

# Light Experiment

by

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## 1. Introduction

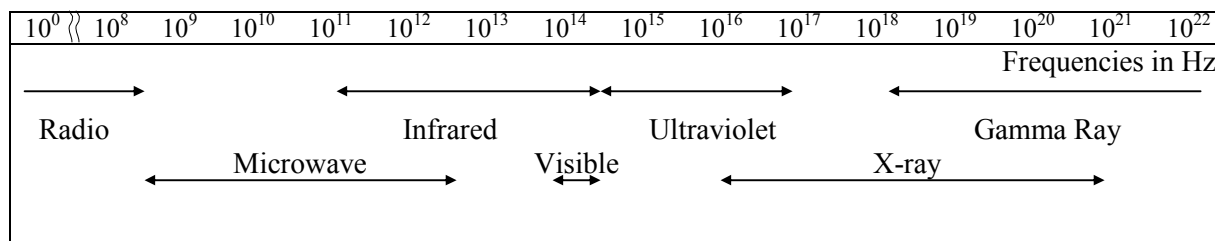
Have you ever imagined what life would be like without light? The prospect seems entirely dreadful. It is impossible to comprehend the notion of living in total darkness. It may seem that light merely makes our lives more comfortable, yet light is one of the most basic and fundamental needs for our continued survival. Light is the fuel that drives *photosynthesis*. Photosynthesis is the process by which various organisms, most notably plants and trees, convert carbon dioxide (CO<sub>2</sub>) into organic material. Through photosynthesis plants release oxygen, the necessary ingredient in the air that we breathe, into the atmosphere. Although we can appreciate that we need light, it is much harder to explain what light actually is. It is an intangible quantity in that we can sense light without actually being able to touch or quantify it. What are its properties? How does it behave? In this experiment, we will observe certain characteristics of light such as reflection and refraction. In addition, we will study why some materials allow light to pass through while others absorb it. We will investigate these properties through two mechatronic experiments that utilize electrical sensors to provide sensitive measurements of light. Typical sensors that are sensitive to light include photoresistors, photodiodes, phototransistors, solar cells, and infrared detectors. We will conclude this investigation by suggesting some challenging mechatronic projects related to light and light sensors.

## 2. Background

### 2.1. Light

The human visual system is activated when retina in the eye is stimulated by an external input. The external input, which in this case is a form of electromagnetic radiation, is called light or specifically visual light. Visual light has wavelengths ranging between 400 nanometer (nm) and 750 nm, which is a very narrow range out of the entire spectrum of electromagnetic radiation (only one-thousandth of a percent). Broadly speaking, infrared and ultraviolet radiations can be called light as well. See [3, 5, 14] for more details.

Table 1: Electromagnetic spectrum



The exact scientific definition of light has been a source of controversy for many years. In current scientific literature, light is treated both as a particle and a wave. This dual nature helps explain some commonly observed phenomenon of light, such as reflection, refraction, transmission, and absorption, which are briefly discussed in the sequel. See [5, 7, 14] for more details.

### Reflection

When light hits an object some of the light bounces off the surface, while the remainder is absorbed by the object. We call the light that bounces off the surface the reflected light. To determine the angle at which the light reflects, point a flashlight at a mirror and draw a line, normal to the mirror, from the point where light hits it. Next, we define the *angle of incidence* as the angle between the normal line and the light hitting the surface. Similarly, we define the *angle of reflection* as the angle between the normal line and the reflected light. It can be shown that the angle of reflection is the same as the angle of incidence. Shortly, we will experimentally verify that the angle of reflection equals the angle of incidence. See [3, 5, 7, 14] for more details.

### Refraction

The speed of light in a vacuum is a constant,  $c = 2.9997 \times 10^8$  m/s. The velocity,  $v$ , of light in any medium is given as follows

$$v = f \times \lambda$$

where  $f$  is the frequency of the light and  $\lambda$  is the wavelength of the light. The velocity of light in any medium will always be less than the speed of light in the vacuum, and is a property of the medium. The frequency of the light, however, is constant, since it depends only on the source of the light. Therefore, the wavelength  $\lambda$  must decrease to preserve equality. When light enters a medium at some angle, relative to the normal line, the light slows down at an uneven rate. This occurs because a portion of the light has already entered the medium, slowing it down, while a portion is still traveling at a higher velocity. A mechanical analogy is that of a long cylinder rolling on a pavement towards a grassy area at an angle to the boundary. One end of the cylinder reaches the grass first, slowing it down, and causing the cylinder to rotate through an angle towards the normal line [14]. Similarly, light is bent (or the direction of light is changed) at the boundary of two media as light travels from one medium to another. When light is bent, we say that it has been refracted. We define the index of refraction,  $n$ , for a given material as the ratio of the speed of light in the vacuum to its velocity in that medium

$$n = c/v.$$

The angle of refraction for a beam of light traveling from medium 1 to medium 2 is given by Snell's Law

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

where  $\theta_1$  and  $\theta_2$  are the angles between the normal and the respective paths of the light. From this equation it is obvious that refraction is a reversible phenomenon. It is also clear that if the light is incident perpendicular to the boundary, the light will continue to travel along its original path. An interesting result of refraction's dependency on the velocity of light is that light of different wavelengths, that is to say of different colors, will have different indices of refraction. This enables a prism to separate the incident light into the entire spectrum of visible light. Also, the depth of a pond is perceived to be less than its actual depth due to the phenomenon of refraction. See [5, 7, 14] for more details.

### *Transmission*

All matter is made up of many atoms. Atoms consist of neutral, positive, and negative charge carriers, *viz.*, neutrons, protons, and electrons, respectively. It is useful to think of the electrons as though they are bound to specific atoms, although this may not necessarily be the case. The electrons will vibrate if they are excited by an energy oscillating at one of several specific frequencies. The frequencies that cause the electrons to vibrate depend on the atomic composition and structure of the matter. Light, being a form of electromagnetic radiation, is one type of energy source. If the frequency of the light incident upon a material is much higher or lower than the frequency required for the electrons in the material to vibrate, then the light will simply pass through the material unaffected. See [3, 5, 7, 14] for more details.

### *Absorption*

If the frequency of the light is similar to one that causes the electrons in a material to vibrate, the electrons will begin to vibrate when they are exposed to the light. Therefore, no light will pass through the material, and the temperature of the material will increase. This is because the electromagnetic energy of light is converted to heat energy in the material. See [3, 5, 7, 14] for more details.

### *Color*

Subtractive color mixing is an interesting phenomenon that is a direct result of a material's ability to affect the absorption of light. What is commonly known as *white* light is actually a combination of all the various wavelengths that make up the visible spectrum. When white light is incident upon a material, the light's energy is separated. Part of it may be reflected while some of it may be refracted. Similarly, some of the light may be absorbed, while the rest of the light is transmitted. The visible spectrum includes light of many wavelengths. Each distinct wavelength corresponds to a specific color. Although there are infinite distinct wavelengths in the visible spectrum each corresponding to a distinct color, we broadly separate the spectrum into the following colors, Red, Orange, Yellow, Green, Blue, Indigo, and Violet, commonly referred to by the mnemonic ROY G. BIV. Of these colors, we refer to red, yellow, and blue as the *primary* colors. A material may appear red, for example, because the light of all other wavelengths is absorbed by the material, and only the red light is reflected and/or transmitted. A material appears *black* if it absorbs light of all wavelengths in the visible spectrum. Colors other than those in the visible spectrum are created when a material reflects and/or transmits more than one color. For example, cyan is created by materials that reflect and/or transmit blue and green light only, which combine to create a color that we call cyan. In this manner many thousand distinct colors, tones, and shades can be created. See [3, 5, 8] for more details.

## 2.2. Light sensors

### *Photoresistors*

A photoresistor is a resistive element that is sensitive to light. It is usually made from cadmium sulfide (CdS). Its resistance is extremely large under dark conditions, in the range of mega-ohms, and very low, only a few hundred ohms, when exposed to light. We can therefore use a photoresistor to detect lighting conditions because the voltage across, or the current through, the photoresistor will vary with respect to the intensity of light incident upon it. See [11, 13] for more details. Figure 1, [4], depicts two photoresistors, and Figure 2 shows the common schematic used to represent a photoresistor. The arrow drawn through the resistor indicates that the resistance of the element is variable, while the filled arrows indicate that the element is sensitive to incident light.



Figure 1: Photoresistors

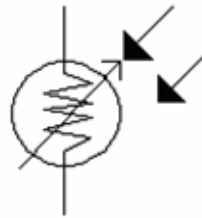


Figure 2: Schematic of photoresistor

*Photodiodes*

A simple diode is a semi-conductor element that allows current flow in only one direction. A light emitting diode (LED) emits electromagnetic radiation when a voltage is applied across its terminals in the forward bias direction. Photodiodes are similar to light emitting diodes except that the roles of the input and the output are reversed. That is, light emitting diodes ‘turn on’ like a light bulb when current flows through them. Conversely, photodiodes pass current depending on the light intensity incident upon them. When exposed to light, a photodiode allows current to flow. In the absence of light, a photodiode will prevent the flow of current. This is analogous to a photoresistor in the absence of light, when the resistance becomes exceedingly large so that current does not flow through it. See [13] for more details. Figure 3, [4], depicts photodiodes. The common representation for a photodiode is shown in Figure 4.

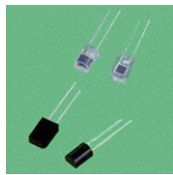


Figure 3: Photodiodes

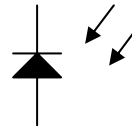


Figure 4: Schematic of photodiode

*Phototransistors*

One common transistor is an NPN bipolar junction transistor (BJT). These are three lead semi-conductor elements. The leads are commonly labeled as base, collector, and emitter. In this type of transistor, when the base is at a slightly higher potential than the emitter, roughly 0.6V, and a small current flows from base to emitter, a much larger current flows from collector to emitter. The most common phototransistors are BJT transistors where the base lead has been replaced by a light sensitive surface. When this surface is exposed to light, the base to emitter pair will pass current, allowing a larger current to flow from collector to emitter. Conversely, when this surface is placed in the dark, current cannot flow from the base to emitter. Therefore, no current flows between the emitter-collector pair. See [12, 13] for more details. Figures 5, [10], and 6, [12], depict phototransistors and their schematic representation, respectively.



Figure 5: Phototransistors



Figure 6: Schematic of phototransistor

### *Infrared detectors*

Infrared light has a longer wavelength (or shorter frequency) than the red light, placing it just outside the spectrum of visible light. Therefore, we cannot see it without special devices. Unlike visible light, however, infrared radiation makes up a sizable percentage of the electro-magnetic radiation spectrum. Therefore, there is a much larger assortment of materials that are sensitive to infrared radiation. A partial list of such materials includes lead sulfide (PbS), lead selenide (PbSe), and mercury cadmium telluride (HgCdTe). See [6] for more details. In order to use an infrared detector, an infrared emitter is also required. The emitter is chosen so that the frequency of electro-magnetic radiation generated is in the range of energies that the detector is sensitive to. Figure 7, [9], shows an infrared detector.



Figure 7: Infrared detector

## 3. Equipment list

### *Board of Education (BOE) with Basic Stamp 2 (BS2)*

The combination of the BS2 embedded within the BOE will serve as the microcontroller that monitors the experiments that you are about to do. The BS2 is a 24 pin Dual Inline Package (DIP) integrated circuit (IC). It is based on Microchip Inc.'s PIC 16C57 microcontroller. The BS2 is powered by a 6-14V direct current (VDC) power supply. An onboard voltage regulator provides a steady 5VDC output to the BS2. The BS2 comes with ROM, 2KB Electronically Erasable Programmable ROM (EEPROM), and a small amount of RAM. The BS2 is programmed in PBasic language, the instruction set that is stored in the BS2 ROM. The user defined program is downloaded into the EEPROM from a PC to the BOE using a DB-9 serial cable. The excess EEPROM can be used for long term data storage. The BS2 has 16 general purpose digital input/output (I/O) pins that are user defined. The high position on a digital I/O pin refers to a 5VDC and a low position on a digital I/O pin refers to a 0VDC (ground potential). Each pin can source (supply) a maximum current of 20mA and sink (draw) a maximum current of 25mA. The 16 I/O pins on the BS2 at any given time can source/sink a maximum of 40mA/50mA. If using an external 5VDC voltage regulator, these limits apply to each group of 8 pins, P0-P7 and P8-P15. Exceeding these current source/sink limits or establishing a voltage on a pin greater than 5VDC will damage the BS2. See [11, 13] for more details.

A limitation that often arises when using the BS2 is the lack of support for floating point variables. Utilizing floating point operations like division in the absence of floating point variables may lead to mathematical errors due to truncation. The largest variable or constant that can be stored on the BS2 is of *word* size (16 bits), which has a numerical range of 0-65,535 in decimal notation.

A BOE and BS2 are depicted in Figure 8 [9]. The BS2 is placed, in the same orientation as shown, in the IC socket in the lower left corner of the BOE.

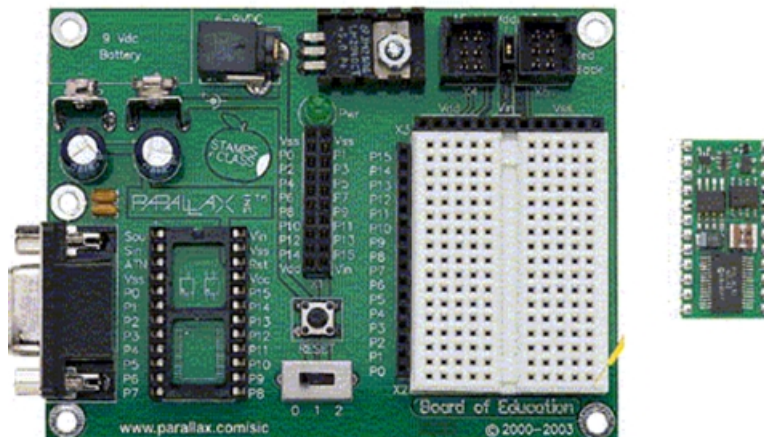


Figure 8: Parallax Board of Education with a Basic Stamp 2 at right

*Reflection experiment test bed*

The reflection experiment test bed will be used for both light reflection and absorption experiments. It consists of a light source and light sensor that can each be rotated independently in the horizontal plane. A common laser pointer is used as the light source. A photoresistor is used as the light sensor. The test bed was built so that the source and sensor have a common origin. The light source emits light directed at this common origin. The test bed has been constructed so that the user can change the material that light is incident upon. This facilitates the determination of the angle of reflection as well as the amount of light a particular material will absorb. Rotation of both light source and sensor is performed using servo motors, commonly called servos. A servo is a DC motor with built-in position control. Servos can be interfaced quite easily with a BS2. In these experiments, the servos direct the light source/sensor to any specific angle using the PBasic *pulsout* command. The intensity of the reflected light is measured using a simple resistor-capacitor (RC) circuit in conjunction with the PBasic *rctime* command, where the capacitor in this circuit is constant. This command instructs the BS2 to measure the amount of time it takes to charge/discharge the capacitor in the circuit to a specified level. This time is related to the values of the resistance and capacitance present in the circuit. Since the resistance of a photoresistor decreases with increasing light intensity, smaller *rctime* values correspond to higher light intensities. In the event of extreme darkness, the resistance of the photoresistor becomes large, which results in a situation where the time exceeds the storage size of a variable on the BS2 thus returning a null value. See [11, 13] for more details. A complete circuit schematic for the reflection experiment test bed can be found in Appendix A.

Figure 9 is an overhead view of the reflection experiment test bed. The left hand of the Figure 9, labeled *incidence*, houses the light source. The right hand side, labeled *reflection*, houses the light sensor.

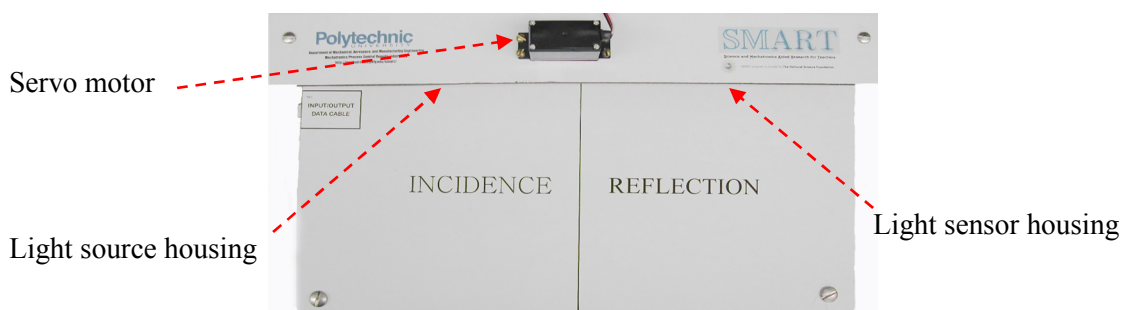


Figure 9: Top view of the reflection test bed



Figure 10 is a head on, frontal view of the test bed showing the light source/sensor arms. The light source/sensor each rotates, independently, in the plane coming out of the figure. The light source is located on the left hand side of the figure, and the light sensor is on the right hand side of the figure. In the center of the figure is the experimental material used to reflect the light. The black box at the top of Figures 9 and 10 is the servo motor used to control the rotation of the light sensor. The servo use to control the light source is below the test bed, hidden from sight in these two figures.

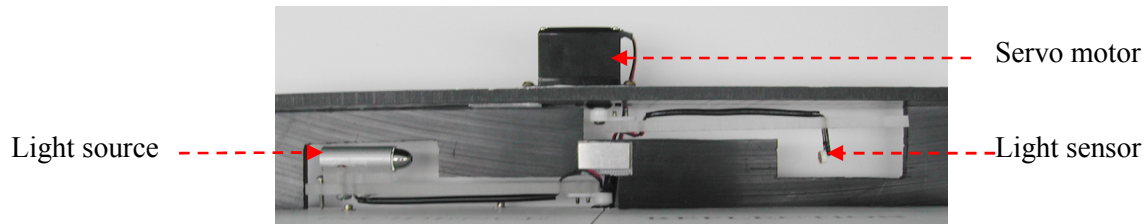


Figure 10: A view of the reflection test bed

### *Refraction experiment test bed*

The refraction experiment test bed will be used to measure the index of refraction for various media. It consists of a light source, a light sensor, and a tank for holding various liquid media. As in the reflection experiment, a laser and photoresistor are used as the light source and light sensor, respectively. The laser is rotated by a servo about a point at the front of the tank. The photoresistor, connected to the BS2 using an RC circuit, moves along the base of the tank. The light sensor displacement is measured by a linear potentiometer in an RC circuit. The intensity of the refracted light is measured using the *rctime* function. Similarly, the linear position of the light sensor is measured using the *rctime* function. The sensor moves along a screw, its motion controlled by a DC motor. The speed of the motor can be controlled by varying the voltage supplied to the DC motor. Reducing the supplied voltage causes a decrease in the motor's rotational speed, while increasing the supplied voltage will cause an increase in the motor's rotational speed. The minimum voltage that should be applied is 50% the manufacturer's voltage rating. Similarly, one should not exceed the upper limit of 130% of the manufacturer's voltage rating. Exceeding these thresholds overstrains the motor and can cause permanent damage. Directional control is achieved by reversing the polarity of the supplied voltage. To control a DC motor with a microcontroller an H-Bridge circuit, known as such because its schematic resembles the upper case letter h, is often employed. An H-bridge uses two I/O pins on a microcontroller to control the supplied voltage's polarity. If both inputs are kept low, the motor will be in the "stalled" state and will not rotate. By driving one of the pins high, while maintaining the low position on the other pin, the motor will rotate in a given direction. The motor will rotate in the opposite direction if the state of each pin is reversed. Care should be exercised not to drive both pins high simultaneously as this "forbidden" state will damage the motor. Small motors that can run on 5VDC and small amounts of current can be interfaced with a BS2 directly. However, most motors, including the one used in this experiment, require a larger supply voltage and current. Therefore, the inputs from the microcontroller are not connected directly to the motor, but through relays or switches to a regulated voltage supply. In this particular test bed, reed relays are used, although transistors of either the field effect (JFET) or channel (MOSFET) variety can be used as well. When one uses reed relays or JFETs in the H-Bridge it is advisable to place a reverse biased diode in parallel with the relay or transistor to prevent a reverse voltage spike, or back emf, from damaging other electronics in the circuit. Because it is sometimes difficult to determine the correct electronic components needed to construct an H-Bridge, it is usually easier to use a commercially available H-Bridge IC such as the LMD18200 (manufactured by National Semiconductor). See [1, 13] for more details. A complete circuit schematic for the refraction experiment test bed can be found in Appendix A.

Figure 11 is a top view of the refraction experiment test bed. The tank that holds the various experimental media lies in the center of the test bed. At the bottom of the figure lie the light sensor and the linear potentiometer that measures its displacement. The light source is at the top of the photo, and is shown perpendicular to the tank. On the left of the figure, the electrical circuitry that operates the test bed is shown.

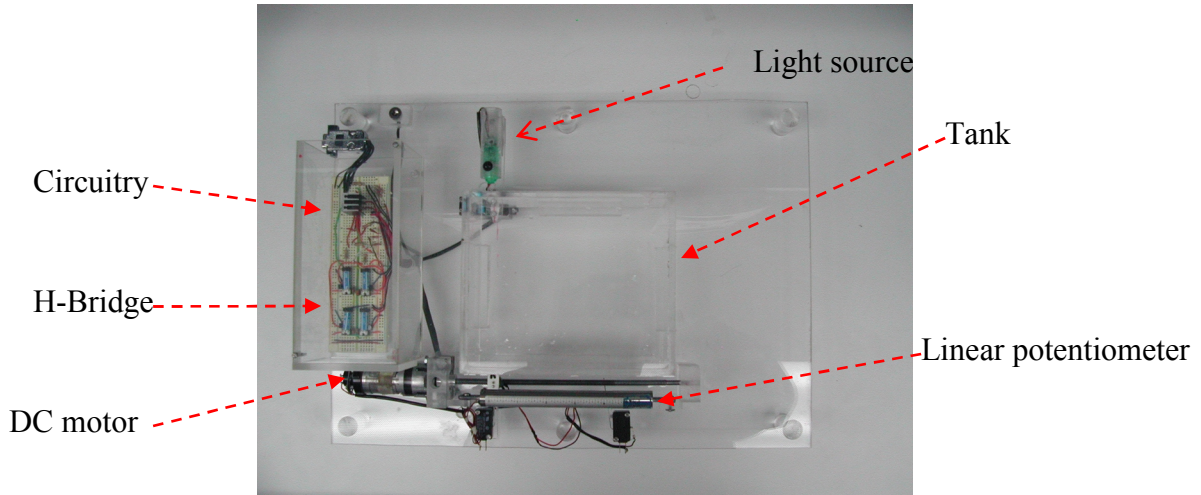


Figure 11: Top view of the refraction experiment test bed

Figure 12 depicts the light source used in this test bed mounted on the servo motor used to rotate it. In this figure, the light source is directed perpendicular to the tank holding the experimental media.

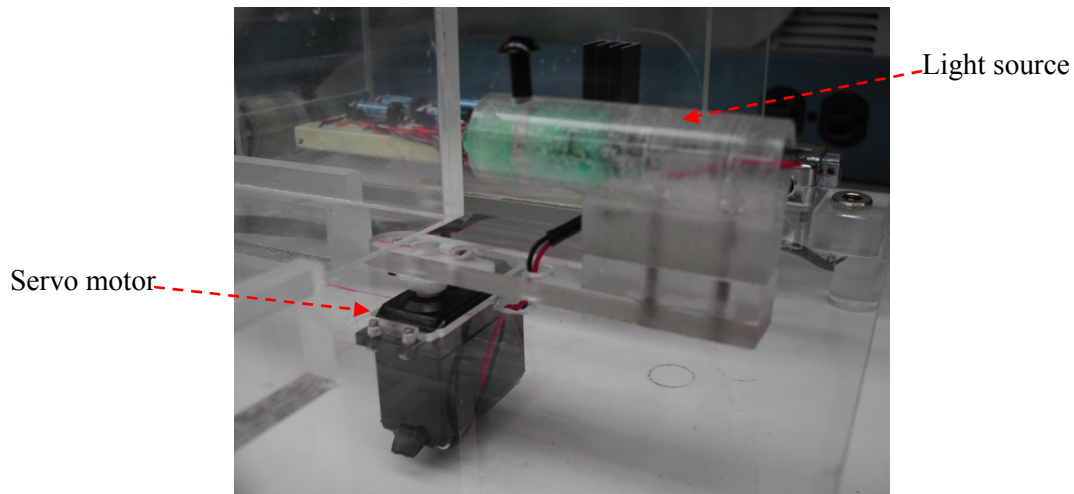


Figure 12: View of the light source used in the refraction experiment test bed

Figure 13 depicts the light sensor used in this test bed. The sensor moves along the linear potentiometer in the center of the figure. In this figure the sensor is at its starting position, the extreme right of the linear potentiometer. Just below the potentiometer are two limit switches. The limit switches are used to detect when the sensor has reached the start and end positions.



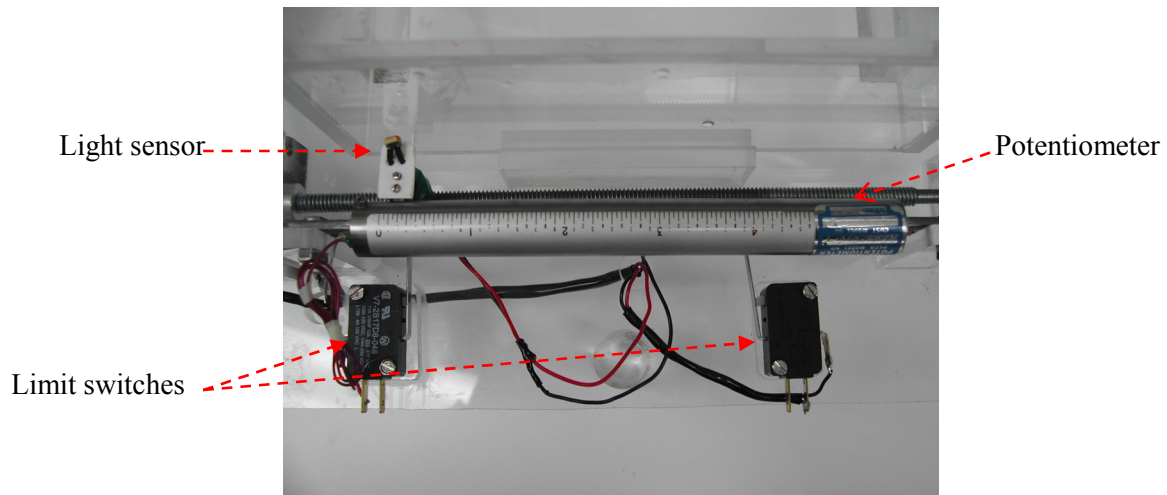


Figure 13: A view of the light sensor used in the refraction test bed

The circuit schematic for the H-bridge used for motor control in this experiment is shown below in Figure 14.

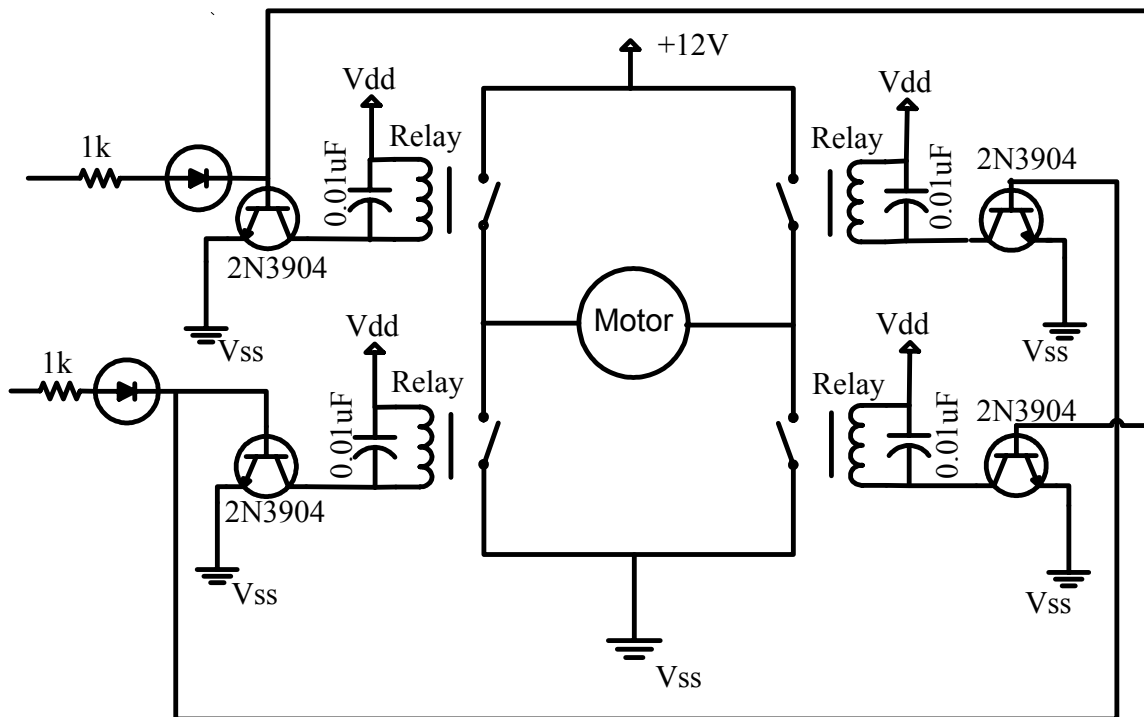


Figure 14: Schematic of an H-Bridge using reed relays

## 4. Experimental procedure

### 4.1. Reflection measurement and absorption experiment

Figure 15 is a diagram of the reflection experiment. The light source, represented by the arrow can be moved to a fixed location along the arc between the horizontal and vertical reference positions within quadrant 1. The light sensor, represented by the circle can be moved along an arc within quadrant 2 determining the angle of reflection.

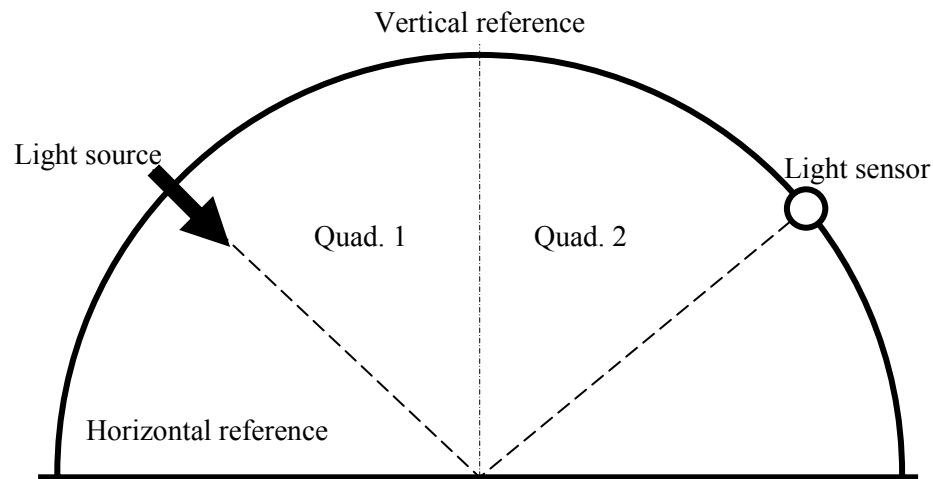


Figure 15: Reflection experiment

#### Goals:

1. Experimentally verify that the angles of incidence and reflection are equal.
2. Study how a material affects the light incident upon it, i.e., whether it is reflected or absorbed

#### Reflection experiment procedure

1. Place an experimental material on the plate on the back panel of the test bed taking care that it is properly centered.
2. Connect the BS2 to the test bed with the DB-9 adapter located on the test bed, and to a computer with another DB-9 serial cable.
3. Connect the BS2 to a 9VDC power source (either a power adapter or battery may be used).
4. Download the *Reflection.bs2* file to the BS2.
5. At the prompt regarding choice of experiment, opt for the reflection experiment.
6. At the prompt enter a value for the angle of incidence within the specified range.
7. The BS2 will then rotate the sensor along an arc ( $0^\circ$  to  $90^\circ$ ) and collect data from the light sensor.
8. The BS2 will analyze the sensor data and search for the most activated output value.
9. The BS2 will conclude this segment of the experiment by moving the sensor to the point corresponding to the highest light intensity and display the angles of incidence and reflection.
10. To continue with this experiment follow the prompts regarding restarting the experiment.

#### Absorption experiment procedure

1. Replace reflective material with another (non transparent) material on the plate.
2. Repeat steps 2-4 from the reflection experiment.
3. At the prompt, opt for the absorption experiment.
4. The BS2 will rotate the light source and sensor to  $45^\circ$  angles.

5. The BS2 will take an initial reading on the sensor to establish the ambient light conditions.
6. The BS2 will then turn on the light source and take a second reading on the sensor.
7. The BS2 will conclude this segment of the experiment by displaying the absorptivity of the material.
8. To continue this experiment follow the prompts regarding restarting the experiment.

### Discussion

How do different materials affect the intensity of the reflected light? What role does this dependency play in the selection of material for clothing? For which applications would highly reflective materials be beneficial? (Hint: Biker shirts/shorts). When would you want materials that absorb light? (Hint: camouflage clothing).

## 4.2. Refraction measurement and transmission experiment

Figure 16 is a diagram of the refraction experiment. The light source, represented by an arrow, can be moved to a fixed location along the arc between the horizontal and vertical reference positions. The tank holds liquid media of various indices of refraction. The light sensor, represented by a circle at the bottom of the figure is moved along a line parallel to the base of the tank. The dotted line represents the path the light would travel in the absence of refraction. A solid line, as marked, represents the actual path that the light travels along, due to refraction at the boundary between the air and the liquid media.

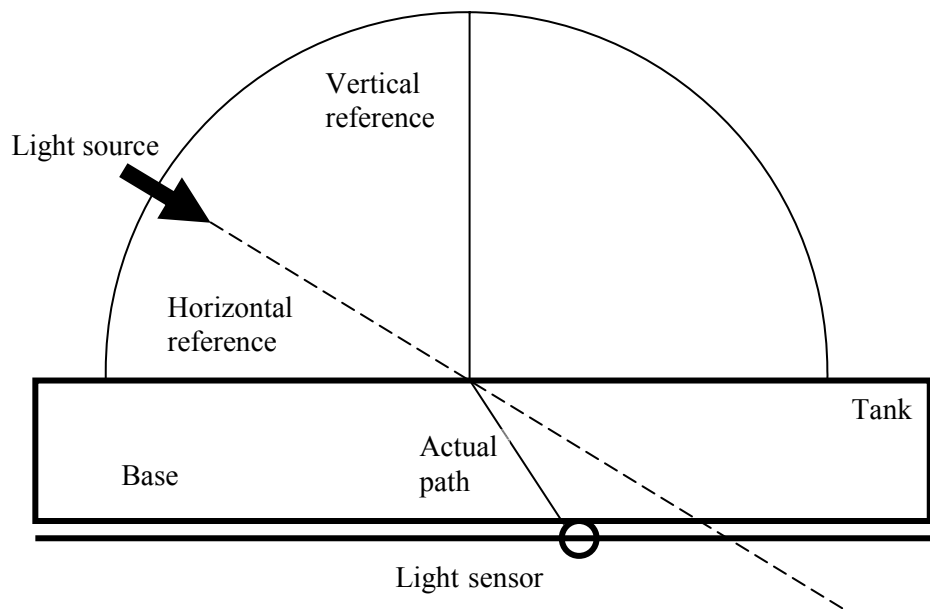


Figure 16: Refraction experiment

### Goal:

1. Measure the angle of refraction for different materials, given a light source and angle of incidence, and establish the affect a material has on the angle of refraction.

### Refraction experiment procedure

1. Fill tank with an experimental liquid (e.g., water, oil, sugar solution, etc.).
2. Download the *Refraction.bs2* file to the BS2.
3. Connect the BS2 to the test bed with the DB-9 adapter located on the test bed, and to a computer with another DB-9 serial cable.
4. Connect the BS2 to a 9VDC power source (either a power adapter or battery can be used).
5. Download the *Refraction.bs2* file to the BS2.

6. At the prompt enter a value for the angle of incidence within the specified range.
7. Follow the prompts regarding the input of an angle of incidence.
8. The BS2 will then collect data on the light sensor and search for the most activated output value.
9. The BS2 will monitor the data on the light sensor and after moving the sensor along its maximum range will calculate from the linear position the index of refraction for the liquid.
10. Follow the prompts regarding continuing the experiment
11. If you have finished the experiment, the BS2 will conclude by displaying the average index of refraction for the liquid.

### Discussion

How do different materials affect the transmission of light? Do different materials affect intensity, color, or both? Why might it be beneficial to allow only certain colors of light to pass through? (Hint: cameras, eyeglasses). Why would you want the entire incident light to pass through? (Hint: think of windows and light as a source of electromagnetic radiation).

## 5. Suggested projects

- 1) Artificial intelligence eye model
- 2) Infrared: Use an infrared emitter-detector pair to sense movement.
  - a. Home/office theft alarm: Interruption of the infrared beam will result in an alarm going off.
  - b. Automated door opener: Interruption of the infrared beam will result in a door opening. The door will close when detection of the beam is reestablished.
    - i. Using a microcontroller (digital controller)
    - ii. Using electronic parts only (analog controller)
- 3) Visible light region (using photoresistors)
  - a. Night time driver safety system: Design a system that automatically deflects an automobile's headlights downward, out of the eyes of driver's of incoming traffic. Figure 17 demonstrates this concept [2].



Figure 17: Night time driver safety system

## 6. References

- [1] Online: <http://www.dprg.org/tutorials/1998-04a/>, web site of Dallas Personal Robotics Group containing information on the theory of and applications for H-Bridges.
- [2] Online: <http://www.get-free-clipart.com/gallery/album72?&page=1>, web site of Get Free Clipart containing free clipart, fonts, and pictures.
- [3] Online: <http://www.glenbrook.k12.il.us/gbssci/phys/Class/light/u12l2a.html>, web site of The Physics Classroom containing high school physics tutorials.
- [4] Online: <http://www.globalsources.com>, web site of Global Sources containing product and trade information for volume buyers of electronic components.
- [5] Online: <http://science.howstuffworks.com/light.htm>, web site of How Stuff Works, Inc. containing the article How Light Works.
- [6] Online: <http://www.judsontechnologies.com/prod.htm>, web site of Judson Technologies, LLC. manufacturer and distributor of high performance infrared detectors and accessory products.

- [7] Online: <http://library.thinkquest.org/13405/>, web site of See the Light containing tutorials on the properties of light.
- [8] Online: <http://nebula.uakron.edu/~light/color/grating/grating.html>, web site of the Department of Physics at the University of Akron containing light experiments.
- [9] Online: <http://www.parallax.com>, web site of Parallax, Inc. manufacturer and distributor of Basic Stamp microcontrollers containing technical specifications and user manuals.
- [10] Online: <http://www.radioshack.com>, web site of RadioShack, a retailer of electrical components.
- [11] Online: <http://www.stampsinclass.com>, web site of Stamps in Class containing educational resources for Basic Stamp microcontrollers.
- [12] Online: <http://zeus.eed.usv.ro/misc/mirrors/cc/circuit.cmp/trans2.htm>, web site of Circuit Central containing information, schematics, and pictures of electrical components.
- [13] V. Kapila, *Course Notes for Mechatronics ME 3484*, Polytechnic University, Brooklyn, NY, (2003).
- [14] R.A. Serway and R.J. Beichner, *Physics for Scientists and Engineers*. Saunders College Publishing, Orlando, FL, 5<sup>th</sup> Ed., (2000).



Appendix A: Circuit schematics

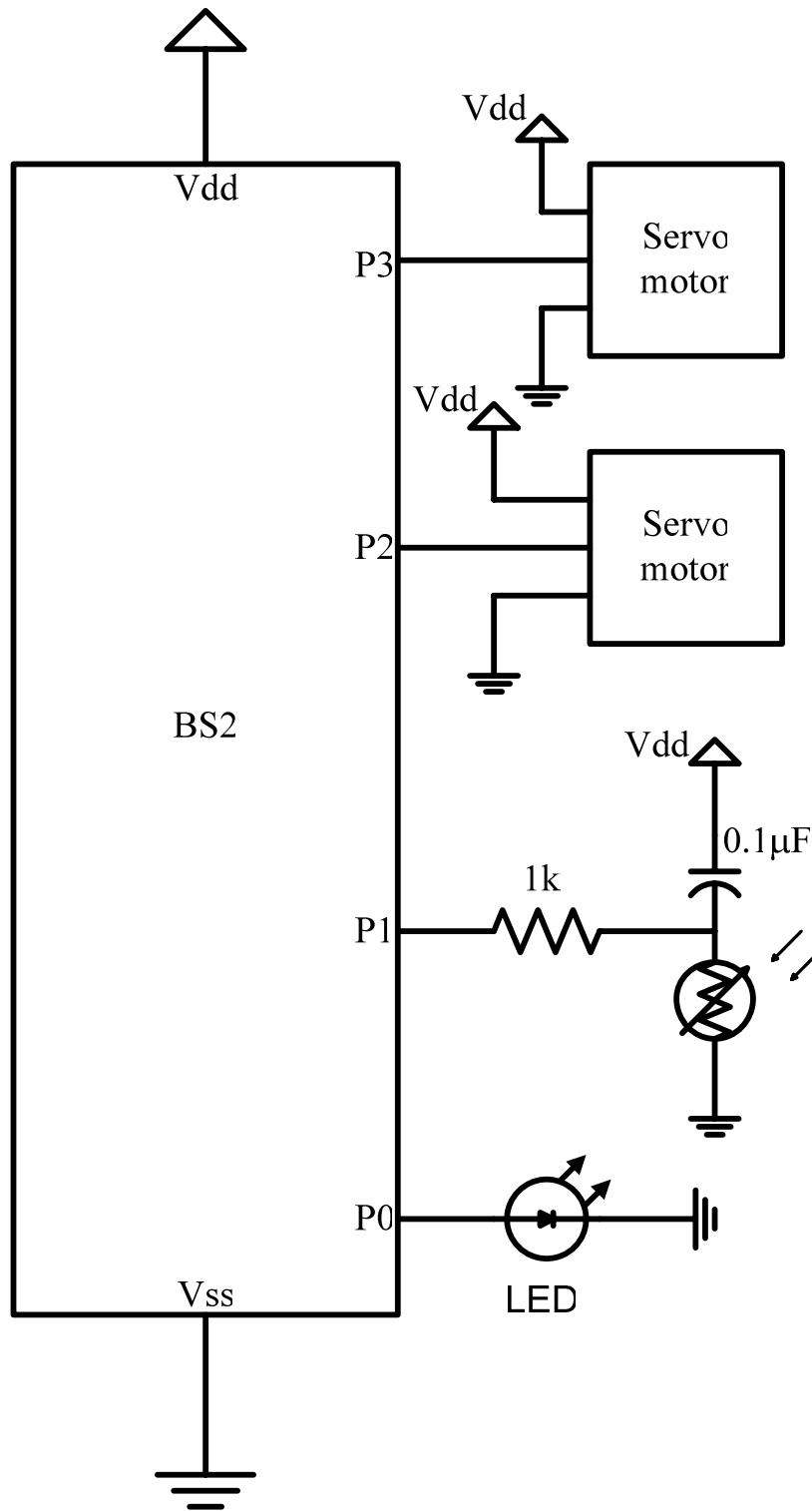


Figure A1: Circuit schematic for the reflection experiment test bed

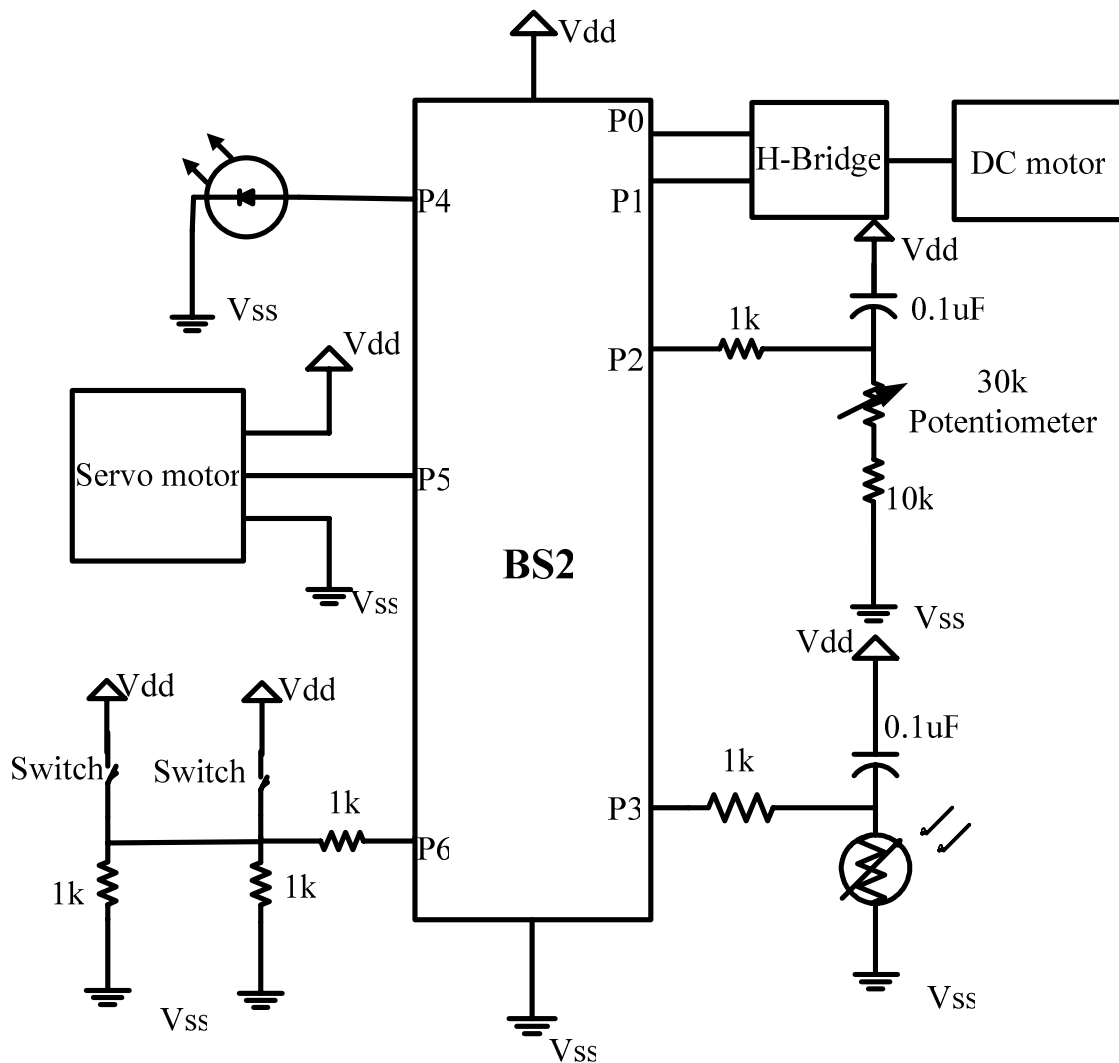


Figure A2: Circuit schematic for the refraction experiment test bed