Build a Monochromator

Summary

This activity is aimed at the high school level, but it could very easily be adapted for use at the middle year level. Building a monochromator will provide students with an opportunity to explore the properties of light and the spectrum within a practical context. It could be used either as a culminating activity to make use of information learned about the properties of light or as an exploratory beginning activity to generate interest in the topic. Students will be provided with a light source, a prism, and materials with which they can select the wavelength of light projected. To be successful they will have to consider the appropriateness of their light source, the distance and angle placement of the prism, the shape, size, and placement of their 'filter', and the 'sample' onto which they are projecting the selected wavelengths of light.

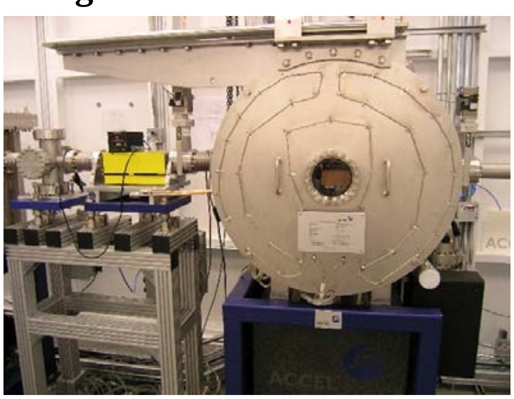
Pan-Canadian Objectives

Science Grade	Knowledge	Science, technology, society and the environment	Skills	ATTITUDES
10-12	327-7	116-1, 116-3, 116-6, 116-7, 117-8	212-all, 213-2, 214-14, 214-15, 214-16, 214-18, 215-all	436, 439, 440, 441, 442, 443, 445
7-9	308-8, 308-11	109-4, 111-all, 112-4, 112-12	208-all, 209-1, 209-6, 210-13, 211-all	422, 425, 426, 430, 431

Materials

- Several light sources (at least one for each group): suggestions include overhead projector, flashlights, microscope lights, dissecting scope light, you might consider deliberately providing lights that won't produce a spectrum (laser pointers, etc)
- Prisms (we used right angle prisms, but some felt 60 degree prisms might work better and it might be interesting to experiment with different shapes of prisms)
- A filter to block unwanted wavelengths such as cardstock, cardboard, several pieces of paper, piece of plastic, etc with several sized slits and one round hole cut into it

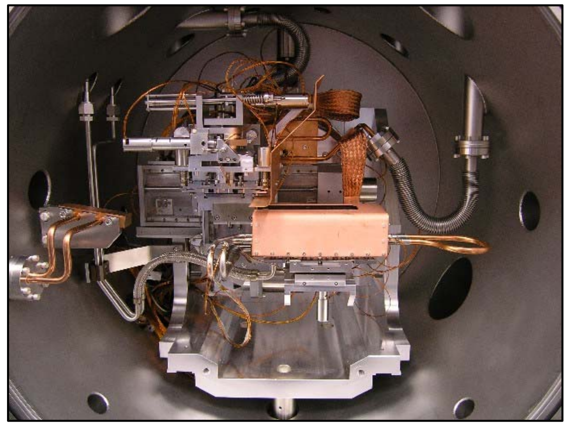
Background



Synchrotron radiation includes wavelengths of light from the Infrared to hard X-ray regions of the spectrum. To gather useful data, scientists select wavelengths appropriate to the experiment they are conducting and block the rest from interacting with the sample. The process involves directing the light, within a vacuum tube, from the synchrotron down a beamline. The light then passes through a monochromator where the light is refracted by two crystals and the desired X-ray wavelengths are focused onto the sample with mirrors. Other monochromators might use gratings or slits to refract the light.

This is the monochromator on the crystallography beamline. It will select X-ray wavelengths of light from 6.5 to 18.0 keV. The light travels through the vacuum tube from right to left.

This photo is of the inside of the monochromator. The light enters on the right, travels through the silicon crystal housed in the brass box and the selected wavelengths exit through the hole on the left.



Photos courtesy of Dr. Pawel Grochulski, CLS Staff Scientist and Alan Duffy, CLS Science Associate

Some more details regarding CLS beamlines and their applications can be found in the CLS Activity reports: http://www.lightsource.ca/brochures and in the general explanation of a synchrotron: http://www.lightsource.ca/education/whatis.php

Activities

1. Students need to be somewhat familiar with the purposes of a synchrotron monochromator. To summarize, a monochromator selects particular wavelengths of light to be focused onto a sample.

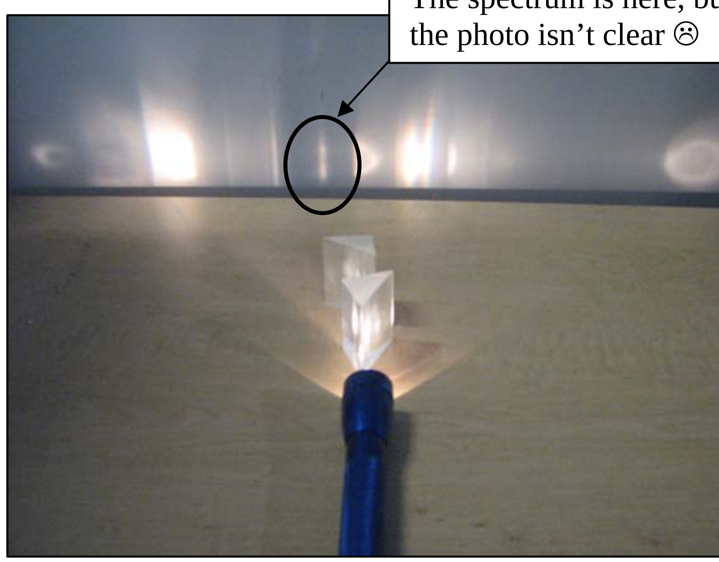
2. Divide students into small groups. Four students per group would be ideal with one student responsible for manipulation of each component (light source, prism, and selector) and one for recording. Instructions for the students are provided on the student pages. Some clarification and direction is provided below.

STEP ONE – THE SPECTRUM

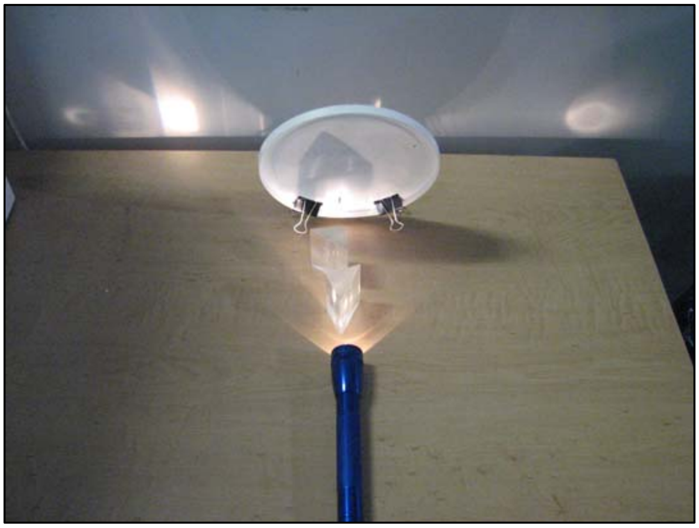
Students will be provided with a light source and at least one prism to create a clearly defined spectrum. They should explore

- where the prism should be placed
- how many prisms are required
- the distance between the prism(s) and the light source
- the distance between the prism(s) and the 'screen' (a piece of plain white paper or a white wall works well)

Some may find more success if they focus the light from a large source with a slit or pinhole cut into something opaque (paper, plastic or cardboard).



STEP TWO – SELECTING WAVELENGTH



Once students have developed a sharp spectrum projected either onto a wall or a piece of white paper, they need to figure out how to 'select' wavelengths (colour). They will need to choose an appropriate material (cardboard, cardstock, paper, plastic, etc) that will block the other colours out without diffracting at the edges very much (cardboard, for example, will fray at the edges more and thus produce more diffraction, reducing the sharpness of the selected wavelength/colour). Students will also have to determine that a slit will work better than a pinhole. The size and shape of that slit will also make a difference. Students will also have to determine where the best place is for the filter to be placed (closer to the paper/wall or to the light source).

STEP THREE – REFLECTION

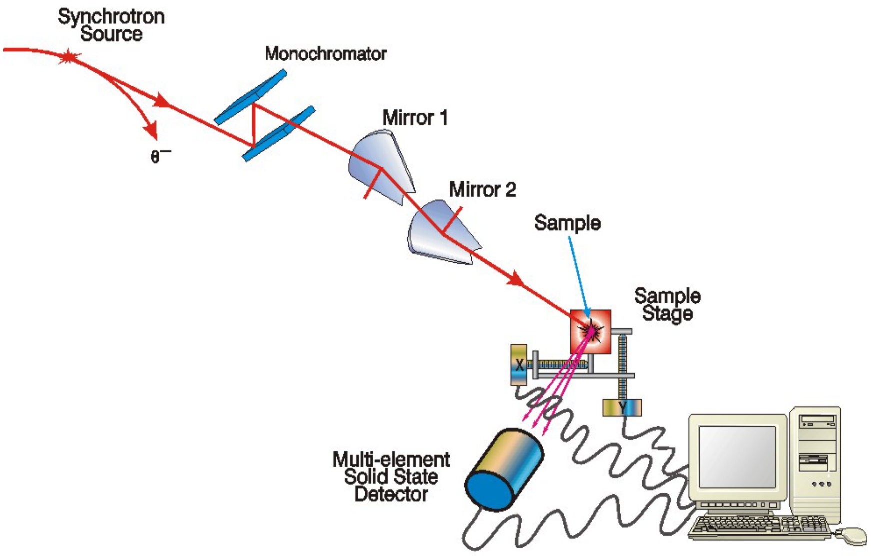
Students will be asked to provide comments and advice as if they were consultants on beamline design. Questions are designed to help them reflect on the location of components, influences from the environment such as lighting and vibration, properties of light, etc. It might be interesting to allow the students some time to peruse the technical explanations of CLS beamlines for comparison purposes. This information can be found at http://www.lightsource.ca/experimental/. Where there is a web site specific to a beamline, follow that link as there will likely be more information (some in more general terms) as well as photos of the actual beamline components.

STEP FOUR – DEMONSTRATION

Students demonstrate for the class that their beamline is capable of selecting any given visible range of light and describe any 'advice' they would have for others undergoing a similar experience.

Student Pages – Build a Monochromator

The purpose of a beamline is to take synchrotron radiation, select the particular wavelengths of light required for the experiment and focus it onto a sample in order to gather information about the molecular structure of that sample. The monochromator is that part of the beamline that selects the wavelengths of light required.



Your objective in this activity is to be able to select a particular wavelengths of visible light (determined by the colour) using the materials provided. Choose your materials carefully and record your results.

STEP ONE – THE SPECTRUM

1. Choose one of the light sources provided by your teacher.
What type did you choose? ______________________________
What properties did you expect that source to have that lead you to choose it?

2. Holding your prism in front of the light and slowly turning it, try and produce a spectrum that sharply defines the colours of the rainbow. You will have to explore where to hold the prism to get the sharpest image. You may also have to explore where and onto what surface your spectrum is projected. You may find it helpful to use more than one prism if that is available.

3. How far away from your light source does your prism have to be to produce a sharp spectrum? What happens when you move the prism closer?

What happens when you move the prism farther away?

4. Estimate the angle at which your prism is held relative to the direction of the rays of light. ___________________ How does changing the angle affect your spectrum?

5. What are you directing your spectrum onto? ____________________ Does the distance of the 'sample' to the light source affect your spectrum? If so, how?

Distance of the 'sample' to the prism

Does the material of the 'sample' itself affect the spectrum? (colour, size, etc)

STEP TWO – SELECTING A WAVELENGTH

6. Now that you have managed to project a nice sharp spectrum onto your 'sample', you need to install your 'selector'. Choose something from the material provided by your teacher that will be able to block out all of the light that you don't need. Cut a hole or slit in that material designed to only allow one colour of light through to shine on your 'sample'. You will have to figure out how and where to place your selector to get the best results. Record your findings!
What material did you choose for your selector? ___________________ Why?

How did you cut your opening for your selector?
Did you have to change the shape or size of that opening? Why or why not?

How far away from your prism have you located your selector?
What happens when you move it closer to your prism? Further away?

7. Draw a scale diagram of your beamline (like the one provided of a CLS beamline).

STEP THREE – REFLECTION

Now that you have successfully built a beamline capable of selecting wavelengths of light within a visible colour range, it is time to reflect on what worked for you and why. Answer the following questions as if you were consulting a company wanting to use this type of activity for actual research, based on the explorations that you have experienced.

7. What kind of light source would work best? Why?

8. What suggestions do you have for the location of the prism? How should it be held so that it works the best? Do you think a different kind or shape of prism would work better?

9. What suggestions would you make regarding the environment this beamline will be used in? For example: should the room be light or dark; what kind of structure should hold the light source, the prism, the sample; how clean does the area need to be; etc

10. How did you determine the location of each component of your beamline? Why do those distances work best? What advice would you have for the designers of the research beamline?

11. What type of selector should be used and how should it be constructed. What things should the designers be careful of when they build their own beamline?

STEP FOUR – DEMONSTRATION

7. Demonstrate for your teacher and/or class that your beamline is able to select individual colours of light and share any reflections you feel are relevant to the class.