Ultraviolet-visible Spectroscopy
An analogy and learning cycle approach

This is the fifth lab of the five-lab experiment sequence. Each of these laboratories will be structured around a learning cycle and an analogical modeling activity.

Experiment 1. Making Experimental Observations
Experiment 2. Paper Chromatography
Experiment 3. Conservation of Mass
Experiment 4. Limiting Reactants
Experiment 5: Ultraviolet-visible Spectroscopy

Introduction:

Goals:
1. To be introduced to UV-vis spectroscopy and observe and analyze what energies of light are absorbed by known metal ions.
2. To construct an analogical model to gain insight about how light interacts with atoms.
3. To design an experiment to determine whether the energies of absorption are characteristic of metal ions.

Light and atoms:

Atoms consist of neutrons, protons, and electrons. Electrons are capable of absorbing energy. When this occurs, we say the electrons are in an excited state or at a higher energy level. However, electrons can only absorb certain amounts of energy. Because of this, energy levels are quantized or can only be a certain set of values.

Often, chemists use energy level diagrams (see image right) to represent the different energy levels that electrons in an atom can occupy. The ground state represents the baseline level of energy an electron has. Each line above the ground state represents an excited state, or a specific amount or level of energy the electron could have. Notice that lines are in specific positions on the energy scale that increases vertically. Each line position corresponds with an exact numerical quantity of energy that has been experimentally determined.
How do electrons gain energy to be promoted to an excited state or a higher energy level? Electrons can absorb energy associated with different wavelengths of electromagnetic radiation. For the electromagnetic radiation to be absorbed by the electron, the amount of energy must match the amount of energy the electron needs to reach a particular excited state.

Different wavelengths of electromagnetic radiation (see picture above left) are associated with different amounts of energy. The longer the wavelength, the lower the amount of energy. The shorter the wavelength, the higher the amount of energy. We call electromagnetic radiation with wavelengths between about 300 nm and 800 nm light.

The amount of energy (in Joules) associated with a particular wavelength can be calculated with Planck’s constant, the speed of light, and the wavelength (converted from nanometers to meters). For example, we can calculate that there are \( 3.97 \times 10^{-19} \) Joules associated with 500 nm light.

![Image of electromagnetic radiation wavelengths]

**Ultraviolet-visible spectroscopy:**

In Ultraviolet-visible spectroscopy, a chemical sample is exposed to a particular range of wavelengths of light. Electrons in the chemical sample may be able to absorb particular wavelengths of light if the energy associated with the wavelength matches the energy needed to promote that electron to an excited state.

![Diagram of ion sample in cuvette with light source, light detector, and computer]

The wavelengths of light that have too much or too little energy associated with them to coincide with the energy needed for an electron to be promoted will pass through the sample. A spectrometer (literally, “light-measurer”) detects the types of wavelengths of light that pass through the sample and are not absorbed (see picture above). It is then able to create a graph, called a spectrum, that tells you how much of each type of light (which wavelengths) was absorbed by the sample.
Understanding spectra:

Based on wavelengths of light that are transmitted through the sample, the computer generates a graph (called a spectrum, plural: spectra) of the various levels of absorbance of each wavelength.

The y-axis of the spectrum indicates absorbance. The x-axis shows the spectrum of light, or all the wavelengths that the sample was exposed to. The height of the blue squiggly line at various positions along the x-axis indicates how strongly the sample absorbed each of the wavelengths of light.

In the example spectrum on the right, we can tell that the scanned sample absorbs light at a wavelength of 640 nanometers. This “peak” has the highest absorbance (it’s the tallest). Next, we can see that the sample has a second peak at 425 nanometers, so it absorbs this type as well. Additionally, we can see which types of light (which wavelengths) are not absorbed by this sample: At 350 nanometers and from 500 to 550 nanometers, the absorbance is close to or at zero.

Spectra and energy:

By identifying the wavelengths with the highest absorbance (the peak maxima) in a chemical sample, we can calculate how much energy it takes to promote electrons to various excited states in that sample. For the sample above, based on the wavelengths (\(\lambda\)) of light the sample absorbs, we can calculate the changes in energy (\(\Delta E\) is the difference between the ground state and excited state energies). The peak maximum of 640 nm and 425 nm corresponds with energy changes of 3.10 x 10^{-19} Joules and 4.67 x 10^{-19} Joules, respectively. Notice the higher energy corresponds with the shorter wavelength.
Analogy Learning Cycle Laboratory Structure:

**Phase 1:** We will ask you and a partner to go into the lab, follow a procedure, and make observations about the wavelengths of light each sample absorbs.

**Phase 2:** You will then be asked to review material that provides an explanation about what you observed in lab and create an analogical model of the underlying chemistry at play.

**Phase 3:** Before going back into the lab, you will be asked to apply your understanding by designing an experiment. You and your partner will then go back into the lab to conduct your experiment and gather experimental results.

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**Pre-lab Assignment**

In your lab notebook, please prepare the following information and answer the questions. You must complete the pre-lab before coming to the lab meeting or you will not be permitted to go into the laboratory.

1. Please write a 2-3 sentence introduction to the lab.

2. Please create a safety information table including the chemicals used in the lab, the hazards associated with them, and any safety handling precautions. (See example.)

3. What can a spectrum tell you about how atoms in a solution interact with light?

4. Please think of one question you have about the material you read in the introduction and write it down.

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**Preparation before going to the lab:**

You should pair up for doing lab work in this experiment. If there are an odd number of participants in lab, then one group should have three people. Each pair of students should discuss and answer questions as they encounter them in this experiment. These questions are set off in the experiment (i.e. "Q:"). The questions offer guidance during the lab and writing the answers can help you practice taking notes in the laboratory. Each student is INDIVIDUALLY responsible for collecting the information needed to complete the lab report and post-lab portions of the experiment.

To use the spectrometer, you will need the log-in information for your ICN account. Your spectra will be sent to your ICN account and you will be able to access it from any computer. Spectra can only be sent to one lab partner’s account so please make arrangements before leaving lab for how you will
share this information with your partner.
Goggles are required at all times in the lab. There are no exceptions. If you have questions about safety, please do not hesitate to ask your laboratory instructor.

Materials:

<table>
<thead>
<tr>
<th>Chemicals</th>
<th>Equipment and Supplies</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25 M copper (II) nitrate for the Cu^{2+} ion solution</td>
<td>UV-VIS spectrometer</td>
</tr>
<tr>
<td>0.25 M nickel (II) nitrate for the Ni^{2+} ion solution</td>
<td>Cuvettes</td>
</tr>
<tr>
<td>0.25 M iron (III) nitrate for the Fe^{3+} ion solution</td>
<td>Cuvette holder and caps</td>
</tr>
<tr>
<td>0.25 M cobalt (II) nitrate for the Co^{2+} ion solution</td>
<td></td>
</tr>
</tbody>
</table>

**Phase 1 of the Learning Cycle: Making observations**

The following activities should be completed in the lab.

1. Obtain 5 similar, clean, dry cuvettes and a cuvette holder. Handle cuvettes with gloves so they stay clean.

2. Fill one of the cuvettes half full with distilled water. Label the cuvette, “blank.”

3. Fill another cuvette half full with the Cu^{2+} ion solution.

4. Prepare three other cuvettes for solutions of Ni^{2+}, Fe^{3+}, and Co^{2+}.

5. Place the cuvettes into the holder, cap them, and take the cuvettes along with your lab notebook to a UV-vis spectrometer.

6. Record the instrument name and type and the instrument number in your lab notebook. Ask your laboratory instructor to point out the parts of the spectrometer to you.

7. Log on to the UV-vis spectrometer software by entering your ICN account name (the same one that you use to access your Progress Page) in the requested space on the Interchemnet Data Acquisition program.

8. First, you will need to blank the instrument. Pick up the cuvette containing distilled water. You will notice that the cuvette is actually a rectangular shape. You will want to scan all of your samples so that the light travels the longest path through the cuvette. Use a Kim wipe to clean cuvette of smudges and then place it in the spectrometer sample holder.
9. Use the mouse to click on the Blank button. This will collect the value for the absorbance of both the cuvette and the water and will subtract this value from the samples to follow.

10. To scan the Cu$^{2+}$ solution, insert that cuvette into the instrument holder and click on the Scan sample button.

11. After you hit scan, the program:
   a. Scans your sample with the UV-vis spectrum (between 200 and 800 nanometers).
   b. Records the absorbance values at each of these wavelengths in a file.
   d. Generates a graphical representation of the data onto the computer screen. This graph is called a spectrum.
   c. Sends this file to the ICN server in order to place a copy in your account (The ICN program automatically saves your files, so you do not need to re-draw or record wavelengths and absorbances at this time).
   f. The computer generates a code for the file name of each spectrum it generates. Make sure you record which sample corresponds with which filename code in your notebook!

12. Scan the rest of your samples (Ni$^{2+}$, Fe$^{3+}$, Co$^{2+}$).

13. Click the exit button and return your samples to your lab station.

**Why does the instrument get “blanked”?**

The metal nitrates that you scan are dissolved in water. Because we wish to measure only the interactions that the metal ions have with the light, a sample of water is scanned first in a cuvette. In theory, the water molecules do not absorb the range of wavelengths of light emitted by the light source, but slight impurities in the water could cause some absorption of light. In addition, light can be reflected to some extent by the plastic cuvette. During the blanking scan, the instrument is instructed to ignore any absorption (lack of transmittance) it might record that is due to either the reflection or the water. Thus, it records an absorption of 0 for every wavelength. The instrument then stores this information and corrects each reading it takes after the blank.

**This is the end of Phase 1.**
Phase 2 of the Learning Cycle: Constructing an Analogy

The following activities should be completed in the breakout room.

Part 1. Analyzing your data

Using your lap top or a computer in the break out room, analyze each of your known spectra on your ICN account to determine which wavelengths of light are being absorbed by each of the samples. Determine the wavelengths that correspond with the maximums of the two largest peaks. Some peaks are broad and may be best described as a range (for example: 320 nm – 430 nm), but try to find the maximum. Some ions may only have one peak absorbance wavelength. Create a table of this information in your notebook.

<table>
<thead>
<tr>
<th>Metal ion:</th>
<th>Wavelengths (nm) with peak absorbances</th>
<th>Energy (Joules) associated with wavelengths absorbed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu(^{2+})</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Co(^{2+})</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fe(^{3+})</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ni(^{2+})</td>
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</tr>
</tbody>
</table>

Next, find another group and compare your spectra of each ion to their spectra of each ion.

Q: Do the wavelengths that the other group recorded peak absorbances at match your spectra for each ion? Are there any discrepancies?

Q: Different ions will absorb different types of wavelengths because the electrons in each ion require unique amounts of energy to be promoted to higher energy states. Do your results support this statement? Why or why not?

Part 2. Constructing an analogy

You might have noticed that we did not already discuss an analogical model earlier in the procedure. In this lab, we are going to ask YOU and your partner to create an analogical model for how light and atoms interact after looking at the following cartoon scenarios of two different ions being exposed to the same type of light and reacting differently. The cartoons depict energy level diagrams and are one way of modeling and describing the interaction of different atoms and light.

Coming up with an analogical isn’t easy. But, remember, there’s no such thing as a perfect model. Be creative!
Energy level diagrams represent some features of what occurs at the submicroscopic level when atoms interact with light. They are useful for thinking about interactions, but, like any representation, they’re not perfect. For example, the lines on the energy level diagram do not correspond with actual positions or distances of electrons. Instead, they are only supposed to represent differences in amounts of energy that an electron has. Keep this in mind as you consider the cartoon scenarios below.

**Cartoon 1.** The energy a chromium ion electron needs to reach the first excited energy level is exactly $2.48 \times 10^{-19}$ Joules. It is exposed to an 800 nm wavelength of light, the electron absorbs the light, and is promoted to the next energy level.

**Q:** Using the equation in the introduction, how much energy is associated with an 800 nm wavelength of light?

**Cartoon 2.** The energy a zinc ion electron needs to reach the first excited energy level is more than $2.48 \times 10^{-19}$ Joules. It is exposed to an 800 nm wavelength of light. It does not absorb this wavelength of light.

Working with your partner, come up with an analogical model for the cartoon scenarios that would help another student understand what happens when different ions are exposed to different kinds of light. Why are particular wavelengths of light sometimes absorbed by electrons but sometimes are not? How could you explain this to someone using a comparison to an everyday situation? Be sure to think of the ways that your analogical model breaks down (or isn’t an accurate representation of the chemistry phenomenon). Please use the following page (9) to explain and illustrate your analogical model.
Analog to Target Worksheet (your model)

*Please work on constructing the analogical model together, but each person should fill out this sheet individually. You will need to hand a copy in with your lab report.*

<table>
<thead>
<tr>
<th>Please describe the analogical model you came up with:</th>
<th>Provide a labeled illustration of the model:</th>
</tr>
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<tbody>
<tr>
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</table>

<table>
<thead>
<tr>
<th>How is your analogical model similar to the target chemistry phenomenon?</th>
<th>In what ways does your analogical model break down?</th>
</tr>
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</table>
Phase 3: Designing experiments

Plan your experiments in the breakout room before proceeding to lab to complete them.

Using the analogical model to make predictions:

Q: Based on your observations and your thinking in phase 2, do you think mixing two types of ions together will have an effect on the particular wavelengths of light that each ion absorbs? Why or why not? Use the analogy you created to justify your response.

The experiment:

We would now like you to design an experiment to determine how mixing two of the known ions will impact the wavelengths of light that are absorbed.

Scientific Question: When two samples of different ionic solutions are mixed together, does the mixed solution absorb light at the same wavelengths as each individual solution?

Use the Designing Experiments worksheet (page 11) to summarize this process. You will hand in one copy of this sheet as a lab group at the end of lab. Make sure to also take careful notes of the process in your laboratory notebook. Check in with your laboratory instructor before starting your experiment.
### Designing Experiments Worksheet

*Please use this sheet to summarize your lab group’s experiment and findings. Please hand one copy of this sheet in per group to your instructor before you leave.*

<table>
<thead>
<tr>
<th>Please describe your proposed experiment.</th>
<th>(attach extra pages if needed)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>(Check in with your lab instructor before performing experiments)</em></td>
<td></td>
</tr>
<tr>
<td>Instructor’s initials: __________</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Describe the data you collected:</th>
<th>(attach extra pages if needed)</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>What claims can you make?</th>
<th></th>
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</thead>
</table>
Reflections & post-lab discussion (group discussion)

To be completed at the very end of the laboratory session

1. In a group, discuss how the analogical model you constructed can be used to explain the spectrum that results from mixing different metal ions together.

2. If you were given an unknown solution containing several metal ions, do you think UV-vis spectroscopy could be used to identify which metals ions are in the solution? Why or why not?
**Instructions* for your laboratory report (due next lab meeting)**

Your assignment has been to design an experiment, gather evidence, analyze the evidence, and construct scientific claims. Now we would like you to write a report that explains this process.

<table>
<thead>
<tr>
<th>Rubric:</th>
<th>Section:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Claim(s):</strong></td>
<td><strong>Summary of claims:</strong> Clearly state your major conclusions or claims that answer the scientific question: When two samples of different ionic solutions are mixed together, does the mixed solution absorb light at the same wavelengths as each individual solution?</td>
</tr>
<tr>
<td>Statement(s), derived from evidence, using scientific reasoning. (15 pts total)</td>
<td><strong>Introduction:</strong> Provide background information to put the experiment in context. How can atoms interact with light? What is UV-vis spectroscopy? How does it work? (Drawing a schematic diagram of the instrument might help your explanation).</td>
</tr>
<tr>
<td><strong>Evidence:</strong></td>
<td><strong>Procedure:</strong> In a narrative (not numbered directions) carefully describe how you developed your procedure and what you did. How did you collect evidence? Did anything go wrong? You may reference parts of this procedure by providing the title and web address.</td>
</tr>
<tr>
<td>Scientific data that supports the claim. The data needs to be appropriate and sufficient to support the claim. (30 pts total)</td>
<td><strong>Results:</strong> Carefully organize and present the data you collected that supports your argument. Provide all of the spectra you collected (carefully labeled) for the known ions and your mixture. Include a table of wavelengths absorbed and associated energies for each known ion and your mixed sample. Make sure to show a sample of the calculations you perform.</td>
</tr>
<tr>
<td><strong>Reasoning:</strong></td>
<td><strong>Discussion:</strong> Explain why the evidence you presented supports your claim. Does the mixed sample absorb the same wavelengths of light as each of its components did? Be specific – reference actual wavelengths in your comparison.¹</td>
</tr>
<tr>
<td>Scientific explanations that use evidence and appropriate chemistry concepts to construct claims. (30 pts total)</td>
<td>What underlying chemical explanations can you provide about your evidence? Use the lab procedure, outside sources, or talk to your instructor to gather information. Be sure to discuss the phenomena at both the submicroscopic (molecular) level and macroscopic (visible to your eyes) level. ²</td>
</tr>
</tbody>
</table>

¹Use YOUR analogical model to further develop your explanations of the results and the underlying chemical concepts throughout your discussion.

*General instructions for completing your laboratory report are available in the course guide: [http://umaine.edu/general-chemistry/lab-report-instructions/](http://umaine.edu/general-chemistry/lab-report-instructions/). Be sure to look over the examples and guidelines in the course guide as well as the specific instruction above.

**Attach these items to the end of your laboratory report:**

1. Analog to Target Worksheet (your analogy)