

# Building a Visible Light Spectrophotometer

<b>Subject Area(s)</b>	Physical Science, Science and Technology
<b>Associated Unit</b>	None
<b>Associated Lesson</b>	None
<b>Activity Title</b>	Visible Light Spectrophotometer
<b>Header</b>	Insert image 1 here, right justified to wrap

## Image 1

ADA Description: Students using a LEGO® built spectrophotometer

**Caption:** Students using a LEGO® built spectrophotometer

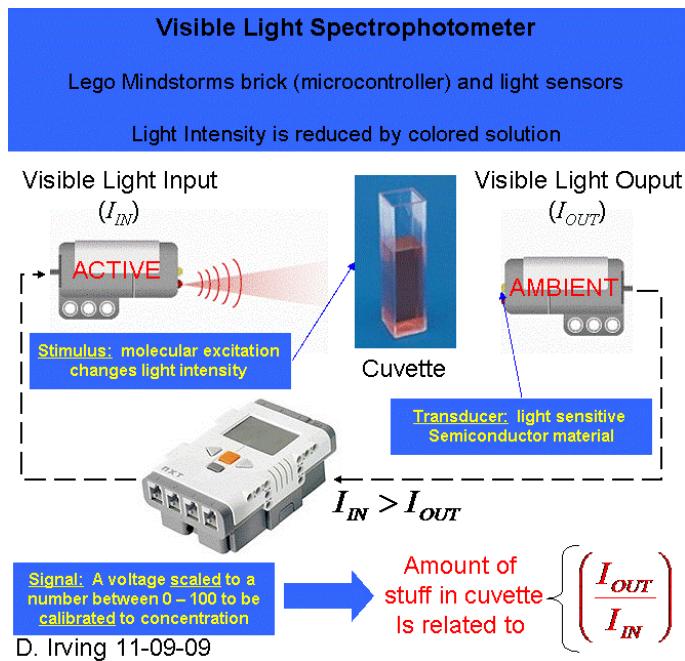
**Image file name:** vis\_spec\_image\_2.jpg

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Student Picture in Activity

<b>Grade Level</b>	8 (9-12)
<b>Activity Dependency</b>	None
<b>Time Required</b>	90 minutes
<b>Group Size</b>	3 – 5
<b>Expendable Cost per Group</b>	\$3 to \$10

Insert Figure 1 here, centered



**Figure 1**

**ADA Description:** Overall of operation and design schematic of a visible light spectrophotometer

**Caption:** Overall of operation and design schematic of a visible light spectrophotometer

**Image file name:** vis\_spec\_figure\_1.gif

## Summary

This activity introduces students to visible light spectroscopy and chemical kinetics. In spectroscopy light is used to characterize a liquid solution or suspension. The idea is that the intensity of light that enters a liquid is lowered as the light energy excites species, thus the light is emitted at a lower intensity. As shown in Figure 1, the idea of the anatomy of a sensor can be used to explain the operation of a visible light spectrophotometer. The following mnemonic is used: Sensors = Stimulus + Transducer + Signal (STS). Here it is clear that, a sensor is a device that detects an external stimulus, and changes that stimulus to a detectable signal, by means of a transducer. For our device, light intensity (the stimulus) is detected, the semi-conductor material responds by becoming a conductor of electricity (transducer), and the resulting current flow is the sensor response (signal). The end goal is to design a crude visible light spectrophotometer (vis-spec) or more correctly a colorimeter using the NXT brick, and two NXT light sensors. One sensor is used in the light active mode as a visible polychromatic light source (LED), and the other is used in the light inactive mode as a

detector (via a phototransistor). This process is repeated for a reference solution, and a ratio of intensities is calculated, that relates directly to amount of substance in the liquid.

### **Engineering Connection**

The engineering connection rests on the student's ability to grasp the principles of operation and design the vis-spec appropriately. A minimum distance between the cuvette and light sensors is required to lower the effects of ambient light, and refraction and reflection. A key question for students is as follows, will the spectrophotometer function independently of distance, if there is no ambient light? (That is, would the device function in the dark?) Another design variable that is highly dependent on the measured process is the sample interval, and its effect on the resolution versus total time of measurement. This is a result of the instrument, in this case the NXT microcomputer, that has a sample interval limit of 1msec and a storage capacity of 4,500 data points. Clearly the students will have to compromise, or choose optimal design parameters to correctly capture the process being measured.

### **Engineering Category**

Category 3: Engineering Analysis or Partial Design

### **Keywords**

Spectrophotometer, colorimeter, sample interval, chemical kinetics, phototransistor

### **Educational Standards**

New York State Chemistry:

Standard 1—Analysis, Inquiry, and Design Scientific Inquiry

Standard 5—Technology Education Engineering Design

Standard 6—Interconnectedness: Common Themes Systems Thinking

Standard 7—Interdisciplinary Problem Solving Connections

### **Pre-Requisite Knowledge**

Knowledge of chemistry is helpful but it is not necessary. Familiarity with the LEGO® Mindstorms kit and the Robot C programming language is a necessary prerequisite. Students must be familiar with exporting acquired data to a spread sheet format .csv.

### **Learning Objectives**

After this activity, students will be able to:

- Explain what a spectrophotometer is
- Describe how a visible light spectrophotometer (vis-spec) may be used to characterize a solution

- Design and build a vis-spec through estimation of key design parameters such as process time, sample interval, minimization of ambient light levels, and minimization of reflection and refraction as a function of distance
- Obtain process data via the NXT and transfer that data to a spreadsheet environment
- Qualitatively describe a chemical reaction process and compare expectations to measured data
- Qualitatively relate the amount of dye, bleach, and solution temperature to the speed/rate of reaction
- Describe the so-called process reaction curve, in terms of delay, change of light level, and steady state
- Explain how an increase in light level relates to a decrease in concentration of dye

## Materials List

Each group needs:

- Disposable cuvette
- Disposable pipette
- Household bleach
- Food coloring
- Scotch tape
- Black electrical tape
- Cardboard boxes, of various sizes
- Water
- Ice
- Hot water

To share with the entire class:

- LEGO® Mindstorms Kit, including 2 light sensors
- Robot C programming language

## Introduction / Motivation

Determining the concentration of a substance taking place in a reaction, also called a reactant, is important in the chemical industry. .

## Vocabulary/Definitions

Word	Definition
Spectrophotometer	A device used to measure the transmission of light through a liquid sample, and determining a concentration based on comparison of light intensities between the sample and a reference sample. The light is usually of one wavelength.
Colorimeter	A device similar in operation to a spectrophotometer, but measures color and relates that to concentration.

Chemical Kinetics	The study of the rates of chemical reactions, and the influence of experimental conditions such as concentration of reactants and temperature.
Sample Interval	The time interval in between measurements.
Phototransistor	A semiconductor device that allows more current flow as the intensity of light shining on the device increases.
Pipette	An instrument used to measure and dispense specific volumes of liquids.
Cuvette	A tube that allows the transmission of light through its walls over a defined path length, and does not absorb or reflect light significantly.
Oxidation	A chemical reaction where the number of available electrons is decreased as oxygen is added. Dyes often have a large number of electrons that determine the color reflected

## Procedure

Students will build a visible light spectrophotometer, supplied with scotch tape, black electrical tape, cardboard boxes, and an NXT kit. The end goal is measure the chemical reaction taking place when Blue#1, a common food dye, is oxidized by common household chlorine bleach, under various conditions.

## Background

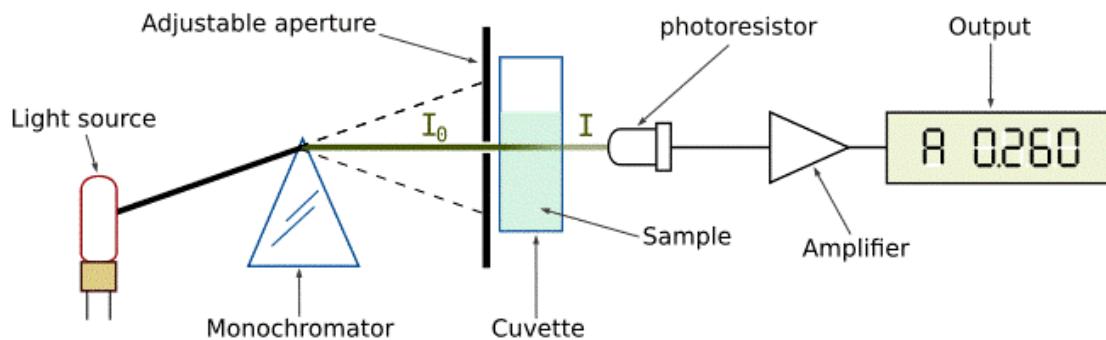
The characterization of chemical processes is important in many industrial and scientific endeavors. One robust method uses light transmitted through a transparent tube, in this case a cuvette. The requirement is that this cuvette does not decrease the intensity of light much itself, while measuring the concentration of a substance in the liquid. Another necessary property is the need for a non-interacting and fast response time. Light transmission satisfies these requirements, since the chemical reactions that are measured using this method are not influenced by light. Since the speed of light, through an opaque to transparent, liquid is still close to the speed of light in a vacuum,  $3 \times 10^{10}$  cm/s, through a path length of 1cm, we are near the times (or time scales) of some of the fastest chemical reactions. We are, however, limited by the measurement devices such as the phototransistor, and the data acquisition device, in this case the NXT microcomputer. This is where careful engineering becomes valuable. In this experiment, a Robot C program, written, to acquire data from a light sensor is provided, with design options for determining the sample rate and the total measurement time. As an example of the response time of the NXT sensors and data acquisition capabilities the response of an incandescent light source is tracked (see Before the Activity).

An oxidation reaction for Blue#1 is to be monitored, using the NXT light sensors, setup in the vis-Spec configuration as depicted in image 3 below. The reactants used are 40cc of a 1 drop Blue#1/100cc water, and 5cc of household bleach. The 5cc of bleach is added after 60sec. A monotonic increase is expected as the bleach oxidizes the

Blue#1. During the oxidation reaction the electrons, responsible for the intense blue color seen, are used up as they combine with oxygen. The delay (figure 3) observed after adding the bleach and an increase in the light level, is due to diffusion. That is, it takes a certain amount of time for the bleach to mix evenly in the Blue#1 solution.

In our device many wavelengths of visible light are transmitted through the cuvette and detected by the phototransistor. For commercially available devices, as shown in image 3, one wavelength of light is used. The polychromatic light is filtered by a monochromator, a device that behaves like a prism, figure 2.

**Insert Figure 2 here, centered**



**Figure 2**

**ADA Description:** Principle of operation of a visible light spectrophotometer

**Caption:** Principle of operation of a visible light spectrophotometer

**Image file name:** vis\_spec\_figure\_2.gif

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File:Spetrophotometer-en.svg

The monochromatic wavelength of light that is used depends on the color of the solution being measured. The idea is that a maximum transmission is measured when the correct wavelength of light is used.

### **Before the Activity**

The intensity of an incandescent light bulb that is turned off can be tracked, to get a feel for the sensitivity and speed of data acquisition. Students should try three different sample intervals 100msec, 10msec, and 1msec. All other variables such as steady state light intensity and sensor positioning should be fixed for all three experiments. The data should show qualitatively the response of a Tungsten filament. That is, when there is no electrical current provided to the lamp, the filament cools down. This rate of cooling is proportional to the rate of change of light intensity, and both processes can be approximated by a first order decay. While we are not measuring the speed of light with

an NXT, we can capture the dissipation of heat and radiant energy, when power is removed.

**Insert Image 2, centered**



**Image 2**

**ADA Description:** Image of a typical spectrophotometer

**Caption:** Image of a typical spectrophotometer

**Image file name:** vis\_spec\_image\_2.jpg

**Source/Rights:** Open Source,

[commons.wikimedia.org/wiki/File:Spektrofotometri.jpg](https://commons.wikimedia.org/wiki/File:Spektrofotometri.jpg)

## With the Students

After the Before the Activity section the students should take part in a brainstorming session, where the objective is presented, along with the design constraints discussed above. In Bedford Academy where the activity was developed, the students formed teams, where tasks were delegated. The major tasks were building, programming, and data acquisition. These three tasks are structured in that the basic design of a vis-spec has a certain configuration that allows for light transmission; this is the building section. The program is simple and easy to understand but rather involved; the solution is to provide a pre-written Robot C program, “Diff n React.c”. Although the program is prewritten there are key design variables that must be specified and tailored to the user’s implementation. These variables are the sample interval, “waittime”, and the constrained total time of measurement based on a 4,500 data point memory limit. The data acquisition task is structured in the sense that an excel sheet is provided, so that the acquired data can be easily visualized. Data acquisition is still open ended in that

the placement of the bleach, can affect repeatability. If the liquid is agitated, the characteristic delay from diffusion will be different.

**Insert Figure 3 here, centered**



**Image 3**

**ADA Description:** Image of a LEGO® visible light spectrophotometer

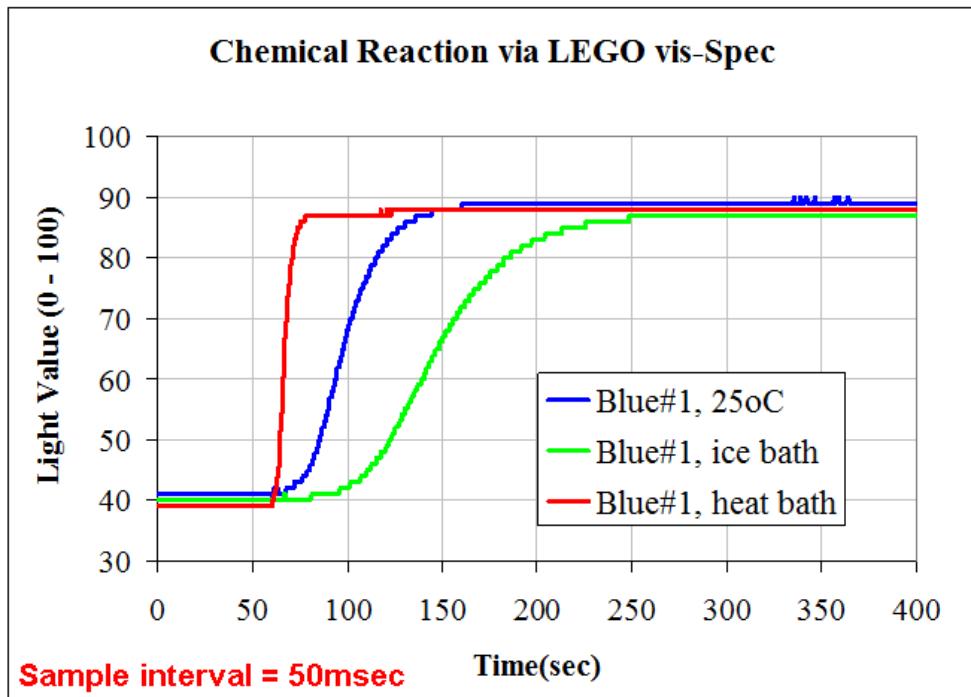
**Caption:** Image of a LEGO® visible light spectrophotometer

**Image file name:** vis\_spec\_image\_3.jpg

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Image 3 shows a simple vis-spec setup, while the results from such a device, exposed to ambient light, are presented in figure 4. Here the bleach was added after 60 sec for all three experiments. The experiments differed in the ambient temperature.

**Insert Figure 4 here, centered**



**Figure 3**

**ADA Description:** Data results of LEGO ® visible light spectrophotometer

**Caption:** Data results of LEGO ® visible light spectrophotometer

**Image file name:** vis\_spec\_figure\_3.gif

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## Attachments

Diff n React.c

poly-nyu-logo.jpg

vis\_spec\_figure\_1.gif

vis\_spec\_figure\_2.gif

vis\_spec\_figure\_3.gif

vis\_spec\_image\_1.jpeg

vis\_spec\_image\_2.jpeg

vis\_spec\_image\_3.jpeg

vis\_spec\_worksheet.xls

## Safety Issues

- Bleach should be used with care. It is a mild corrosive that should not be inhaled or made to come in contact with skin. Bleach should be used in a laboratory setting with gloves and goggles. An emergency eye wash should be available. Bleach also ruins clothing, and should not be used without protective laboratory clothing. Hot

water is potentially dangerous. Finally, food dye can also ruin clothing, by permanently staining certain fabric.

## **Troubleshooting Tips**

It is important to remember that the resolution obtained depends strongly on the sample interval. In addition to this, there is a maximum of 4500 data points that can be stored in NXT microcomputer. Estimates must be made regarding the sample interval and the total time of the reaction. The surfaces of the cuvette must be clean and free of condensate, from lowered or raised temperature.

## **Investigating Questions**

None

## **Assessment**

### **Pre-Activity Assessment**

None.

### **Activity Embedded Assessment**

1. Why is light transmission a good candidate for measuring a chemical reaction?
2. What is necessary in order to use a spectrophotometer to measure a chemical reaction? What are the “stimulus” and “signal” in such a device?
3. Could a colorimeter be used to estimate the mixing of two liquids? Could a tracer or dye be used?
4. After the temperature variation is completed, how could varying the volume of bleach, while keeping the total volume fixed, systematically change the speed of reaction as in figure 3.

### **Post-Activity Assessment**

A photodetector is a device that serves as a transducer from light intensity to current produced. A phototransistor is an example. These are used extensively in chemistry and physics to characterize materials; our spectrophotometer is an example. Research the idea of turbidity as applied to microorganism growth, and write a description of how the vis-spec could be used for that purpose. How could the growth of say yeast be monitored? Is a tracer or dye necessary.

**Activity Extensions**

None

**Activity Scaling**

- For lower grades, the design parameters could be predetermined and the activities carried out as is.

**Additional Multimedia Support****References**

1. Spectrophotometry. Wikipedia. Accessed January 29, 2010. <http://en.wikipedia.org/wiki/Spectrophotometry>.

**Other**

None

**Redirect URL**

<http://GK12.poly.edu/amps-cbri/>

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