of dirt.

If you drop a pinch of dirt into a tall glass of water, the minerals will fall to the bottom, while the salt and other substances will dissolve, some of the pollen and lighter debris should float to the top. The rate at which each mineral grain falls should depend on its size, shape and density. The AtariLab Light Module can be used to record how fast the the mineral particles are falling.

Equipment and Materials

An ATARI Laboratory Station with the AtariLab Light Module items
Samples of dirt or sand
Water
Oil
Syrup
Liquid detergent

Recording the "Fingerprint" of a Dirt Sample

Geologists have used light to measure the average rates of fall of particles in soil samples. This information provides a convenient way to learn more about the size, shape and density of particles in soil samples.

You can use the AtariLab Light Module to record a graph which measures the increase in light from light level readings as falling dirt particles pass by the Light Sensor. The resulting graph is usually a curve which, for convenience, we will call a **Settling Curve**. This settling curve provides us with a "fingerprint" of the soil sample. The shape of the settling curve depends on the mixture of sizes, shapes, and densities of mineral particles in the sample. Just as no two fingerprints are exactly alike, soil samples are very specific to the area from which they are taken.

The average rate of fall of particles in the sample can be related to the time it takes the light level on the settling curve to increase to 50 %LIGHT. If the dirt sample contains small, slowly-falling particles, the time taken for the light level transmitted through the test tube to reach 50 %LIGHT will be long. On the other hand, if a dirt sample contains large, rapidly-falling particles, the time taken for the light level to reach 50 %LIGHT will be short.

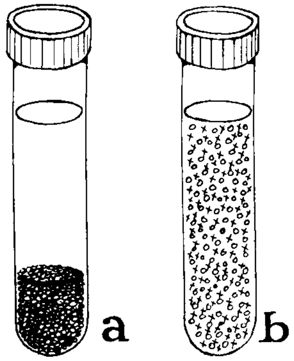


Figure 3.1-1. *(a)The dirt particles are settled on the bottom of the test tube before calibration takes place.*
(b)Water, detergent, and dirt all mixed together before starting graphing proceedures.

When you add dirt or fine sand to a test tube full of water, you should use a drop of liquid detergent to keep small particles from clumping together as they fall. The dirt should settle on the bottom of the test tube before you put the test tube in the Light Stand between the Light Sensor and Light Assembly for calibration.

After calibration, shake the test tube and quickly place it in the Light Stand as you start a %LIGHT vs. TIME graph. Obviously, as the dirt settles, the transmission of light through the test tube increases (Figure 3.1-1).

Choosing the best total time for your graph depends on the dirt sample. The 10-second time might work well for a sample of fine sand. On the other hand, the very tiny particles in a sample of red clay-like soil can take 20 minutes or more to settle completely.

You can have a lot of fun determining settling curves for dirt samples collected from various places.

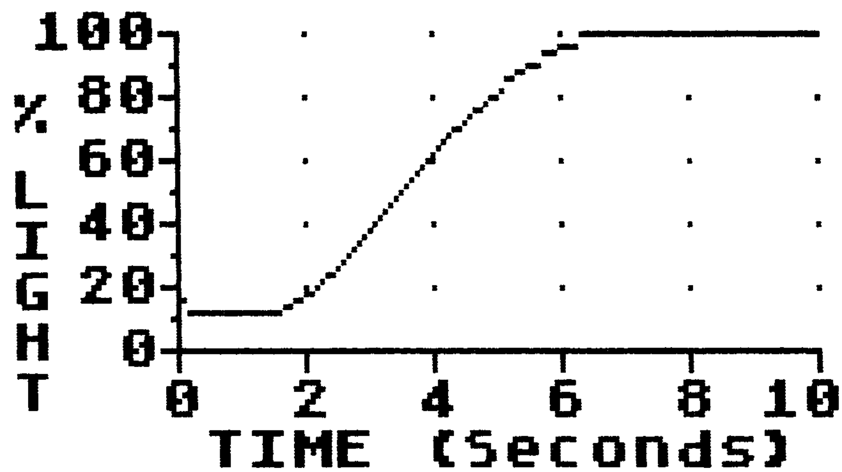


Figure 3.2-3. *Settling curve for sample of fine sand collected on Assateague Island in Maryland.*

Suggestions for Other Projects

1. Look at the size and shape of various dry dirt samples under a microscope. Sand particles, when viewed under a microscope, are needle-shaped rather than round. Study how particle shape and size effect the average rise time of the settling curve and its shape.
2. Use different liquids such as alcohol, light corn syrup, or salad oil instead of water. The density and viscosity of these and other commom materials can be found in *The Handbook of Physics and Chemistry* available in the reference sections of most libraries. You can study the effects of density and viscosity of the liquid in the test tube on the fall time of the particles in your sample.
3. Study samples of soil taken at various depths in a hole that you dig. Do the rise times or shapes of the settling curves change as you dig deeper?

CHAPTER 3: Project Two
Things that Glow

The Glow Panel and Light Stick included in the Light Module as well as fireflies have a common characteristic—they are luminescent. Matter of any type that can absorb energy and then re-emit it in the form of visible light is **luminescent.** In this project you can study the way in which the Glow Panel, the AtariLab Light Stick, and fireflies give off light as time passes. The processes by which each of these materials gives off light is somewhat different. An exploration of the differences and similarities of these luminescent materials is fascinating.

Equipment and Materials

An ATARI Laboratory Station with the AtariLab Light Module items
The Glow Panel
The AtariLab Light Stick
Three styrofoam cups
Ice
Hot tap water
Room-temperature water

OPTIONAL
A dozen fireflies (if available)
A large styrofoam cup with a lid
A sheet of aluminum foil

The Glow Panel

The Glow Panel is a special type of luminescent material that absorbs visible and ultraviolet light. Ultraviolet light has wavelengths that are shorter than those associated with violet light. It cannot be seen.

The Glow Panel is special because the ultraviolet and visible light energy that it absorbs are captured by its chemicals and given off slowly in an after-glow. Luminescent materials that have an after-glow are **phosphorescent.**

When certain molecules in the Glow Panel absorb light they gain energy and become excited. When an excited molecule gives off its extra energy, it undergoes **decay.**

If you place the Glow Panel directly under an ordinary light bulb or a fluorescent lamp for about ten seconds and then cup it in your hands and peek at it, you will see a beautiful glow as the excited molecules decay. Although this bright glow fades within a second or two, if you put the Panel into a dark closet, you can observe a dimmer after-glow for hours afterwards.

A Simple Observation Using the Glow Panel

You can observe the changes in light level when you place the Light Sensor directly in front of a light-activated Glow Panel.

This observation should be made in a dark room or an Experiment Box.

This observation takes practice, and you should be prepared to fiddle a bit before getting good results. To make this observation, you can:

1. Place the Light Sensor in the Light Stand directly behind a filter slot.
2. Prepare to Calibrate the Sensor.
3. Activate the Glow Panel by placing it in sunlight or about an inch away from a light bulb for 10 seconds or more.
4. Quickly place the Glow Panel in the filter slot directly in front of the Light Sensor. Be sure it is facing the Light Sensor.
5. Immediately calibrate the Sensor to the light of the Glow Panel.
6. After the Sensor is calibrated, set up a one-minute long %LIGHT vs. TIME experiment.
7. Re-activate the Glow Panel by placing it near the source of light for 10 seconds or so.
8. Place the Panel in the filter slot, eliminate stray light, and begin the experiment in about the same time it took you put the Panel in place to calibrate the Light Sensor.
9. If things don't go too smoothly, try again. You can activate the Glow Panel over and over again.

Studying the Results of the Simple Observation

If you master the procedures outlined above and record a good graph, you will see %LIGHT values that fall off very rapidly and then more slowly as time passes. The curve you see is known as a **decay curve**.

Compare the shape of the curve to the apparent decrease in brightness that you see if you look at the Glow Panel in a dark room. The graph and your own perception of the brightness should be similar at first, but once your eyes adapt to the dark, they can see light from the Glow Panel long after the computer has recorded a minimum light level from the Light Sensor.

Observing the Rapid Fading of Light from the Glow Panel

The Glow Panel is known to be made of two different chemicals. One that gives off its light energy rapidly and one that gives it off more slowly. At first, almost all of the light given off comes from the molecules of the chemical that give off light rapidly. This corresponds to the very bright light that you see for the first few seconds. You can observe this rapidly-fading light by repeating the steps outlined above and using a total time of 2 or 4 seconds.

Note: *This observation takes a lot of fiddling to do well. You must transfer the activated Glow Panel to the Light Stand for calibration and, also, start the experiment in the shortest possible time.*

The shape of the rapid decay curve you should see on your graph can be explained by describing the decay of the collection of excited molecules in the Glow Panel more carefully.

Exponential Decay—What Is It?

When the Glow Panel is exposed to light, a whole collection of molecules are excited. Some of these molecules start decaying by giving off photons immediately while others wait. The rate at which the photons are given off is proportional to the number of excited molecules in the collection. Twice as many excited molecules give off light at twice the rate.

As time goes by, some of these excited molecules have decayed already. There are fewer excited molecules in the collection and they in turn give off photons at a slower rate.

If half of the excited molecules decay in one second, then half of the remaining half—or one quarter—should decay in the next second and so on. The curve that results from this type of decay is an **exponential decay curve**. The time for half of the excited molecules to decay is known as the **half-life**. A one-second half-life exponential decay curve is shown in Figure 3.2-1 below.

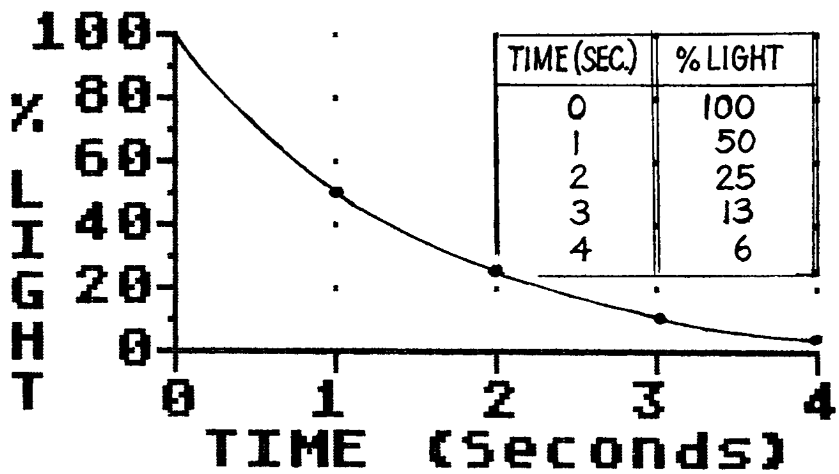
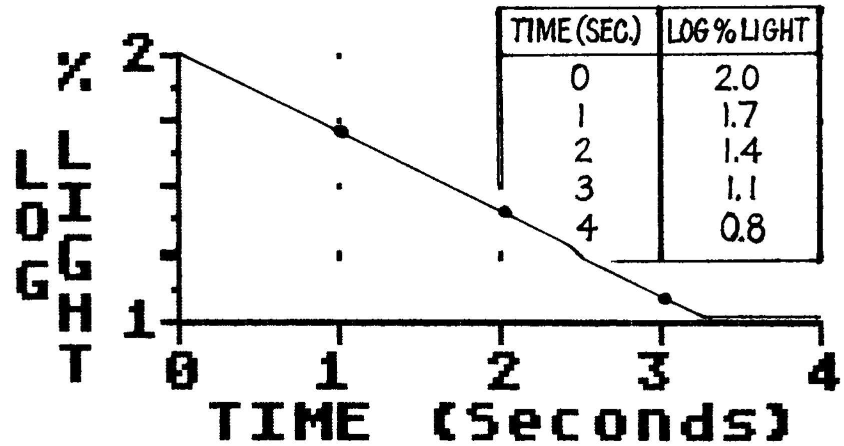


Figure 3.2-1. *%LIGHT vs. TIME graph representing an exponential decay with a half-life of one second.*

By changing all the %LIGHT numbers in a special way we can obtain a quantity called LOG %LIGHT. If a decay process is exponential, the data points on a graph of LOG %LIGHT vs. TIME should lie along a straight line. The LOG %LIGHT vs. TIME graph of the exponential decay curve shown above is shown in Figure 3.2-2 below. Whenever you see a LOG %LIGHT vs. TIME curve that is a straight line, you know that you are observing some type of exponential decay process.



Is the Glow Panel Decay Exponential?

Let's examine the %LIGHT vs. TIME graph you just obtained for the rapidly-fading chemical in the Glow Panel. How much time did it take for the %LIGHT to decrease from 100 to 50? This time is, of course, the half-life of the rapidly decaying molecules in the Glow Panel.

Observing the Dim Glow on the Glow Panel

After about 10 seconds, almost all of the molecules in the rapidly-fading part of the material have given off their photons. The other material which has a much longer half-life now gives off almost all of the photons.

To observe the decay of brightness from the slowly-fading material, you should repeat the %LIGHT vs. TIME observation by choosing a 2-minute graph and waiting exactly 10 seconds after the light shining on the Glow Panel has been turned off to begin calibration and the experiment.

The curve you record from this observation should correspond to light given off almost entirely by the slowly decaying chemical. How much time did it take for the %LIGHT to decrease from 100 to 50? What is the half-life of this second chemical?

The AtariLab Light Stick

Like the materials in the Glow Panel, when the chemicals in the AtariLab Light Stick mix together, they are also luminescent. However, instead of the molecules in the Light Stick being activated by light, they are activated by a chemical reaction. The Light Stick has a special luminescence called **chemiluminescence**.

The AtariLab Light Stick consists of a plastic tube containing two special mixtures of chemicals. The first mixture is in a flexible plastic tube. The second mixture is in a smaller glass tube or ampule that floats in the first mixture. You can take off the moisture-proof foil wrapper that protects the Light Stick and see the glass ampule floating in the mixture inside the plastic tube. Be careful not to bend the tube yet!

When the flexible plastic tube is bent, the glass ampule breaks and the two chemical mixtures react. As the reaction begins, yellow-green light similar in wavelength to that given off by the Glow Panel is given of by the Light Stick.

Each excited molecule produced by the chemical reaction gives off its photon immediately after the reaction takes place. When a luminescent material gives light off instantly, it is **fluorescent.**

Observations with the AtariLab Light Stick

Because the decay process is fluorescent and the photons come off immediately, the rate at which the Light Stick gives off light depends entirely on the rate at which the chemical reaction takes place between the mixture in the plastic tube and the mixture in the glass ampule.

As soon as you bend your Light Stick, molecules in the two mixtures begin reacting. Instead of reacting all at once, the molecules react with each other slowly. The rate of the reaction depends upon the time it takes for all of the molecules to react with each other. Since temperature also affects the rate at which chemical reactions occur, the temperature of the Light Stick will also affect the rate of the reaction

Although you only have one Light Stick, you can study how temperature affects the reaction by dipping the Light Stick in ice water and hot tap water and observing the differences in brightness while you do this. Then, use the Light Module to create a graph describing the changes in temperature and light level from the Light Stick.

We recommend that before you bend your Light Stick to start a reaction, you set up the ATARI Laboratory Station to measure temperature and light level and calibrate the Light Sensor. Then you should prepare three styrofoam cups. The steps are outlined below:

1. Set up the ATARI Laboratory Station with the Light Sensor in the right (orange) paddle input and the Temperature Sensor in the left (blue) paddle input of the Interface.
2. Place the Light Sensor in the Light Stand and place the Light Stand in a dark room or an Experiment Box.
3. Choose a total time of two hours.
4. Be prepared to start calibrating the Light Sensor.
5. Fill the first cup with hot tap water.
6. Fill the second cup with ice water.
7. Fill the third cup with water at room temperature.
8. Now, bend the Light Stick until you hear it crack, breaking the glass ampule and starting the chemical reaction.

Temperature and Reaction Rate

Shake the Light Stick and put it in the hot water for a few minutes. Observe its color and brightness. Next, place the Light Stick in the ice water for a few minutes, and observe its color and brightness again. It should be much dimmer in the cold water.

Note: *If you put a Light Stick in the freezer, it will stop giving off light. When you take it out of the freezer, it will begin glowing again.*

Changes in Light Level

Since the light level from the Light Stick depends on temperature, you should monitor both temperature and light level in this experiment. The results of the observation will be easier to interpret if the temperature of the Light Stick is kept constant. The Light Stick should be in the room-temperature water for at least 5 minutes before the observation begins.

You should set up a two-hour graph using the Light Module Cartridge. Place the Light Stick in the test tube, then place the test tube in the top hole of the Light Stand. Next, the Light Sensor should be shielded from stray light and calibrated. Finally, you should monitor the temperature and light level for two hours.

Interpreting the Results

The graph that you recorded, like that for the light level from the Glow Panel, should give you an exponential decay curve. The reason for this exponential decay curve is very different from the first one you recorded.

This Light Stick decay curve is exponential because the rate at which the chemical that gives off the light photons is created depends on the number of molecules left in the original chemical mixtures that have not yet reacted. As more and more of the reactions take place, there are fewer molecules left to react. The light output of the Light Stick decreases as time passes.

Is the LOG %LIGHT graph a straight line? Do your observations agree with the prediction that the decay is exponential? Is the LOG %LIGHT graph a straight line? What is the half-life of the chemical reaction in the Light Stick at room temperature?

If you had more AtariLab Light Sticks you could study how the half-life of the reaction in the Light Stick depends on temperature. You can get more Light Sticks by buying a larger "fun size" CYALUME® Light Stick available in toy and hobby stores.

Learning More About Light Sticks

The manufacturer of the AtariLab Light Stick publishes a pamphlet on CYALUME® Light Sticks that describe the chemical reactions which take place. This pamphlet can be obtained by writing to:

American Cyanamid Company
Chemical Light Department
Bound Brook, NJ 08805

Fireflies

Fireflies, like the Light Stick, get light energy for their glow from a chemical reaction. Since the firefly is living, scientists refer to the firefly as being **bioluminescent**.

The firefly uses oxygen in its light-producing reaction. As it breathes, the firefly can control its output of light by opening a duct that allows oxygen to flow from its head to its tail section.

Each species of firefly sends out a pattern of light by turning its glowing tail section on and off. Biologists have observed that male fireflies give off a special pattern of light as they fly over grass. A female of the same species hiding in the grass can echo that pattern. This allows members of the same species to identify each other and mate.

Observing Patterns in Firefly Light

If it is summer and you are lucky enough to live near fireflies, you can observe the pattern of firefly light directly. Dusk is the best time to observe. Follow a firefly around and watch its glow. How long is each flash of it's tail light? About how much time is there between each glow? What color is the light? Is there any pattern to the sequence of glows?

Observing Patterns in Firefly Light with the AtariLab Light Module

If you are careful and quick, you can catch about a dozen fireflies in a styrofoam cup at dusk on a night when there are many fireflies.

Put a piece of aluminum foil around the top and sides of the cup. Punch some small holes in the foil that covers the top of the cup. Fireflies need lots of oxygen. Next, punch a hole in the bottom of the cup and put the AtariLab Light Sensor through it.

Try monitoring the patterns of light from the group of fireflies by recording how much light they give off. You can use a 30-second or one-minute %LIGHT vs. TIME graph.

If the fireflies don't seem willing to glow much in the cup, you might try creating a pattern of light with a flashlight that may stimulate the fireflies in the cup to glow.

CHAPTER 3: Project Three

Baking Yeast— How Fast Does It Grow?

Yeasts are simple one-celled plants classified as fungi because they cannot produce their own food.

When a yeast cell is placed in a warm, moist environment in the presence of sugar or starch, it can multiply and grow. Glucose, the sugar present in corn syrup, is the principal food for the type of yeast used in baking. Although baking yeast can break down other foods into glucose, the yeast takes longer to grow in the presence of foods that are not pure glucose.

As yeast cells consume glucose and multiply, they give off alcohol and carbon dioxide gas. The holes in bread dough are formed as the bubbles of carbon dioxide produced by baking yeast expand. This makes the bread rise and gives it a light texture.

When yeast cells lack the moisture, food or warmth they need to grow properly, the yeast stops working and forms small round seeds called spores. This form of baking yeast can be acquired easily in a supermarket as dry granules or in small cakes. In this project you can prepare some sugar water in a jar, add baking yeast to the sugar water, and observe how it grows using the AtariLab Light Module.

Equipment and Materials

An ATARI Laboratory Station with the AtariLab Light Module items
A dark room
A lamp with a 50-watt bulb
Several books
Tape
A measuring cup
Measuring spoons
2 small glass jars
A clock, watch, or timer
A 1/4 oz. package of active dry yeast
Water
Table sugar

OPTIONAL:
Other sugars and starches (corn syrup, fructose, honey)
Salt
Cornstarch
Flour

Observing the Growth Rate of Yeast

The growth rate of yeast increases with temperature. You should, if possible place a jar with the yeast and sugar water solution directly under a warm reading lamp during the time between observations.

You can measure the light transmission through a jar containing yeast, sugar, and water using the Light Module. As the yeast cells multiply they block some of the light passing between the Light Assembly and the Light Sensor.

Studying yeast growth takes time, and you should allow an hour or more to make your observations.

Preparing the Yeast and Sugar Solutions

1. Prepare a stock yeast solution by mixing a 1/2 cup of room-temperature water with a half a 1/4 oz. package of dry yeast in a small jar.
2. Prepare a stock sugar water solution in a small jar by mixing 3/4 cup of room-temperature water with 1 teaspoon of table sugar.

Setting Up the Equipment

1. Work in a room that you can darken.
2. Set up the ATARI Laboratory Station with the Light Sensor in the right (orange) paddle input and the Temperature Sensor in the left (blue) paddle input of the Interface.
3. Tape the Light Sensor and Light Assembly opposite each other on two stacks of books with the jar in between.

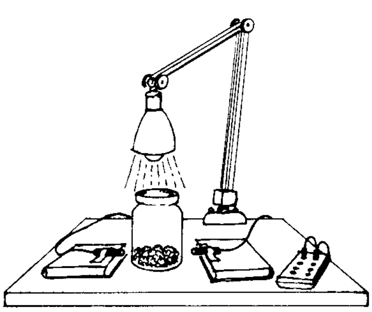


Figure 3.3-1. *Set-up for measuring the growth of yeast.*

Doing the Experiment

1. Place the Temperature Sensor in the jar of sugar water and place the jar under the lamp.
2. Choose the %LIGHT vs. DATA POINT # graph. Turn on the lamp and wait until the sugar water heats up to about 40° Celsius.
3. Add 1 teaspoon of stock yeast solution to the jar of sugar water and stir gently until the yeast is completely mixed with the water.
4. Turn off the lamp and Calibrate the Light Sensor. Then return to the %LIGHT vs. DATA POINT # screen.
5. Turn the lamp back on and wait for 10 minutes.
6. After 10 minutes have passed, turn the lamp off, stir the yeast solution in the jar gently but thoroughly, and press **START** to record light level and temperature.

Note: *As the yeast multiplies it will produce bubbles of carbon dioxide gas in the jar, these should be stirred out each time before you record your data.*

7. Repeat steps 5 and 6 until at least 10 data points have been collected and the %LIGHT readings are no longer

decreasing. This signifies that the growth of yeast has stopped. If you need to collect more than 10 data points you can display the data table, copy down the data, and call on a new %LIGHT vs. DATA POINT # graph.

Interpreting the Results

When we measure the light transmitted through a jar containing yeast cells, we can assume that the amount of transmitted light should decrease as the yeast cells multiply in the jar. These cells can absorb and scatter the light from the Light Assembly. The difference between 100 %LIGHT and the %LIGHT transmitted at any one time represents the %LIGHT absorbed and scattered from the main light beam. This difference should be proportional to the number of yeast cells in the jar.

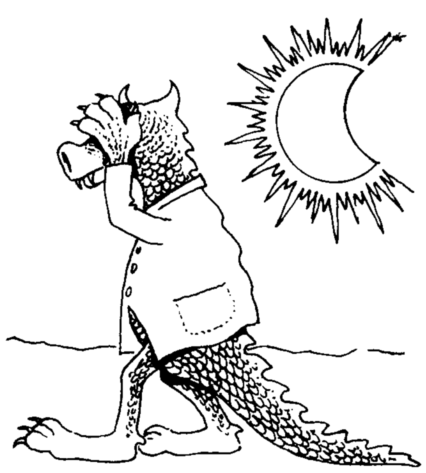
We expect that as long as the yeast cells have plenty of food available to them they will double in number during a given time period, and then double in number again during the second time period of the same duration. This type of growth is known as **exponential growth** rather than exponential decay. As the cells consume all the sugar in the jar their growth will slow and then stop.

You should plot your values of (100 - %LIGHT) vs. DATA POINT # using a graph from Appendix D. Each DATA POINT # will represent a different time after the yeast started growing.

Examine the resulting "curve". Does it seem at all like the curves you obtained in the project on luminescence? What is the time it took for (100 - %LIGHT) to double its value? Does the growth appear to be exponential at first? How long does it take to flatten out?

Suggestions for Other Observations on Yeast Growth

1. Measure the growth rate and, particularly, the doubling time at a higher or lower temperature. What happens?
2. Does cake yeast work differently than powdered yeast?
3. How does the amount of sugar in the jar effect the growth rate?
4. What happens to the growth rate when you use the same sweetness of a different kind of sugar, such as light corn syrup, fructose, or honey? This project will require a taste test before you begin.
5. What happens to the growth rate when you use salt, cornstarch, or flour instead of sugar for the yeast food?



CHAPTER 3: Project Four

Astronomy—Observing Eclipses of the Sun

An eclipse of the Sun takes place when the Moon comes between the Sun and the Earth so that its shadow sweeps across the Earth's surface. The study of the Sun during solar eclipses is of great interest to astronomers.

Solar Eclipses

By a remarkable coincidence, the relationship between the actual sizes of the Moon and the Sun and their relative distances to the Earth are such that the Sun and the Moon appear to be the same size during an eclipse. Although the diameter of the Sun is about 370 times larger than the diameter of the Moon, the Sun happens to be about 370 times farther from the Earth.

There are times when the center of the Sun and the center of the Moon are in line with each other in the sky. Because the Sun and the Moon have nearly the same apparent size when viewed from the Earth, the Moon then hides the Sun. When this happens, it is called a **total solar eclipse**. If the Moon and the Sun are not exactly lined up and the Moon hides only a portion of the Sun, we say the eclipse is **partial**.

A total solar eclipse was a rare and frightening event to ancient peoples who did not understand its cause. Today the times and locations on the surface of the Earth of both partial and total solar eclipses are predicted long in advance by astronomers. Because certain aspects of the Sun can be studied only during a total eclipse, it is a very exciting event for astronomers.

Because the Moon's orbit is not quite circular, the distance between the Moon and the Earth changes slightly. Sometimes the Moon is too far away from the Earth to obscure the Sun completely even when their centers are lined up. In this case the eclipse is known as an **annular eclipse**.

How Eclipses Are Observed

As the Moon begins to pass in front of the disk of the Sun during an eclipse, the light from the Sun appears to become dimmer and dimmer. Astronomers usually photograph or measure properties of the light from around the eclipsed Sun with scientific instruments.

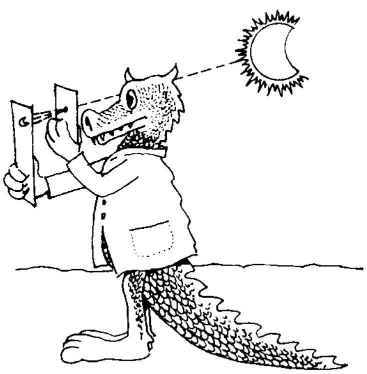


Figure 3.4–1. *Looking at a partial eclipse of the Sun safely with a pinhole and screen.*

Although it is safe to look at a total eclipse, the sunlight during partial phases of an eclipse is too bright to be viewed directly. Many curious eclipse watchers project the image of the Sun on a piece of white paper for safe viewing during partial eclipse phases.

You can use the AtariLab Light Module, to monitor indirect light from the Sun during either a partial or a total solar eclipse. In this way, the light level can be monitored as a function of time as the Moon slips in front of the Sun and then passes by leaving full sunlight again.

In this project we offer suggestions about how to monitor eclipses. We have included information about eclipses predicted between May 1984 and July 1991.

Suggested Procedures for Monitoring a Solar Eclipse

The first step in monitoring is, of course to find out more about upcoming solar eclipses. In general, when an eclipse is going to occur in a certain region, the local newspapers publish articles announcing the type of eclipse and its time and location. More details can be found in the popular astronomy magazine *Sky and Telescope* available at newstands.

The easiest way to measure the changes in light level as the result of any eclipse—total or partial—is to measure indirect light from the Sun. This can be done as follows:

1. Mount the Light Sensor in the Light Stand and place the Light Stand with the Light Sensor facing outward in a north window, out of direct sunlight.
2. (Optional) If you want to monitor temperature changes during the eclipse, place the Temperature Sensor from the Starter Set in the left (blue) paddle input of the AtariLab Interface. Mount the Sensor outside using the directions outlined in Chapter 3:Project Seven of the *Temperature Module Project Guide.*
3. Place enough paper filters or the Polarizer and Analyzer Wheel partially angled to filter out light in the Light Stand filter slots so the Light Sensor can be properly calibrated just before the eclipse begins.
4. Calibrate the Light Sensor about 10 minutes before the local time that the eclipse is to begin.
5. Choose a total time that is just a bit longer than the predicted duration of the eclipse.
6. At the same time as you press a key to begin monitoring the eclipse, record the local time.
7. When the eclipse is over, copy all the data on to the data table. Draw a graph of %LIGHT vs. TIME.

An example of eclipse data obtained with the AtariLab Light Module is shown in Figure 3.4–2.

Figure 3.4–2. *%LIGHT data gathered in Carlisle, Pa. At 11:30a.m., the Light Sensor was adjusted to read 100 %LIGHT. Clouds covered most of the sky. Because of changes in the cloud cover, the graph shows small increases and decreases in %LIGHT during the two-hour period. As you can see from the graph, the maximum coverage of the Sun by the Moon occurred at 12:50p.m.EDT.*

ATARILAB™ LIGHT MODULE SAMPLE TABLES AND GRAPHS

TOTAL TIME 2 HOURS

INVESTIGATOR P. Laws & R. Boyle

TRIAL NUMBER 1 DATE 30 May 84

DESCRIPTION OF PROJECT Annular Solar Eclipse monitored for 2 hrs. in Carlisle, PA Starting at 11:30 AM Eastern Daylight Time

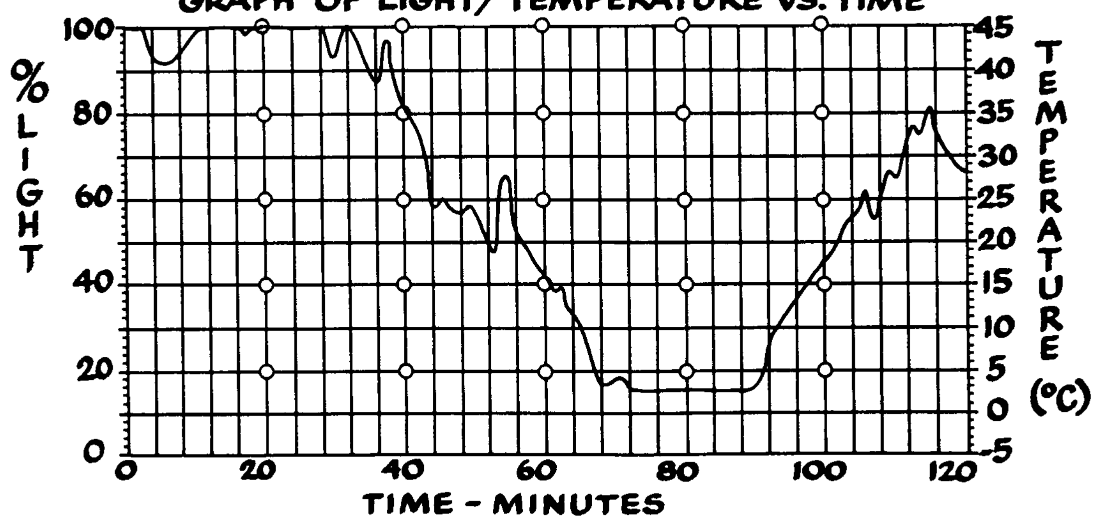
DATA TABLE (Highlighted Numbers)

TIME (SEC.)	TIME (MIN.)	% LIGHT	TEMP. °C
0	0	> 100	
240	4	95	
480	8	92	
720	12	100	
960	16	100	
1200	20	100	
1440	24	100	
1680	28	100	
1920	32	100	
2160	36	83	
2400	40	81	

TIME (SEC.)	TIME (MIN.)	% LIGHT	TEMP. °C
2640	44	59	
2880	48	57	
3120	52	56	
3360	56	55	
3600	60	41	
3840	64	34	
4080	68	18	
4320	72	17	
4560	76	15	
4800	80	15	

TIME (SEC.)	TIME (MIN.)	% LIGHT	TEMP. °C
5040	84	15	
5280	88	15	
5520	92	25	
5760	96	36	
6000	100	44	
6240	104	56	
6480	108	60	
6720	112	76	
6960	116	76	
7200	120	67	

GRAPH OF LIGHT/TEMPERATURE VS. TIME



An Eclipse Calender 1984–1991

Consult local newspapers and popular astronomy magazines for details.

May 30, 1984: Annular Eclipse—United States.

November 22, 1984: Total Eclipse—totality visible in New Guinea. Partial phases visible in Indonesia, Australia, New Zealand.

May 19, 1985: Partial Eclipse—northern North America, Iceland, northeast Asia.

November 12, 1985: Total Eclipse—southernmost Pacific Ocean.

April 9, 1986: Partial Eclipse—Indonesia, Australia, New Zealand.

October 3, 1986: Annular Eclipse—north Atlantic, Greenland, Iceland. Partial phases visible over most of North America.

March 29, 1987: Annular Eclipse—south Atlantic, west Africa, Indian Ocean.

September 23, 1987: Annular Eclipse—China and the Pacific. Partial phases visible in Asia and Australia.

March 17-18, 1988: Total Eclipse—Indonesia, Philippines and the Pacific Ocean. Partial phases visible in Asia, Indonesia, Australia, and the western Hawaiian Islands.

September 11, 1988: Annular Eclipse—Somalia, Indian Ocean. Partial phases visible in eastern Africa, southern Asia, Indonesia, Australia, and New Zealand.

March 7, 1989: Partial Eclipse—Hawaii, northwestern North America, and the Arctic.

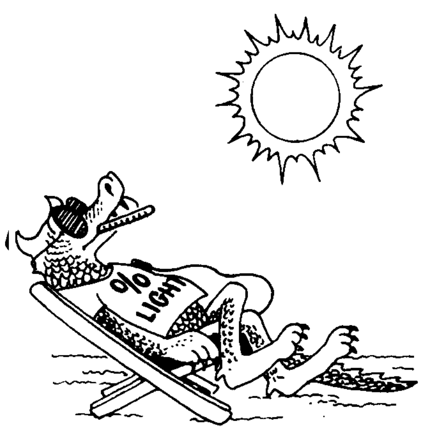
August 31, 1989: Partial Eclipse—southeastern Africa, Madagascar, and Antarctica.

January 26, 1990: Annular Eclipse—Antarctica and the south Atlantic Ocean. Partial phases visible from New Zealand and parts of South America.

July 22, 1990: Total Eclipse—Finland, north coasts of Europe and Asia, Aleutian Islands. Partial phases visible in northeastern Europe, northwestern North America, northern Asia, and Hawaii.

January 15-16, 1991: Annular Eclipse—Australia, Tasmania, and New Zealand.

July 11, 1991: Total Eclipse—Hawaii, Mexico, Central and South America.



CHAPTER 3: Project Five
Solar Energy—Daily Changes in Sunlight and Temperature

When the Sun shines on the Earth some of the light is absorbed and transformed into heat or **solar** energy. Even after the Sun has set, its heat energy is stored in many places on the Earth: the atmosphere, rocks, soils, oceans, lakes, and buildings. In fact, the Sun is our ultimate source of heat since the coal, oil, and wood we burn for warmth are made up of plants that have stored energy from the Sun.

Understanding the relationship between the Sun's light and the temperature of our surroundings is important. This knowledge can help us predict daily weather patterns and learn how to harness the Sun's energy.

In this project, we suggest several ways you can use the AtariLab Light Sensor along with the Temperature Sensor to monitor changes in light level and temperature from the Sun throughout a day. In addition, you can experiment and find effective ways to capture energy from the Sun.

Equipment and Materials

An ATARI Laboratory Station with the AtariLab Light Module items
White construction paper, 8 1/2 by 11 inches
Black construction paper, 8 1/2 by 11 inches
Tape

Monitoring Sunlight and Temperature

As the Sun rises and moves through the sky, the amount of energy it delivers to a given location on the surface of the Earth changes. Early in the morning and in the evening the Sun is low in the sky and does not shine as directly on surfaces. It also passes through more atmosphere at those times. We expect that the amount of sunlight will be greatest in the middle of the day.

Unless a weather system moves in bringing an air mass from a different location, the temperature of the air usually rises as the Sun gets higher in the sky. To do this observation, you want to monitor the light reflected from the Sun and the general air temperature at the same time.

We suggest that you monitor reflected light from the Sun for either 6, 12, or 24 hours depending on how much time you have. In order to calibrate the Light Sensor properly in the brightest light, you should begin monitoring at 12 noon Standard Time or 1 pm Daylight Savings Time, even on a cloudy day.

Obtaining the Best Light Level Measurement

The Light Sensor cannot record light levels when it is pointed directly at the Sun because the Sun is too bright and the Sensor, too sensitive.

The easiest way to monitor the light level is to gather general background or reflected light. To do this you can mount the Light Sensor in the Light Stand and place the Light Stand on the window sill of a north window. The Light Sensor should be facing out the window and shielded from direct sunlight.

A more accurate way to monitor is to position the Light Sensor face down a few inches above a piece of black construction paper. The paper must be placed on a flat surface in direct view of the sky. In this position, light reflected from the construction paper can shine into the Light Sensor, even on a cloudy day.

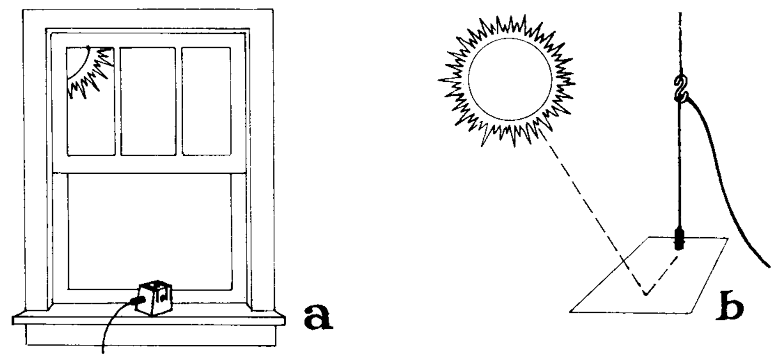


Figure 3.5–1. *Two possible ways to monitor sunlight. (a) indirect background light, and (b) reflected light from a piece of paper.*

Obtaining Air Temperature Measurements

The AtariLab Temperature Sensor should be mounted outdoors outside of direct sunlight. It should not be touching any surfaces. Details on how to mount the Temperature Sensor properly are contained in Chapter 3: Project Seven, "Measuring Daily Changes in Air Temperature" in the *Temperature Module Project Guide.*

Monitoring

We suggest that the first time you monitor, you should choose a day that will not have dramatic weather changes. A sunny day with just a few clouds or a completely cloudy day is fine.

1. Set up the ATARI Laboratory Station with the Light Sensor in the right (orange) paddle input and the Temperature Sensor in the left (blue) paddle input of the Interface.
2. Mount the Temperature Sensor outside as recommended.
3. Place the Light Sensor on a windowsill or a few inches over a piece of black construction paper as recomended.
4. Wait until what you predict to be the brightest part of the day, and Calibrate the Light Sensor. (If necessary, tape paper filters in front of the Light Sensor to reduce the light level for best Calibration.)

5. Set up an experiment for the number of hours that you want to monitor, record the time of day, and begin the monitoring.
6. During the time that you are monitoring, you should keep a record of the weather conditions. Did clouds move over the Sun? Was it cloudy the whole time? Did it rain? Did the wind pick up or shift direction? Did a few fluffy, white clouds reflect more light into the Light Sensor?

Interpreting Your Data

There are some questions you might ask as you examine your results. At what time was the light level the highest? When was the temperature the greatest? What happens to the temperature as the Sun goes down?

On sunny days you should see the most change in the light level and temperature. If the day is partly cloudy the graph will have dips in it at those times when clouds passed in front of the Sun. What happens to the temperature at those times?

Solar Energy

Because of the worldwide concern for a reliable and inexpensive supply of energy in the future, solar energy has become a very active field of research. The key questions in solar research center around the best methods for capturing sunlight and tranforming it into other useful forms of energy.

Transforming sunlight into heat is, at present, the most common use of solar energy. The AtariLab Light Sensor and Temperature Sensor are the most basic tools needed for solar heat energy research. Using these two sensors it is possible to build models of large scale solar devices and test their effectiveness.

There are many books and articles about how to experiment with small solar devices or build full scale solar collectors. The simple activity suggested below is intended as a way to begin the study of solar energy.

A Construction Paper Solar Collector

You can make a solar collector by taping a piece of construction paper to a flat surface on which full sunlight can shine.

You can study the effectiveness of this collector by monitoring the temperature directly behind the paper while at the same time measuring the amount of light reflected from the surface of the paper.

Several observations can be made. Does the temperature behind the paper depend on:

1. The color of the paper? Is black or white paper a better absorber of solar energy?
2. The level of light reflected from the paper?
3. The angle of the Sun above the horizon?

APPENDIX A
General Instructions and Information

This appendix contains a summary of the standard instructions needed to set up various light experiments described in this manual. The definition of special words is also included. The following set of instructions and definitions are listed in alphabetical order.

ATARI Laboratory Station

Each computer activity in this Light Module Experimenter's Guide requires the ATARI Laboratory Station. This refers to the ATARI Computer, a television set or monitor, and the AtariLab Interface.

Optional accessories connected to the computer through the AtariLab Interface include the Light Sensor, the Light Assembly and the Temperature Sensor which is included in the Starter Set with the Temperature Module. Other optional equipment includes an EPSON printer to print out graphs and an ATARI Disk Drive with DOS software for saving data files.

Begin a Light vs. DATA POINT # Experiment with DATA POINT #0 at 100 %LIGHT

1. Calibrate the Light Sensor. (See entry below.)
2. Choose the SET UP EXPERIMENT option. (See entry below.)
3. Choose an X AXIS of DATA POINT # and a Linear Scale. (See entry below.) You should see a graph of %LIGHT vs. DATA POINT # with a flickering cursor at point #1.
4. Check to see that the cursor at position #1 is a flickering light orange rather than a red box. The flickering cursor should also be opposite the 100 %LIGHT on the graph.
5. If the cursor is not reading 100 %LIGHT, press **ESC** or the red joystick button and Calibrate the Light Sensor again. (See entry below.) Repeat steps 3 and 4 above.

Begin a Light vs Time Experiment

1. Choose the BEGIN EXPERIMENT option by pressing the ↑ key or by pushing the joystick up.
2. When the graph appears, press any key or the red joystick button to begin recording light data. Temperature data will also be recorded, if the Temperature Sensor is plugged in.

Calibrate the Light Sensor

Calibration allows the user to record relative light levels as numbers between 0 %LIGHT and 100 %LIGHT. To calibrate properly, the Light Sensor should be exposed to the brightest light it is expected to receive during the course of an experiment. The computer will then associate this level with 100 %LIGHT. To calibrate:

1. Find either the CALIBRATE option or CALIBRATE SENSOR option on one of the menus.
2. Choose the option.
3. Put your AtariLab Light Sensor in the position it will be during the experiment you plan to perform after calibration. For example, if you are going to use the Light Sensor opposite the Light Assembly or in a window, place it there.
4. Expose the Sensor to the brightest light it is expected to encounter during the experiment.
5. If possible, use filters, the Polarizer and Analyzer Wheel, or a different light source in front of the Light Sensor until the message "GOOD LIGHT LEVEL" appears on the TV screen.

Note: *If the light level is to low to be detected by the Light Sensor or too high for it to respond, calibration cannot take place.*

6. When the screen message "GOOD LIGHT LEVEL," "FOR MORE RANGE INCREASE LIGHT LEVEL," or "FOR MORE PRECISION REDUCE LIGHT LEVEL" appears, proceed with the calibration by pressing **START**.

Choose the SET UP EXPERIMENT option

This option allows you to gather data in two ways. First, by choosing the DATA POINT # option, you can record up to 10 data points representing %LIGHT or LOG %LIGHT with each point being displayed on the screen as it is recorded. Second, you can record up to 121 %LIGHT or LOG %LIGHT values in any one of 18 time periods you choose.

If an AtariLab Temperature Sensor in plugged in, temperatures in degrees Celsius are recorded also. As the light levels and temperatures are recorded, they are displayed on a graph.

The Light Sensor can be calibrated just before each experiment if necessary.

To choose the SET UP EXPERIMENT option:

1. Place the main menu on the screen. If you are just starting to use the Cartridge, follow the steps in the Set up the ATARI Laboratory Station instructions. (See below.) If you have been using other options already, press **ESC** or the red joystick button several times until the main menu appears with the words SET UP EXPERIMENT on it.
2. Enter the SET UP EXPERIMENT menu by pressing the ↑ key or by pushing the joystick up.
3. Prepare to choose a linear or log scale for the y-axis representing light and an x-axis scale representing DATA POINT # or TIME.

Choose an X AXIS of ______ and a ______(linear/log) Scale

1. The linear scale for light representing %LIGHT will be used most often. However, to change to the log scale representing the base 10 logarithm of %LIGHT (or LOG %LIGHT) press the ← key or move the joystick to the left.
2. To choose an X AXIS, press the → key or move the joystick to the right. If no choice is made after plugging in the Light Module Cartridge, the X AXIS will be DATA POINT #.
3. When the CHOOSE X AXIS scale menu screen appears press the ↓ key or move the joystick down until the desired X AXIS scale is highlighted.
4. Once the X AXIS scale is chosen press **ESC** or the red joystick button to return to the menu that allows you to begin the experiment.
5. Prepare to begin the experiment.

Choose the LIGHT METER option (and record %LIGHT)

1. Place the main menu on the screen. If you are just starting, follow the steps in the "Set up the ATARI Laboratory Station" instructions. If you have been using other options, press **ESC** or the red joystick button until you come to the main menu with the LIGHT METER option on it.

2. To obtain the LIGHT METER display, press the ← key, or move the joystick to the left. You should see a picture of a light meter on the screen.

Note: *If there is too much light for the Light Sensor to record and the Standard Calibration is being used, the digital display to the right of the meter will have a >100 on it. If the %LIGHT digital display has a <13 on it, then the light is too dim to be recorded accurately.*

3. Each time a light level is to be recorded, press **START**. The recorded light level will appear as green or dark numbers to the right of the meter. Up to three recorded values of %LIGHT will appear on the screen at once with the most recent value on top.

Copy the Highlighted Numbers from the Screen and Plot the Graph

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

Appendix E contains table and graph forms for 19 possible x-axis choices. This includes the DATA POINT # table and graph, and table and graphs for a selection of 18 different times over which data can be collected. You are invited to reproduce any of the tables or graphs needed for your projects.

To fill out a table and graph form:

1. Complete an experiment and push **ESC** or the red joystick button to go to the menu with the DISPLAY DATA option.
2. Choose the SEE TABLE option by pressing the ↑ key or moving the joystick up.
3. Find the special table and graph form in Appendix E having the same x-axis scale as the computer graph you just created.
4. Copy the highlighted values for %LIGHT and, optionally, temperature, from the screen to the blanks opposite the appropriate time or data point number. No highlights are used in the table corresponding to the DATA POINT # graph because there are only 10 data point values and they can all be copied.
5. If necessary, press a key or the red joystick button to display the next 15 data values. Then copy the next few highlighted values into the table blanks. Continue this procedure until you have seen all the data.
6. Finally, plot each value of %LIGHT or TEMPERATURE from your data table onto the graph immediately below your table. Notice that the temperature scale on your graph is on the right. Each vertical line on the graph corresponds to a set of light and temperature values on each line of your table.

Record Data on the DATA POINT # Graph

This set of instructions can be followed after the BEGIN EXPERIMENT option is chosen with an X AXIS scale of DATA POINT #.

1. Notice the flashing orange (or gray) "x" representing the %LIGHT or LOG %LIGHT for DATA POINT #1 on the screen. If the AtariLab Temperature Sensor is plugged into the left (blue) paddle input, then there will also be a blue (or white) "+" representing the temperature in degrees Celsius.
2. Set up the first data point by using whatever Light Sensor location, filters, or Analyzer Wheel setting you want.
3. Press **START** to record the data.
4. The flashing "x" 's and "+" 's will move to the next data point locations. Set up the next data point by rearranging filters, the Light Sensor location, etc.
5. Press **START** to record the next data point.
6. Repeat steps 4 and 5 until all 10 data points are recorded. If you only want to record a few data points, just press **ESC** or the red joystick button to return to the menu.

Reduce the Light Level at the Sensor

Any one of the three measures described below will cause the light level at the Sensor to decrease.

1. Move the Light Assembly or light source away from the Light Sensor.
2. Place one or more layers of plain white paper in one of the filter slots. Usually if the Light Assembly is being used as the source of light, the paper should be put in the filter slot which is next to the Light Assembly. Once the paper is in place it should be taped down.
3. Place the Polarizer and the Analyzer Wheel together in one of the filter slots. Turn the Analyzer Wheel until the light shining on the Light Sensor is reduced to the desired level.

Set up the ATARI Laboratory Station

1. Set up your ATARI Computer and television set or monitor.
2. Insert the Light Module Cartridge.
3. Turn on your computer and television set or monitor. You should now see the title screen for the Light Module.
4. Choose either joystick or keyboard control. If you prefer joystick control, plug the joystick into controller jack 1.
5. To begin, press any key or the red joystick button. You should now see an instruction screen.
6. Plug the AtariLab Interface into controller jack 2.
7. Plug the AtariLab Light Sensor into the right (orange) paddle input of the AtariLab Interface.
8. (Optional) Plug the AtariLab Light Assembly into either one of the red power inputs of the AtariLab Interface.

9. (Optional) Plug the AtariLab Temperature Sensor, included in the AtariLab Starter Set, into the left (blue) paddle input of the AtariLab Interface.
10. Press any key or the red joystick button to display the main menu options for the Light Module Cartridge.
11. All menu selections can be made using the arrow keys (the ↑ key, the ↓ key, the ← key, the → key) or optionally, by moving the joystick lever up, down, left, or right.

Note: *There is no need to press the CTRL key in order to use the arrow keys*

Set up the AtariLab Light Stand with the Light Sensor (and Light Assembly)

1. Insert the Light Sensor in one of the Light Stand holes behind a filter slot.
2. (Optional) Plug the light at the end of the AtariLab Light Assembly into another hole in the Light Stand so it is behind the Light Sensor.
3. (Optional) To reduce the light level coming into the Light Sensor, or to do light absorption experiments, place folded paper, folds of the cellophane filters, or the Polarizer and Analyzer in the two filter slots which lie between the Light Sensor and the Light Assembly when they are placed in the Light Stand.

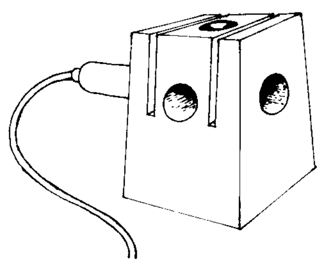


Figure A-1. *Light Sensor inserted in the Light Stand behind a filter slot.*

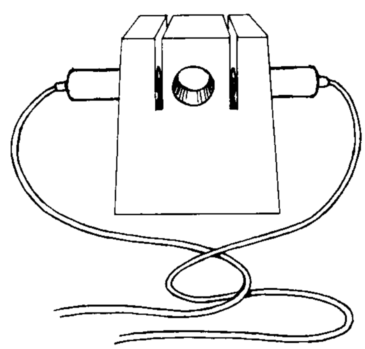


Figure A-2. *Light Assembly inserted in Light Stand opposite the Light Sensor.*

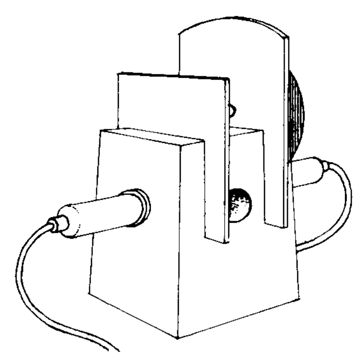


Figure A-3. *Polarizer and Analyzer Wheel inserted in filter slots to reduce light level.*

Shield the Light Sensor (and Light Stand) from stray light

Any of the three measures described below will help eliminate stray light.

1. Place the Sensor (and Light Stand) in a box lined with black paper. See the tips for experimenters section in Chapter 1 for construction details for the Experiment Box.
2. Work in a dark room with the Light Sensor faced away from the TV set or monitor used with the ATARI Laboratory Station. Dark rooms are sometimes hard to

find. In the daytime you will need light-tight curtains or blankets over the windows, or, of course a room without windows. You may find it more convenient to do your experiments at night with the electric lights turned off.

3. Cover the Light Sensor (and Light Stand) carefully with a dark cloth that is thick enough to block out light. You can test how well your cloth blocks stray light by holding it up to a window in the daytime or to a light.

Use the Standard Calibration

Whenever possible, the range of light levels used in an experiment should be the range that can be recorded using the Standard Calibration which is between about one foot-candle and one-tenth of a foot-candle. To use Standard Calibration:

1. If you have inserted your Cartridge but not used the CALIBRATION option, then you are automatically working with Standard Calibration.
2. If you have inserted your Cartridge and used the CALIBRATION option, then you should press **RESET**. The calibration you completed previously will be replaced by the Standard Calibration values, and the title screen will appear.

APPENDIX B

The AtariLab Light Module Cartridge

The software included in the AtariLab Light Module comes on a 16K ROM Cartridge and runs on any ATARI Home Computer. The software is self-documented and requires little or no reference to this manual for its use. The major features of the software are outlined in Figure B-1 below.

The Light Module Cartridge allows users to:

• **Record light levels between about one-twentieth of a foot-candle and about one foot-candle.** When the LIGHT METER option is selected from the menu, a picture of a light meter appears on the screen. The light level is indicated by a yellow bar expanding from left to right on the screen. A number representing light level or degree of illumination as %LIGHT appears to the right of the meter.

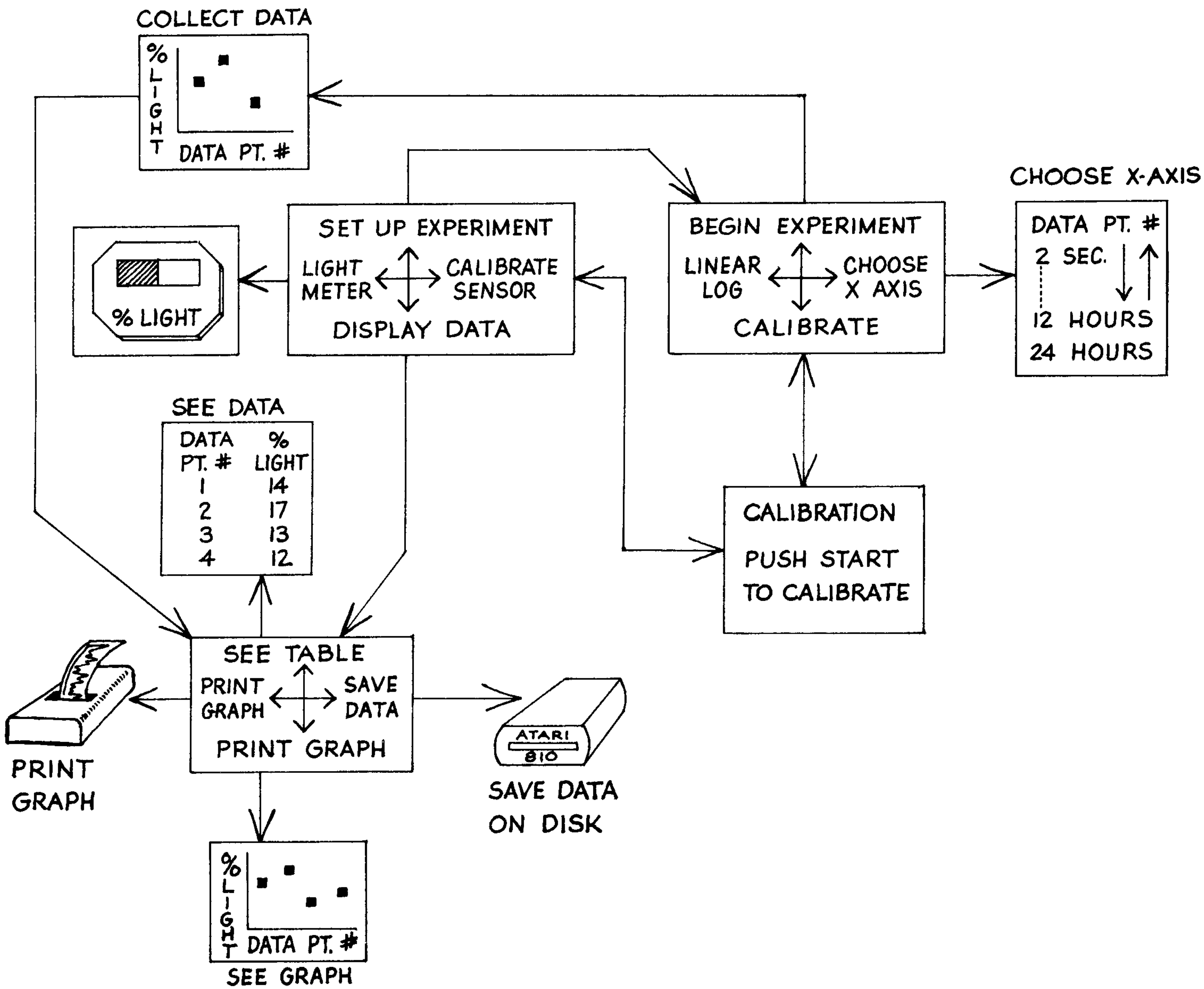
If the light sensor has not been calibrated, then 100% light is about one half of a foot-candle. Using Standard Calibration, any light level above about one-half of a foot-candle (>100 %LIGHT) is too much for accurate detection by the sensor. The signal to the Atari at about .07 foot-candles, or 13% light, becomes too low to be detected by the computer. The yellow bar on the meter that indicates light level turns red if the light level becomes too large or too small and a < or > sign is placed in front of the %LIGHT value on the screen.

By pressing **START** or the red joystick button, current light levels which appear in white, can be recorded in green or darker numbers below the current values to provide data for a table or graph. A new value of %LIGHT will be recorded every time **START** is pressed, and up to three recorded values can be displayed on the screen at one time.

• **Calibrate the light sensor so it is sensitive to a different range of illuminations.** (See Appendix C for details.) In a given project it is best to try to calibrate the sensor so that 100 %LIGHT represents the maximum level of illumination to be encountered in the project.

To calibrate the user should expose the sensor to the brightest illumination expected in the project. If the message on the screen is "GOOD LIGHT LEVEL," the user can press **START** to proceed and a new table of values will be calculated by the calibration program which defines the light level to which the sensor was exposed at the time of calibration as 100 %LIGHT. If messages appear to the effect that the light level is too low or too high for good calibration then the light level should be raised or lowered before calibration can proceed. Recommendations on how to reduce and increase the light levels

Functional Diagram of AtariLab Light Module Software.



are obtained in Appendix A and the section on "Tips for Experimenters" in Chapter One.

• **Set up an experiment to measure up to 121 light levels as a function of time.** The user can choose a vertical display of %LIGHT. In addition, by selecting the CHOOSE X AXIS menu option, the user can then select from a menu of 18 total time durations between 2 seconds and 24 hours. The light levels are displayed in graphical form as they are recorded. Once the experiment is complete the user can see a display of the light levels in table form, print the graph, or store the data on a disk.

A base 10 logarithm display for %LIGHT can be chosen. If this alternative is chosen, then all graphs, tables, and data files will contain the base 10 logarithm of %LIGHT instead of %LIGHT. The graph only displays logarithms between 1.0 and 2.0. However, the table and data files contain all the logarithm values. The logarithm display is useful in examining exponential changes in light level, such as those obtained from the Glow Panel, layers of filters, and the Light Stick.

• **Set up an experiment to record up to 10 data points representing the light level or its base 10 logarithm on a graph.** The horizontal axis is labeled DATA POINT #. The data is collected in order from point #1 to point #10. The current data for the next point to be recorded by the user is indicated by a flashing "x". As soon as **START** is pressed on the computer, the, data point appears as a solid light orange "x" and the flashing "x" is moved on to the the next location. If the temperature sensor is plugged in, its values are represented by +'s on the graph.

DATA POINT # can represent any quantity the user chooses. For example, each data point could represent a different distance between the Sensor and the Light Assembly, a different angle between a Polarizer and an Analyzer Wheel, or a different number of filters between a light and the Light Sensor.

• **Record temperature in degrees Celsius any time a graphical experiment is run.** Any AtariLab user who also has the AtariLab Temperature Module can plug the Temperature Sensor into the left (blue) paddle input. If the Temperature Sensor is plugged in and a color TV set or monitor is used for the display, a blue trace or blue data points or values representing temperature will appear in every graph and table along with the orange data points and values representing %LIGHT. Because of memory limitations in the Cartridge, the Temperature Sensor cannot be calibrated.

Numerical data for both the Light and Temperature Sensors can be printed out in graphical form or transferred to a disk file.

• **Dump graphs to an EPSON Printer.** This routine allows users to print graphs of light level vs. time or light level vs. data point number on an EPSON MX, RX, or FX graphics printer.

• **See a highlighted data table.** This routine dislays the %LIGHT and temperature data taken at up to 121 equal time intervals for each sensor. The corresponding elapsed time at which each light level and temperature is collected is also displayed. If the DATA POINT # option is chosen, then data up to 10 light levels and temperatures are displayed opposite the corresponding DATA POINT # in the table.

Every few entries in the table are highlighted. Users wanting to keep permanant records of highlighted values can enter them on copies of the data summary sheets found in Appendix E.

• **Return to the Standard Calibration and clear data already taken.** This is done by pressing **SYSTEM RESET** or turning the computer off and back on again.

• **See a graph of data recorded most recently.** Once the graph appears, the user may alternate between a graph that displays %LIGHT and one that displays the base 10 logarithm of %LIGHT.

In addition, if temperature data are also recorded, then pressing **SELECT** allows a user to alternate between a graph that displays %LIGHT (or the base 10 logarithm of %LIGHT) and one that displays temperature in degrees Celsius.

• **Choose joystick or keyboard control.** The keyboard can always be used to control the software. However, many users find joystick control less tedious than locating keys. If a joystick is plugged into controller jack 1 and the red button is pressed, then the joystick can be used to choose and control the rest of the menu options.

• **Place the ATARI Laboratory Station in display mode.** By placing a shunt in the right yellow paddle trigger input of the AtariLab Interface, the Light Module Cartridge is placed in a display mode. This mode should be useful for those wanting to set up hands-on demonstrations in schools and science museums. In display mode, joystick control is chosen automatically. The CALIBRATION, PRINT GRAPH, and SAVE DATA options are removed.

By wiring a small box and spring-loaded switches to be inserted between controller jack 1 and a joystick, use of the computer console can be completely avoided. The switches, which can be mounted on a panel above the ATARI Computer, serve the same function as the console buttons—**START**, **SELECT**, and **RESET**.

APPENDIX C
Technical Information on Calibration, Light Sensor Accuracy, and Timing Accuracy

The AtariLab Light Sensor

A General Description

The Light Sensor consists of a cadmium sulfide photocell mounted in a moisture resistant housing. Two wires from the photocell are attached by lengths of insulated wire to a plug.

Cadmium sulfide contains cadmium and sulfer atoms bound tightly together in a structured regular arrangement. Because the arrangement of atoms is regular, cadmium sulfide is a crystal. Cadmium sulfide crystals are usually insulators because an electric current does not pass freely through them.

How Does the Light Sensor Work?

When visible light shines on the sensistive surface area of the cadmium sulfide photocell, the photocell's resistance to the flow of an electrical current decreases. This is because some of the light energy carried by the photons is absorbed by electrons in the atoms in the photocell. These electrons gain enough energy from the light to move away from the atoms and can flow as electrical current.

The Light Sensor can be substituted for a game paddle when it is attached to the computer by means of one of the paddle inputs of the AtariLab Interface. Whenever a sensor is attached to a paddle input, the computer tries to pass a small electrical current through it. Sixty times every second, the ATARI computer automatically records the resistance of the sensor to the flow of an electric current in the form of a paddle reading.

An ATARI paddle reading is a number between 0 and 228. When no light is shining on a photocell, its resistance to the flow of electrical current is high and its paddle value is 228. If the photocell is exposed to a bright light, this resistance becomes so low that the paddle reading is 0 or 1.

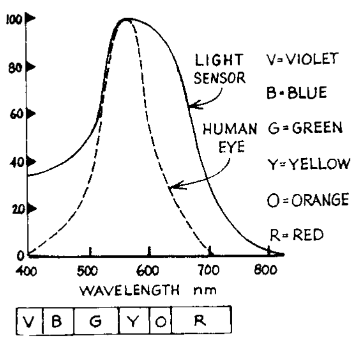


Figure C–1. *Relative Sensitivity of the AtariLab Light Sensor and the human eye to light energy. The wavelengths on the graph are expressed in nanometers. There are a billion nanometers in one meter, and one meter is about three feet.*

Why the Cadmium Sulfide Photocell is Popular for Measuring Light Levels

The type of photocell chosen as a part of the AtariLab Light Module is often used in very sensitive, high quality photographic light meters. This is because its sensitivity to the different wavelengths of light is similar to that of the human eye. (See Figure C–1.)

When photons that the human eye sees as green or yellow light shine on a cadmium sulfide photocell, many electrons are torn away from atoms in the photocell and can flow as electric current. If the same amount of light energy in the form of "blue" or "red" photons shine on the photocell, not as many electrons are released to flow as electric current. The human eye has a similar sensitivity to different photon wavelengths. For the same amount of light energy coming into the eye, green and yellow (medium wavelength) light appear to the viewer to be much brighter than blue (short wavelength) light or red (long wavelength) light.

About Sensor Response Time

If you complete Project Three in Chapter 1, you should find that when the Light Sensor is suddenly exposed to light, the recorded light level changes in less than one- or two-sixtieths of a second. This time is known as the rise time. On the other hand, the fall time which is the response time when the Light Sensor is suddenly plunged into darkness after being in the light, is much slower. Why is the rise time faster than the fall time?

When the light first shines on the photocell, the electrons bound to the atoms in the cystal can absorb the light energy rapidly allowing a current to flow. The paddle reading decreases immediately in response to this current. When the light is suddenly shut off the electons that are no longer attached to the atoms in the cadmium sulfide crystal must recombine with atoms that happen to have missing electrons. It takes more time for an electron to wander through and find an atom with a missing electron than it does for a photon of light to free an electron from an atom.

The rate of the recombination of electrons and atoms which determines the fall time is known to be much faster if there are impurities or other kinds of atoms that don't belong in the crystal. These impurity atoms can attract or "trap" free electrons. Each photocell may have different types and relative numbers of these traps, and we predict that each AtariLab Light Sensor will have a slightly different fall time.

How ATARI Computer Paddle Readings Are Used to Determine Light Levels

If the light shining on the Light Sensor is not too dim or too bright to be recorded by an ATARI Computer paddle input, the paddle reading is inversely proportional to the light level at the Light Sensor as shown in the equation below:

%LIGHT = (100C)÷P

where C is a constant and P is the paddle reading

This simple equation, used to translate paddle readings into light levels, is accurate to about 1 or 2% for the range of foot-candles to which the Light Sensor can respond. The constant, C, is defined as the paddle value corresponding to the brightest light expected in a series of light level measurements. It is determined whenever the Light Sensor is calibrated and we will refer to it as the **calibration constant**.

The AtariLab Light Module Cartridge computes the %LIGHT values from the paddle values recorded by the computer by using the equation listed above.

More About Calibration

The value of the calibration constant, C, used to compute %LIGHT from paddle readings determines the range and accuracy of the light levels that can be recorded by the ATARI Laboratory Station.

The BASIC program listed below can be used to compute the different values of %LIGHT that can be obtained from each possible paddle reading for a given calibration constant.

```
10 PRINT "Enter the Calibration Constant"
20 INPUT C
30 FOR P=C TO 228
40 L=(100*C)/P
50 L=INT(L+0.5)
60 IF L=L0 THEN GOTO 80
70 PRINT "%LIGHT= ";L
80 L0=L
90 NEXT P
```

We suggest that you enter the program and run it several times using different values for the calibration constant, C.

Accuracy vs. Range

When C is small the %LIGHT values decrease in big jumps. For example when C=1, the first few values of possible %LIGHT readings are 100%, 50%, 33%, etc. This limits the accuracy of the %LIGHT readings. Although the accuracy is limited when small values of C are used, the range of light levels that can be measured is as large as possible with 2% being the lowest value of %LIGHT that can be recorded.

We can avoid having big jumps in the %LIGHT values by using a larger number for the calibration constant. When C is 87 or more the possible values for %LIGHT differ from each other by no more than 1%. For example when C=87, the first few values of possible %LIGHT readings are 100%, 99%, 98%, 97%, etc. The accuracy of the measurements of changes in light level is at least 1%.

The disadvantage of using a larger number for C is that the lowest possible value for %LIGHT is relatively large. For example, when the calibration constant, C, is 87, the lowest recorded %LIGHT is 38%. In this case the range of light levels that are recorded is smaller. This is because all the paddle readings that are smaller than C are being ignored. This improved accuracy has been obtained by limiting the range of light levels that can be measured.

How Calibration is Done

When you use the Light Module Cartridge to calibrate, you are asked to expose the Light Sensor to the brightest light needed for a given experiment. When **START** is pressed to calibrate, the paddle reading is recorded and then used as the calibration constant to compute a table of values relating paddle readings to %LIGHT values.

Using an intermediate value for the calibration constant usually affords the best compromise between accuracy and range. In general, we found that values for calibration constants from 25 to 39 were good.

The calibration routine in the Light Module Cartridge forbids users from calibrating in very dim or very bright light where the calibration constant is either quite large or quite small. Users are also discouraged but not prevented from calibrating at light levels lying outside an ideal range. These ranges and the corresponding screen messages are summarized in Table C-1 below.

Table C-1. *Screen Messages and Calibration Constants for the Light Module Cartridge.*

Calibration Constant	*Screen Message*	*Calibration Possible?*
<5	TOO BRIGHT, REDUCE LIGHT LEVEL	no
5–24	FOR MORE PRECISION, REDUCE LIGHT LEVEL	yes
25–39	GOOD LIGHT LEVEL	yes
40–149	FOR MORE RANGE, INCREASE LIGHT LEVEL	yes
>149	TOO DIM, INCREASE LIGHT LEVEL	no

If no calibration has been performed since the computer was turned on or **RESET** was pressed, the Standard Calibration, in which the calibration constant is 30, is used. The range and accuracy of the "brightest" possible calibration (C=5), Standard Calibration (C=30), and the "dimmest" possible calibration (C=149) are shown in Table C-2 below.

Determining the Light Level in Foot-candles

By using the procedures recommended in Chapter 1: Project One, it is possible to measure how many foot-candles are 100 %LIGHT for a given calibration. The number of foot-candles corresponding to each %LIGHT value is given by the equation:

$$\text{Foot-candles} = (F \times \%\text{LIGHT}) \div 100$$

where F is the number of foot-candles at 100 %LIGHT

For example, we found that for one of our sensors, 0.32 foot-candles corresponded to 100 %LIGHT. If a value of 89 %LIGHT was recorded; then the number of foot-candles would be given by:

$$\text{Foot-candles} = (0.32 \times 89) \div 100 = 0.28$$

Table C–2. *Possible Values of Light Level for Different Calibration Levels.*

Brightest	*Standard*	*Dimmest*
>100	>100	>100
100	100	100
83	97	99
71	94	98
63	91	97
56	88	96
50	86	95
45	83	94
42	81	93
38	79	92
36	77	91
33	75	90
31	73	89
29	71	88
28	70	87
26	68	86
25	67	85
24	66	84
23	65	83
↓	↓	↓
2	13	66
<2	<13	<66

APPENDIX D

Sample AtariLab Light Module Programs in BASIC and Logo

When you program your own experiments, you have more flexibility in how data are collected and analyzed. The short programs in BASIC and Logo below are intended to serve as examples of how information coming in from the Light Sensor as paddle readings can be converted into values of %LIGHT.

The sample programs are only a starting point for programmers, since the data can be collected, analyzed and displayed in many ways. For example, the ATARI Computer real time clock registers or simple delay loops can be used to determine the time intervals for data collection. The PLOT and DRAWTO functions in ATARI BASIC or Turtle Graphics in Logo can be used by experienced programmers to graph data as it is collected. Graphs of the results of data analysis can also be created. Users familiar with statistics can also program various statistical tests for the data.

Skills Needed to Use this Appendix

To use this appendix, you should:

1. Have a working knowledge of BASIC or Logo programming.
2. Be familiar with the material in Appendix E of the *AtariLab Starter Set Manual* on how to compute temperatures from paddle values and deal with data files stored on disk using the Temperature Module Cartridge.
3. Be familiar with Appendix C of this manual which tells about the AtariLab Light Sensor and its calibration.

Summary of BASIC and Logo Programs

The programs shown below allow you to:

1. Use BASIC or Logo to compute the light level at a Light Sensor from paddle values.
2. Use BASIC or Logo to calibrate the Light Sensor in the same way it is calibrated with the AtariLab Light Module Cartridge.
3. Use BASIC to retrieve and interpret data files stored on disk by programs in the AtariLab Light Module Cartridge.

Computing %LIGHT from Paddle Values Using BASIC or Logo

When the Light Sensor is plugged into the right (orange) paddle input, and the AtariLab Interface is plugged into controller jack 2, you need to read paddle 3 to obtain information from the Sensor.

The relationship between paddle reading and %LIGHT described in Appendix C is given by the equation below.

%LIGHT = (100C)÷P

where C is the calibration constant and P is the paddle reading.

When Standard Calibration is used, C=30. (See the section "More About Calibration" in Appendix C for details.)

BASIC

```
6 REM Program to translate
7 REM paddle 3 values to %LIGHT
8 REM 6/24/84
9 REM
500 C=30
510 P=PADDLE(3):PRINT "P=";P;
520 IF P<C THEN 560
530 L=(100*C)÷P:L=INT(L+0.5)
540 IF P=228 THEN 570
550 PRINT " %LIGHT is ";L:GOTO 510
560 PRINT " %LIGHT is >100":GOTO 510
570 L227=(100*C)/227:L227=INT(L227+0.5)
580 PRINT " %LIGHT is <";L227:GOTO 510
```

After entering the program above, you should run it and watch the screen as the amount of light shining on the Light Sensor changes. The %LIGHT readings should go up or down between 100 and 13 when C=30.

Logo

ATARI Logo interprets the paddle readings differently than BASIC. The value of P used to compute %LIGHT using Logo must be computed from the equation:

P = 228 - PL

where PL is the Logo paddle value.

The procedures for calculating %LIGHT are shown below, and you should begin by entering them.

```
TO UNDERL
TYPE :P
TYPE [. . . LIGHT LEVEL <]
PRINT ROUND ( 100 * :C / 227 )
END

TO OVERL
TYPE :P
```

```
PRINT [..LIGHT LEVEL > 100]
END
```

```
TO LIGHT
MAKE "P ( 228 - PADDLE 3 )
MAKE "LIGHT.LEVEL ROUND ( 100 * (:C / :P ) )
IF :P = 228 [UNDERL] [IF :P < :C [OVERL] [TYPE :P TYPE
[... LIGHT LEVEL =] PRINT :LIGHT.LEVEL]]
LIGHT
END
```

If you want to use Standard Calibration, then C=30 and you need to enter the statement:

```
MAKE "C 30
```

Finally, change the amount of light shining on your Light Sensor and enter the Logo command LIGHT.

Calibrating the Light Sensor Using BASIC or Logo

Calibration involves finding the paddle reading for the brightest light that will be measured in a project and making it the calibration constant. In Table C-1 in Appendix C, it was suggested that the calibration constant be restricted to values between 5 and 149 for best accuracy and range. When you run the programs below to determine the calibration constant, you can decide to re-calibrate if the calibration constant seems too great or too small by changing the amount of light shining on your sensor.

BASIC

```
0 REM Determining the calibration
1 REM constant for calculating
3 REM %LIGHT from paddle values
4 REM 6/24/84
5 REM
10 DIM A[1)
20 PRINT :PRINT To calibrate expose the Light Sensor
30 PRINT to the brightest light needed for"
40 PRINT your Experiment.:PRINT
50 PRINT "Press RETURN to calibrate."
60 INPUT A$
70 C=PADDLE(3)
80 PRINT "Your Calibration Constant is ";C;".":PRINT
90 PRINT "Do you want to determine a new"
100 PRINT "calibration constant (Y/N)?"
110 INPUT A$
120 IF A$< >"N" THEN 20
```

Logo

```
TO WAITSTART
IF NOT ( ( .EXAMINE 53279 ) = 6 ) [WAITSTART]
END


TO CALIB
PRINT [EXPOSE LIGHT TO BRIGHTEST LIGHT YOU
EXPECT IN YOUR EXPERIMENT]
PRINT [PRESS START]
WAITSTART
MAKE "P ( 228 - PADDLE 3 )
MAKE "C :P
TYPE [CALIBRATION CONSTANT IS . . . ]
PRINT :C
END
```

Combining Calibration with Determining %LIGHT in BASIC or Logo

Usually it is more convenient to calibrate the Light Sensor and then pass immediately to a routine that uses the calibration constant to record paddle values and transform them into %LIGHT values.

BASIC

The program to combine calibration with the computation of %LIGHT is just a combination of the two BASIC programs listed above. However, you must eliminate statement 500 in the first program so the new calibration constant rather than the Standard Calibration constant can be used.

Logo

To combine calibration with the computation of %LIGHT in Logo you merely have to add the procedure CALANDREAD listed below to the procedures already entered from above. No MAKE "C 30 statement is needed since C is determined by the calibration procedure.

```
TO CALANDREAD
CALIB
PRINT [PRESS START TO BEGIN READING LIGHT]
WAITSTART
LIGHT
END
```

Using BASIC to Retrieve AtariLab Light Module Disk Files

The AtariLab SAVE DATA option in the Light Module Cartridge is similar to that in the Temperature Module Cartridge. (See Appendix E in the *AtariLab Starter Set Manual* for details.) However, instead of listing data for one or two Temperature Sensors, each Light Module data file contains a list of light level values, and optionally, a list of temperature values in degrees Celsius. The file names are LIGHT0.DAT, LIGHT1.DAT, etc.

The File Format

The format of the file is shown below.

2	(Number of Sensors)
9	(Number of Data Points per Sensor)
%LIGHT	(Light level scale in %LIGHT or LOG %LIGHT)
4	(Total Time)†
SECONDS	(Time Unit)†
93	(9 %LIGHT values)
88	
78	
67	
55	
49	
40	
67	
69	
CELSIUS	(Temperature List Header—always degrees Celsius.)
-5	(9 Temperature Values in degrees Celsius)
-5	
2	
4	
5	
6	
6	
13	
15	

†If the X AXIS is DATA POINT #, there will be no total time or time unit listed in the file.

To Retrieve A File Using BASIC

It is possible to write a BASIC program to take the information from a data file and display it on the screen in a more readable format. Such a program can be quite similar to the sample program for reading and displaying the data in the Temperature file listed in the Starter Set Manual. (See Appendix D of the *AtariLab Starter Set Manual* under the Heading "Using BASIC to Retrieve AtariLab Disk files.")

The program below allows you to read and display information from the Light Module Files. The file name is assumed to be LIGHT0.DAT in the example.

```
0 REM Filename "READLGHT
1 REM Read an AtariLab(tm) Temperature File LIGHT0.DAT
from Disk for Display
2 REM 6/27/84.
3 REM
5 START=1
10 OPEN #1,4,0,"D:LIGHT0.DAT"
20 DIM LSCALE[10),TSCALE[10),LUNIT[7)
```

```
30 DIM TBLUE(121),LORAN(121)
40 INPUT #1,N
50 INPUT #1,NUM
60 INPUT #1,LSCALE$
70 INPUT #1,LTIME
80 INPUT #1,LUNIT$
85 IF NOT (LUNIT$< >"SECONDS" AND
LUNIT$< >"MINUTES" AND LUNIT$< >"HOURS")
THEN 90
86 LORAN(1)=LTIME
87 LORAN(2)=VAL(LUNIT]
88 LUNIT$="D.P. #"
89 START=3
90 FOR I=START TO NUM
100 INPUT #1,T
110 LORAN(I)=T
120 NEXT I
130 IF N=1 THEN 190
140 INPUT #1,TSCALE$
150 FOR J=1 TO NUM
160 INPUT #1,T
170 TBLUE(J)=T
180 NEXT J
190 CLOSE #1
200 PRINT :PRINT "File: LIGHT0.DAT"
210 PRINT :PRINT "No. of Sensors= ";N
220 PRINT "No. of Data Points per Sensor= ";NUM
230 PRINT "Light Scale is ";LSCALE$
240 IF N=2 THEN PRINT "Temperature Scale is ";TSCALE$
250 IF LUNIT$< >"D.P. #" THEN PRINT "Time for 120
points is ";LTIME;" ";LUNIT$:GOTO 270
260 LTIME=120
270 PRINT
280 DT=LTIME/120
300 FOR I=1 TO NUM
310 ET=INT(I-1)*DT*1000+0.5)/1000
315 IF LUNIT$="D.P. #" THEN ET=ET+1
320 PRINT LUNIT$;"= ";ET,
330 PRINT "LORANGE= ";LORAN(I)
340 IF N=1 THEN 360
350 PRINT " "," ","TBLUE=";TBLUE(I)
360 PRINT
 370 NEXT I
```

Limitations on Timing Accuracy

Appendix D of the lastest version of the *AtariLab Starter Set Manual* includes a section of the limitations of timing accuracy of the ATARI Computer clock. We are adding two more Indicated and Corrected Times to the list for the 2 and 4-second times.

Indicated Time	*Corrected Time*
2 sec	2.0194 sec
4 sec	4.0388 sec

APPENDIX E

Sample Tables and Graphs for the AtariLab Light Module

You can create convenient tables and graphs to record and display data that you get when you do the AtariLab Light Module observations and experiments.

A data table is supplied with the graphs in this Appendix. When you record data for a series of %LIGHT and temperature values, a group of highlighted numbers displayed when you choose the DISPLAY DATA option from the menu is selected for entry into the table.

The values that you enter into the table can then be plotted on the corresponding graph. The graphs are drawn so that each data point lies along one of the vertical lines of the graph.

There are five graph-types. The graph for each x-axis choice is different. The summary of choices for the x-axis for each graph-type is given in Table E-1.

To use the tables and graphs you should:

1. Consult Table E-1 to find the graph-type you need for the x-axis you chose when the data was recorded.
2. Xerox the appropriate graph-type.
3. Copy the highlighted times, %LIGHT or LOG %LIGHT values, and temperature values in the data table.
4. Fill in the numbers indicated in Table E-1 for your x-axis below the marks on the x-axis of the graph.
5. Plot each value of %LIGHT and temperature in order on the graph. (Refer to the *Temperature Module Project Guide* section on graphing procedures if you have forgotten how to plot points on a graph.)

Note: *The Type 1 graph is only used for an x-axis of DATA POINT #.*

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

X-Axis Choice	Graph Type	Times (or X-Value) on Graph Axis
DATA POINT #	1	0, 2, 4, 6, 8, 10 POINT #
2 seconds	2	0, 0.5, 1.0, 1.5, 2.0 seconds
4 seconds	2	0, 1, 2, 3, 4 seconds
10 seconds	3	0, 2, 4, 6, 8, 10 seconds
20 seconds	3	0, 4, 8, 12, 16, 20 seconds
30 seconds	4	0, 5, 10, 15, 20, 25, 30 seconds
1 minute	4	0, 10, 20, 30, 40, 50, 60 seconds
2 minutes	4	0, 20, 40, 60, 80, 100, 120 seconds
3 minutes	4	0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0 minutes
5 minutes	3	0, 1, 2, 3, 4, 5 minutes
10 minutes	3	0, 2, 4, 6, 8, 10 minutes
20 minutes	3	0, 4, 8, 12, 16, 20 minutes
30 minutes	4	0, 5, 10, 15, 20, 25, 30 minutes
1 hour	4	0, 10, 20, 30, 40, 50, 60 minutes
2 hours	4	0, 20, 40, 60, 80, 100, 120 minutes
3 hours	4	0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0 hours
6 hours	4	0, 1, 2, 3, 4, 5, 6 hours
12 hours	5	0, 2, 4, 6, 8, 10, 12 hours
24 hours	5	0, 4, 8, 12, 16, 20 hours

ATARILAB™ LIGHT MODULE SAMPLE TABLES AND GRAPHS

TYPE 1 - DATA POINT

INVESTIGATOR ____________________

TRIAL NUMBER ________ DATE ____________

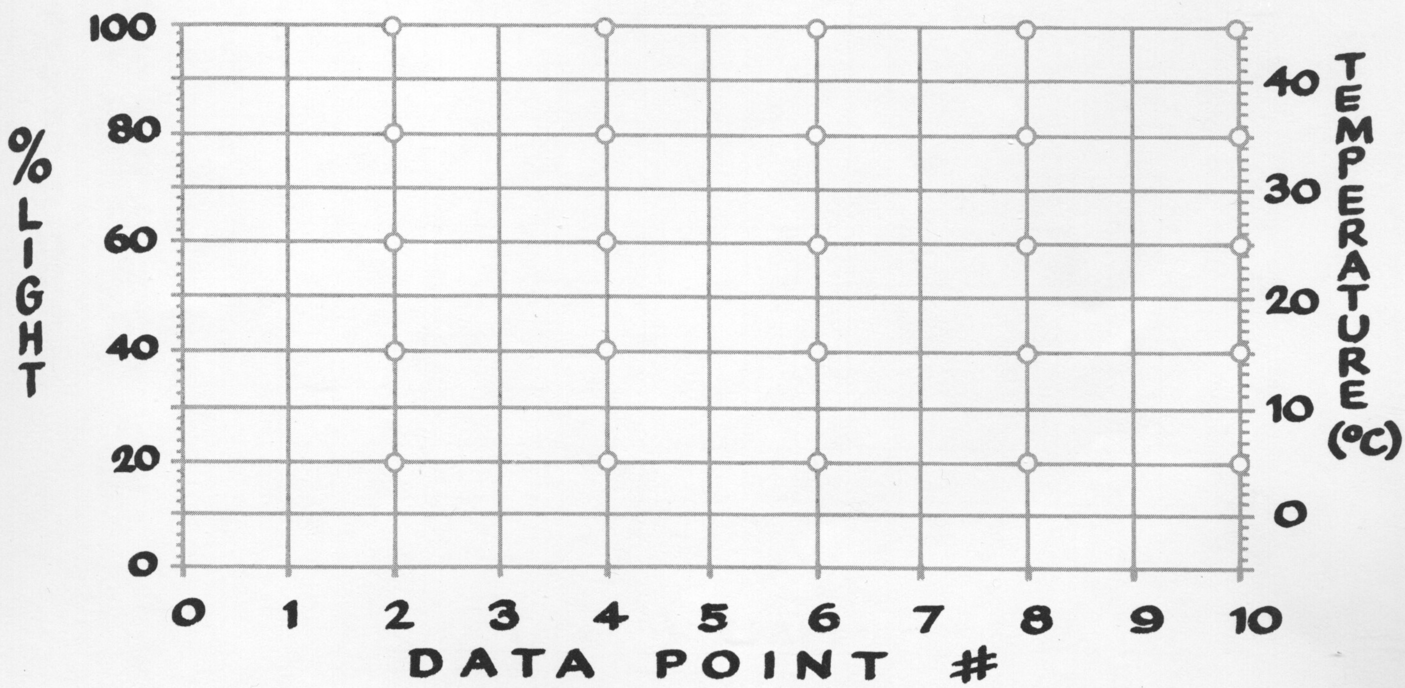
DESCRIPTION OF PROJECT ____________________

____

____

____

DATA POINT #	% LIGHT	LOG % LIGHT	TEMP. °C
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			



ATARILAB™ LIGHT MODULE SAMPLE TABLES AND GRAPHS

TYPE 2 - 2 SEC., 4 SEC.

INVESTIGATOR ____________________

TRIAL NUMBER ________ DATE ____________

DESCRIPTION OF PROJECT ____________________

____

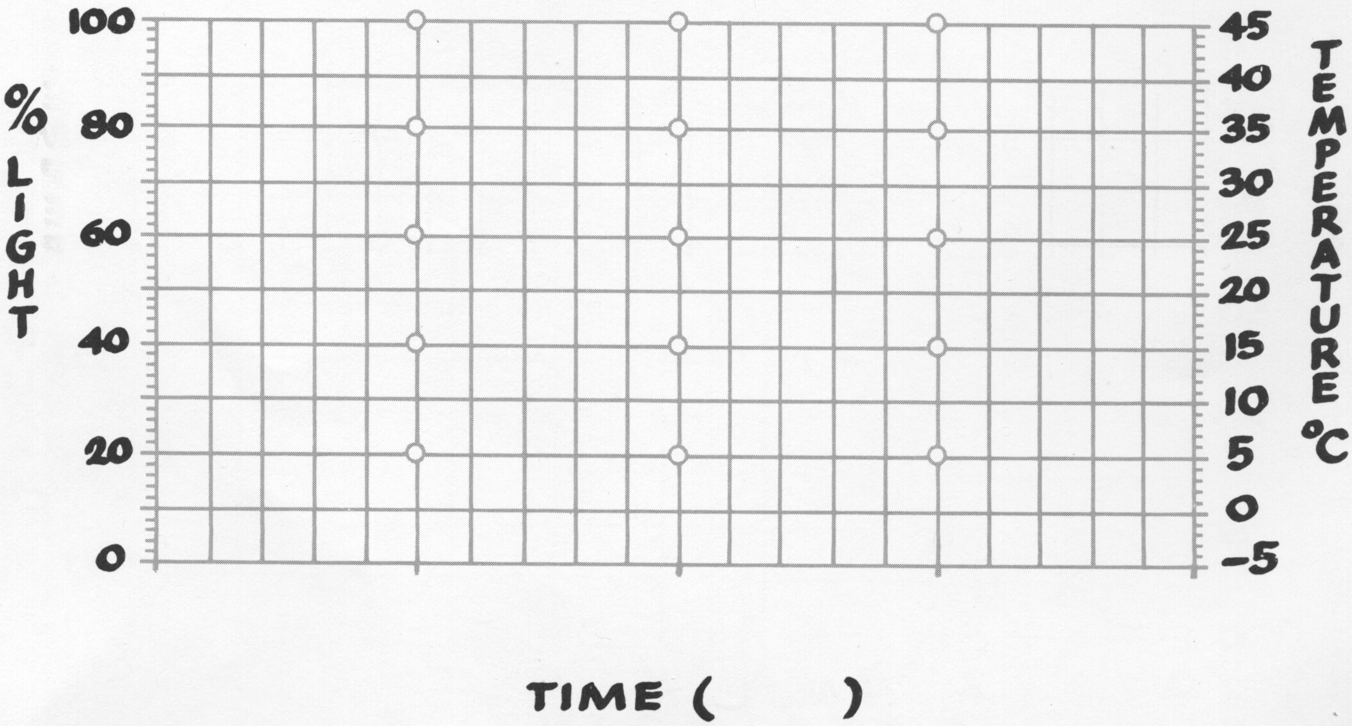
____

____

DATA TABLE (Highlighted Numbers)

TIME	% LIGHT	TEMP. °C

TIME	% LIGHT	TEMP. °C



ATARILAB™ LIGHT MODULE SAMPLE TABLES AND GRAPHS

TYPE 3 - 10, 20 SEC. - 5, 10, 20 MIN.

INVESTIGATOR ______________________

TRIAL NUMBER ________ DATE ______________

DESCRIPTION OF PROJECT ______________________

____

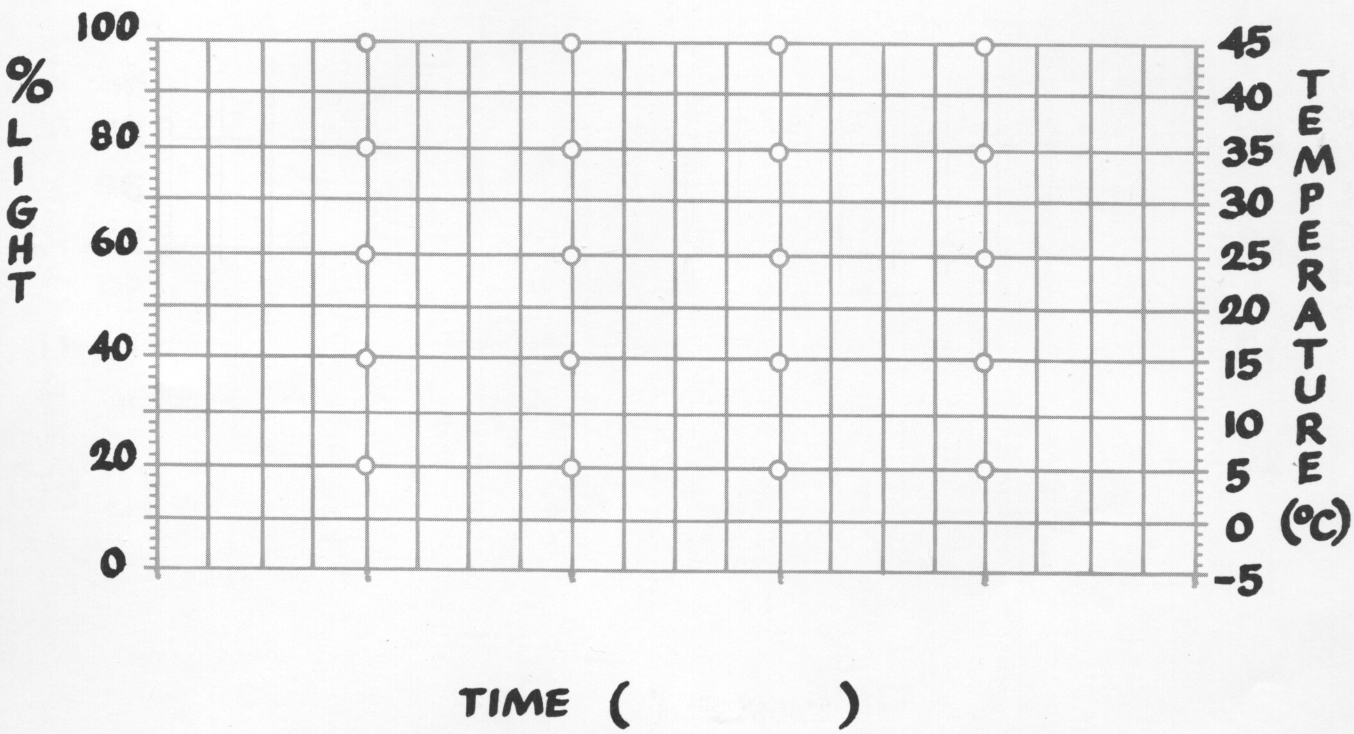
____

____

DATA TABLE (Highlighted Numbers)

TIME	% LIGHT	TEMP. °C

TIME	% LIGHT	TEMP. °C



ATARILAB™ LIGHT MODULE SAMPLE TABLES AND GRAPHS

TYPE 4 - 30 SEC. -
1, 2, 3, 30 MIN. - 1, 2, 3, 6 HRS.

INVESTIGATOR ____________________

TRIAL NUMBER ________ DATE ____________

DESCRIPTION OF PROJECT ____________________

____

____

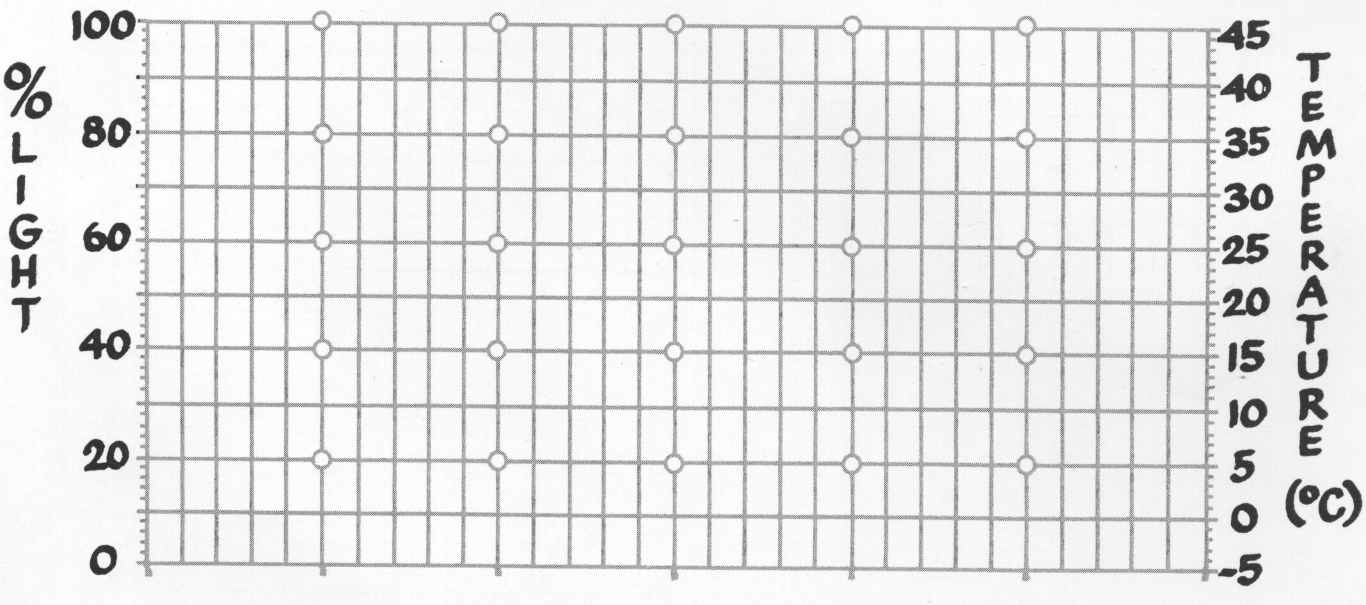
____

DATA TABLE (Highlighted Numbers)

TIME	%LIGHT	TEMP. °C

TIME	%LIGHT	TEMP. °C

TIME	%LIGHT	TEMP. °C



TIME (   )

ATARILAB™ LIGHT MODULE SAMPLE TABLES AND GRAPHS

TYPE 5 - 12, 24 HRS.

INVESTIGATOR ____________________

TRIAL NUMBER ________ DATE ____________

DESCRIPTION OF PROJECT ____________________

____

____

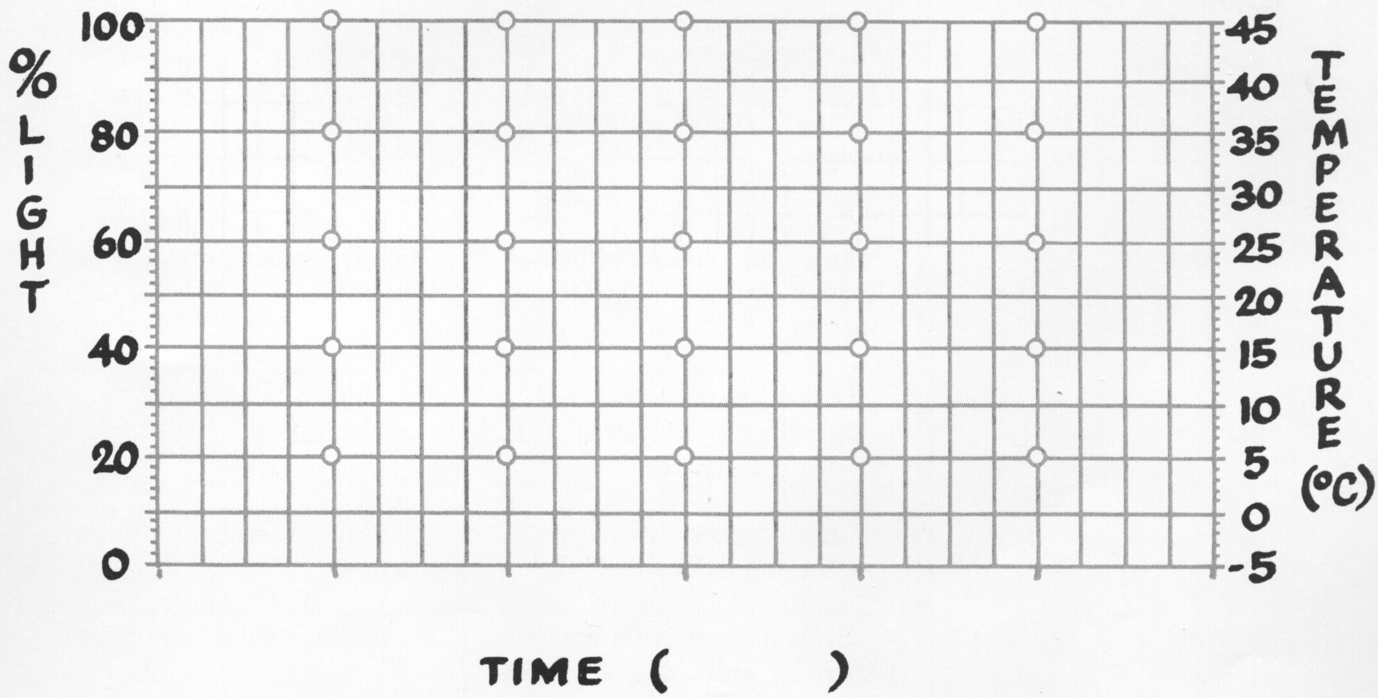
____

DATA TABLE (Highlighted Numbers)

TIME	%LIGHT	TEMP. °C

TIME	%LIGHT	TEMP. °C

TIME	%LIGHT	TEMP. °C



APPENDIX F
Trouble-Shooting Guide

I. Problems with %LIGHT Values

Symptom	*Possible Cause*	*Remedy*
Screen indicates <13% or less when light level is known to be higher	Interface not connected to jack 2.	Connect Interface to controller jack 2.
	Interface connection is loose so green light bottom of Interface not on.	Push 9 pin connector firmly in place in controller jack 2.
	Light Sensor not plugged into orange paddle input.	Plug in Light Sensor.
	Light Sensor connection is loose.	Plug Light Sensor in more firmly.
	Broken connection inside AtariLab™ Interface or connector cable.	Replace Interface.
	Broken connection inside Light Sensor.	Replace Light Sensor.
Screen indicates >100% when light level is known to be lower.	Sensor has a short circuit.	Replace Sensor.

II. Problems with Light Assembly

Symptom	*Possible Cause*	*Remedy*
Light Assembly lamp not lit.	Interface not connected to jack 2.	Connect Interface to controller jack 2.
	AtariLab Interface connection loose so indicator light at bottom of Interface not on.	Push 9-pin connector firmly in place in controller jack 2.
	Light Assembly not plugged into red power input on Interface.	Plug in Assembly.
	Light Assembly connection is loose.	Plug Assembly in more firmly.
	Broken connection inside AtariLab Interface or connector cable.	Replace Interface.

	Broken lamp or connection inside Light Assembly.	Replace Light Assembly.

III. Problems with Analyzer Wheel or Polarizer

Symptom	*Possible Cause*	*Remedy*
View through Polarizer and Analyzer not clear at 0° setting.	Axis of polarization on Analyzer Wheel or Polarizer not aligned properly.	Replace Analyzer Wheel and Polarizer.
View through Polarizer and Analyzer not blocked (reduced) to dim purple light at 90±5° setting.	Axis of polarization on Analyzer Wheel or Polarizer not aligned properly.	Replace Analyzer Wheel and Polarizer.

IV. Problems with Temperature Values

See Section I of Appendix H in the *AtariLab Starter Set Manual and Temperature Module Project Guide.*

V. Problems with Cartridge.

Symptom	*Possible Cause*	*Remedy*
Strange shapes on screen, program not functioning properly, or screen stays on one color.	Defective AtariLab Light Module Cartridge.	Replace cartridge.
	ATARI Computer out of order.	Contact ATARI Service Center to arrange for repair.
Fuzz on screen.	Printer or other electrical equipment near TV screen.	Turn off interfering electrical equipment.
Can't move past screen displaying Plug in Sensors.	Interface not properly connected to jack 2.	Plug in interface and check for firm connection.
	Orange Light Sensor not plugged in.	Plug Light Sensor into orange paddle input and check connection.
	Orange Light Sensor connector broken.	Replace sensor.

VI. Problems with Printing Graphs on EPSON Printer.

See Section III of Appendix H in the *AtariLab Starter Set Manual and Temperature Module Project Guide.*

VII. Problems with Summary Data on Disk

See Section IV of Appendix H in the *AtariLab Starter Set Manual and Temperature Module Project Guide.*

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