Exercise 6: Spectroscopy

How do astronomers know anything about parts of the solar system and universe that we (humans or the probes we send) have never physically touched? The answer lies in the light that is emitted or reflected by an astronomical object.

In this exercise, you will experimentally investigate objects that emit light energy and objects that absorb light energy, and how you measure this absorption or emission. To do this, you will need to know the term “electromagnetic spectrum” which is the whole range of energies (wavelengths, frequencies) that light can have. For this experiment, we will be interested primarily in the visible spectrum, a tiny subset of the electromagnetic spectrum.

The device you will use to measure the spectrum is the spectroscope (called the SCSpec in this experiment), which is basically a smart prism. A prism because, like its glass cousin, it separates light into its component colors (ROYGBV), and smart, because it can tell you what wavelengths are present in the spectrum.

Work in groups of three or four; the order in which you do questions #1–#6 does not matter.
Needed:  
• Laptop computer from the cart (pick from #1 to #7)  
• SCSpec spectroscope kit (in plastic tub)

Set up the spectroscope and laptop as stated in the laminated sheet that comes with the spectroscope kit. Make sure that you have a Desktop visible on the laptop before you plug the USB cable from the spectroscope into the laptop. Make sure the spectroscope is actually plugged into an electrical socket.

Follow the instructions on the laminated sheet to start up the software “SCSpec”. After clicking on the “Connect” button, it should quickly turn into a “Disconnect” button. If this does not happen, let me know! You should see a rainbow-like set of colors appear on the left of the screen.

Do not worry about “Calibration”; after setup, go directly to the back of the sheet to “Capturing Spectra”. You will not need to Save any of the data you collect since you’ll be writing it down, but you will need to make sure that Graph is visible. After clicking “Graph”, you should see a graph appear on the right of the screen.

1. a. Look at the graph and state what quantity the x-axis represents, and what units that quantity is in. Hint: see diagram on first page of this handout.

b. What quantity does the y-axis represent, and why might the units not be so helpful for this quantity?

2. a. Take the laptop and spectroscope outside (please be careful not to drop anything), and use the extension cord to plug in the spectroscope. Point the spectroscope at a piece of white paper that is reflecting sunlight. DO NOT POINT THE SPECTROSCOPE DIRECTLY AT THE SUN; the results are not useful. Sketch the graph below, giving numbers on the x-axis where useful.
b. While still outside, point the spectroscope at nearby shrubbery and sketch that graph below, again giving numbers on the x-axis where useful.

3. Indoors, point the spectroscope at the fluorescent light. Sketch the graph below, giving numbers on the x-axis where useful.

4. Indoors, obtain the ultraviolet (UV) box and carefully point the spectroscope up at the UV light. DO NOT LOOK AT THE ULTRAVIOLET LIGHT YOURSELF unless you wish to have cataracts. Sketch the graph below, giving numbers on the x-axis where useful.
5. a. Indoors, point the spectroscope at a low wattage light bulb. Try to do this in such a way as to minimize the amount of the fluorescent light pointed at the spectroscope. Sketch the graph below, giving numbers on the x-axis where useful.

b. Now point the spectroscope at a high wattage light bulb. Again, try to do this in such a way as to minimize the amount of the fluorescent light pointed at the spectroscope. Again, sketch the graph below, giving numbers on the x-axis where useful.

6. Just for grins, point the spectroscope at the surface of a dark object (like the table) and sketch its graph.
7. Find a gas discharge lamp with a **hydrogen** gas tube. Using the spectroscope pointed at the gas discharge tube with the appropriate gas, measure the wavelength of the emissions (pay attention to the units!). Unlike the previous parts, no graph is necessary but roll the cursor onto the peaks of the graph to get numerical data (look for the x-coordinate in the lower right of the screen). You may need to **calibrate** the spectroscope. Fill in the table with these data.

Find a gas discharge lamp with a **helium** gas tube, and do the same.

Repeat with the **oxygen** gas tube, and finally, the **water vapor** tube.

<table>
<thead>
<tr>
<th>Tube gas</th>
<th>Colors (lines) visible — list both the color and the wavelength (length units?)</th>
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<tbody>
<tr>
<td>Hydrogen</td>
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At this point, put away the laptop and spectroscope; make sure all the parts return to their rightful place.

**Data analysis and drawing conclusions from the data:**

8. a. First, do the Sun, light bulbs, and UV lamps **absorb** or **emit** light? Call these light **sources**.

b. Do surfaces like the table or the shrubbery absorb or emit light? Call these light **sinks** (or absorbers). How can you tell without using a spectroscope that they do?
9. a. Explore the phenomenon of absorption: In question 2 parts a and b, was there a difference in the graphs? State what difference(s) you saw in the graphs, and how this relates to absorption.

b. Specifically identify (using the aid of the diagram on the front page of this handout) what color was absorbed by the shrubbery. How does this make sense in light of the color you see reflected off the shrubbery?

10. Again, related to absorption, in question 2a, why did I have you use a white card to reflect sunlight into the spectroscope, as opposed to any other color card?

11. So when the graph of the spectrum of a light sink has a dip (that is, the intensity declines at some wavelength but recovers on either side of that wavelength), what does that tell you about the object that is the light sink?
12. a. Explore the phenomenon of emission: In question 5 parts a and b, was there an intensity difference between the two bulbs? Was there a peak wavelength (that is, the intensity increases at some wavelength but declines on either side of that wavelength) difference between the two bulbs?

b. What does this suggest to you about the material makeup (chemical composition) of the filament of both bulbs?

c. If what you say in part b is true, then would you expect the emission peak wavelengths from the fluorescent bulbs to be the same or different than the incandescent bulbs? How come?

d. Test your hypothesis from part c by looking at question 3. Were you right?

13. A friend of yours suffers from seasonal affective disorder (SAD) and says that her doctor prescribed sitting in front of a light source for an hour a day. She asks whether a fluorescent bulb or an incandescent bulb would be a better match for sunlight. Which would you recommend, and why?
14. So what is the cause of a graph of the spectrum of a light source having a dip? There are two possible answers, one of which is demonstrated by question 2b.

15. In what way was the result of question 4 surprising to you? In what way was the result not surprising?

Larger conclusions:

16. Do hydrogen and helium have distinct, different emission wavelengths? Let’s generalize; will emission wavelengths be useful for distinguishing different elements?

17. Thus, the solar spectrum (the spectrum of the Sun) is a mystery indeed. How can the Sun’s spectrum be so continuous (as opposed to the fluorescent or incandescent bulb, which have discrete spectra)? That is, what does the continuous nature of the solar spectrum tell you about the Sun? Hint: I have said that the Sun is made of hydrogen and helium. Is it made only of hydrogen and helium?

18. Examine the solar spectrum (either the one you sketched, or the one on the “Spectra of Different Elements” chart). From what source are the “missing” colors of the Sun’s continuous spectrum coming from?
19. What is the chemical formula for water? What are the chemical symbols for hydrogen gas and oxygen gas? So what is the difference between water vapor, and a mixture of hydrogen and oxygen gas?

20. Therefore, is visible light bright-line spectroscopy a good way to detect elements in a glowing object? Is visible light bright-line spectroscopy a good way to detect chemical compounds?

Applying the new understanding

On the next page is a table of stellar spectra; each “row” represents the emissions from a particular star. The star’s abbreviated name is given to the left of its spectrum; for instance, the first star is “10 Lacerta”, which is the tenth brightest star in the constellation Lacerta. The star’s spectral classification is given to the right.

Of interest to us are the apparently light vertical “lines” that appear at irregular intervals throughout each spectrum. These spectra are actually negatives — that is, most of the spectrum should be light-colored, and the lines should appear dark.

21. Do the lines therefore represent light emission or light absorption?

22. Based on your answer above, what is the cause of these “lines”? Note that your answer will depend on whether you believe these are emission lines or absorption lines!
The tick marks at the top of the spectra give the identities of the lines – in other words, what element/compound is responsible for the line. The letter is the chemical symbol of the element or compound; a Roman numeral I or a Greek letter indicates the neutral (not ionized) version of the element/compound. The Roman numeral II indicates a positively charged ion (1+) of that element/compound. The Roman numeral IV indicates a triply positively...
charged (3+) ion of that element/compound. Finally, the four digit Arabic numeral represents the wavelength in angstroms of that particular line.

Note: 1 angstrom = 0.1 nm

23. List an element that appears in both uncharged (neutral) and charged (ionic) form in a spectrum. Do they have the same wavelength absorption?

24. Of course, even ions can be heated. Recall that the Sun was not only made of hydrogen and helium. So, in addition to the source you cited to supply the “missing” colors of the Sun’s spectrum in question 18, what other source of emission do stars have?

25. Annie Jump Cannon’s spectral classification system was based on these lines. The table on the next page shows some unclassified stellar spectra. Based on the table of classified stellar spectra on the previous page, please classify the unclassified stars. You need not worry about the Arabic numeral; just put down a letter.

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