Name of Lesson: Near Infrared Reflectance Spectra

Teacher Background Information
The world looks a lot different in near infrared (NIR). NIR is that region of the spectrum that extends just beyond the edge of the red and inti the beginning of infrared. This portion is invisible to the human eye, but visible to digital cameras. Just as astronomers and chemists use the spectrograms in the visible portion of the electromagnetic spectrum to identify elements (by the specific colors they emit or absorb), so do engineers use the NIR spectrum to identify materials.

In this case however, it's not elements that emit or absorb NIR, but molecule structures. So for example, A C-O bond in a molecule emits or absorbs a different portion of the NIR spectrum than does a C-H bond. So rather than identifying specific elements, NIR spectrometry identifies the bonds on a molecule. There's an additional complication you need to be aware of before starting this unit.

In elements, the specific color emitted or absorbed depends on an electron in the atom jumping up or down the energy levels of an atom. In the case of NIR spectrometry, Bonds absorb or emit IR photons by several mechanisms. Those are as follows,

1. Bending
2. Stretching

A further complication involves the fact that the stretching can be symmetrical or asymmetrical. So for example. One bond in a two-bond molecule could stretch while the other shrinks (asymmetrical) of they could both stretch and shrink at the same time (symmetrical). So you can see that molecular spectrometry using NIR is a bit more complicated than the spectrometry observed n gas tubes.

And as you might expect, the spectrum for molecular bonds is more complicated. Gas discharge tubes produce very narrow bands of color. A NIR spectrum consists of wider bands. These appear in a reflectance spectrum as wide peaks and valleys in the spectrum. Some of the spectral bands may even overlap creating even wider bands. So to analyze a reflectance NIR spectrum, one has to look for patterns in the valleys. In reality, this is far too complicate for your students. However, they need to understand what they are observing and why. So be prepared to share this information with them.

Finally, to use the SCiO to scan objects, you'll need a SCiO developer's license to SCiO Lab. The SCiO is available from Consumer Physics, https://www.consumerphysics.com/ The SCiO is available for around $200 and the developer's license is about the same cost. Therefore, you'll want to write a grant or get other help to purchase a few of them.

Digital cameras can detect light in the near infrared (750 nm to 1400 nm). However, doing so throws off the color balance of the camera. So in front of the digital imager is an infrared-blocking filter. The filter is not perfect, some NIR can still get through. We can take advantage of this by blocking all visible light from the camera and forcing it to only record images in NIR by placing a red and blue theater gel in front of the camera lens.

Theater gels cover very hot stage lights. They will melt if they block infrared light. Therefore, by placing complementary colored gels in front of the camera. Visible light is blocked and NIR allowed to pass. The camera shutter must remain open longer to compensate for the fainter NIR reaching the sensor. So students will want to place their cameras on a steady surface, rather than hold them during an exposure.

Safety Information
Students will be scanning everyday objects with a SCiO molecular scanner. Since none of the items they will scan are dangerous, there should be no risks in this unit. The unit emits NIR light through in internal LED. The light is a save source, so no eye protection is needed.

Since students will cutting open apples, you will need a cutting surface to protect tables and to review how to safely cut with a knife with your students. Keep an eye open for unsafe practices.

Gas discharge tubes are fragile and get very hot in use. Don't let students touch them and be sure to wear hot mitts when handling them.

Student Objectives
1. Be familiar with the electromagnetic spectrum
2. Understand that colors exist in the NIR spectrum, just like they do for the visible spectrum
3. Learn how to use a SCiO scanner and its software
4. Use the SCiO to estimate the sugar of apple samples
5. Develop an app for the SCiO

Materials
1. SCiO
2. Access to the SCiO Lab
3. Apples (be sure to get some that aren't as ripe as others)
4. Sharp knife
5. Cutting board
6. Digital cameras (one per student team)
7. Red and blue theater gel filters
8. Gas discharge tubes of various gases
9. Power supply for discharge tubes
10. Plastic spectroscopes

Time Required
Two Weeks

Teacher Prep
Try out the SCiO and try using it to measure the color of apples. You'll need access to the SCiO Lab account to do this. Your students will being doing this, so you need to be

familiar with the process. Then test out the SCiO Lab for measuring the sugar content of sliced apples.

You need to practice setting up a collection and how the data is analyzed in a model. Fortunately, the SCiO Lab does the analysis for you, you just need to know how to click all the right buttons.

Disposal Information
None

Daily Procedure
Day 1
Divide students into teams and give each team a name. Students will remain in these teams for the unit.

Ask teams the following question, how do you use vision to evaluate objects? What does seeing allow you detect about objects that other senses don't? Come up with practical applications that apply to engineering or science. Make a list of practical examples to share with the class.

Before the end of the day, have teams present their ideas.

Day 2
We use the visible portion of the spectrum to make measurements about the world. But what near infrared? Quickly, what is near infrared (NIR)?

Now let's observe the world in NIR using a digital camera and colored filters. Cut theater gels, one for each camera, and tape them over the lens. Set the cameras to record in monochrome or else the color balance gets really confusing. Now use the cameras and take pictures of the natural and artificial world. Use a cellphone to take an accompanying picture so you can compare the NIR image to what your eye sees.

After taking pictures, your students will see that some objects appear roughly the same. But the dyes in some clothes and green foliage will appear really different. Remind students to keep their images and to document which are paired together.

Day 3
Continue taking NIR and visible images. Put together a presentation on what on the difference between NIR and visible light and you might be able to measure using images from both bands of the electromagnetic spectrum. One thing students should discover is that NIR is a way to identify plants by their chlorophyll. Healthier plants are typically brighter in NIR that are stresses plants.

Day 4
Presentations

Day 5
Our eyes and brain make images from the entire visible band. If we use a spectroscope, we can split the colors in the visible band into specific wavelengths. This is another way to give us information on the composition of objects.

Today, students will look at the emission lines from discharge tubes and record the bands each gas produces. Then they'll be given an unknown gas that they need to identify. Without using emission lines it produces, gases cannot be identified from just sight. But a spectroscope will let you identify gases, even if those gases exist in another galaxy a billion light years away.

Day 6
The spectroscope let you identify gases by their visible light they emit. We can do the same thing using NIR. However, there is a difference. Since NIR is lower energy photon, it's not the transition of electrons in elements they measure, but the bending and vibrating of chemical bonds in molecules. So while visible spectroscopes allow you to detect elements, NIR allows you to detect portions of a molecule. With enough of that information, you can begin to piece together the structure of a complex molecule. That process is too difficult for this class, but we will use it to differentiate between molecules and possibly even measure their concentrations.

The tool you will use is call the SCiO. Watch the following videos to become familiar with this device and its use.

https://www.youtube.com/watch?v=UIFyAOD_E3E

https://www.youtube.com/watch?v=e_dnVf9IxX0

https://www.youtube.com/watch?v=NuT0NtZVxTY

Then read the following article, https://spectrum.ieee.org/view-from-the-valley/at-work/start-ups/israeli-startup-consumer-physics-says-its-scio-food-analyzer-is-finally-ready-for-prime-timeso-we-took-it-grocery-shopping

Try out a SCiO just for fun.

Day 7
Now start a research project. You will use the SCiO to measure the sugar content of an apple. There's already an app for doing that, so you'll need to install the SCiO Lab app on a cellphone in your team.

Please be careful when slicing apples so that you don't get cut.

Take notes as your team uses the app. You will be developing one of your own for samples you choose. So your team must become familiar with using the SCiO

Days 8 – 10
Teams need to pick an item to analyze with the SCiO and how they will create the model to do so. This means they need to read the SCiO Lab website to become more familiar with the process. Tell teams they will use the SCiO website to learn how a model is created and that you will only help out when teams run into a jam.

Be sure each team gets approval from you for the item they want to analyze as their project. Then give them the rest of the week to collect data, built a model, and then test it.

At the end of the unit, have student teams demonstrate their model.

Some of the models will work well. Ones where students are recording darker objects, or those that aren't very reflective will probably not work as well. Ask students to discuss why their models may have failed to produce good results.

It is acceptable to have failures. But it not acceptable to just give up and not ask why failures occur. When we understand our failures, we begin to understand the limits of our tools and methods. This can result in better tools in some cases.

At the end of this unit, students will have gained experience using a new technology being used in industry and research. Be sure students get this message and what they learned may be related to a career they have in the future.