TA Guide for

Decoding Light

Notes

Description

In this activity, students use diffraction grating slides to observe the spectra of a light bulb, the fluorescent lights on the ceiling and the emission spectra of several gases like hydrogen, helium, neon, and mercury (depending which tubes are available.) The students create their own "catalogue" of emission lines and then match that catalogue to the absorption spectra of two "mystery stars".

Learning Goals

After this tutorial, together with lecture materials, students should be able to

- distinguish between continuous, emission and absorption spectra by their appearance and by how they form
- determine the chemical composition of a glowing gas by comparing its absorption spectrum to a catalogue of emission spectra

Set-up 20 minutes

Apparatus and Materials:

- Create 4 stations throughout the room (for example, counter at front left, counter at front right, counter by windows, desk nearest exit). Each station needs:
  - 2 gas discharge tube power supplies (8 power supplies in total)
  - 2 gas tubes (with the same gas) containing hydrogen, helium, neon or mercury (8 gas tubes in total) New tubes can be ordered through Arbor Scientific (`arborsci.com`) but they take about 2 weeks to arrive.

    Plug in and test the tubes. They should glow quite brightly so that when you look at them through the diffraction grating, you see the emission lines. The hydrogen tube has a short lifetime. It should not be left on for longer than 30 seconds at a time.
  - labels identifying the gases
  - basket of crayons (4 baskets in total)

- each group needs a whiteboard and a couple of coloured dry erase markers
- basket of diffraction grating slides, one for each student. These slides (1000 lines/mm) are available from `rainbowsymphony.com`.
- incandescent light bulb you can turn on and off
- overhead transparencies
  1. Page 1 (with apple sorting "story" and diagram)
  2. histogram of apples in the Absent Selection bin

3. apple sorter diagram at the top, formation of spectra at the bottom
4. Catalogue entry for fluorescent lights

- special set of dry erase markers for the TA to use for the fluorescent lights demo: red, orange, green, blue, purple
- Attach the absorption spectra of Mystery Gas 1 and Mystery Gas 2 to the walls of the room. We create these absorption spectra by simply "doing the lab" to find the pattern of lines for each gas, then transfering the lines' locations with a black pencil crayon onto a full spectrum. Mystery gas 1 has only one of the gases they catalogue to give them some success (= motivation). Mystery gas 2 has 2 sets of lines.

  Just in case students are tempted to "reveal the secret" of the mystery gases to their friends in tutorials later in the week, consider creating different combinations of elements for different sections.

For the "apple sorting" invention activity, students will work together in groups of 2 or 3. After that, they'll individually create the catalogue of emission spectra and identify the chemical compositions of the mystery gases.

When we hand out all the pages for a tutorial at the beginning, students often rush thru important steps because they think they have to get the last page ASAP. A better strategy for the students is to hand out pages as needed:

- (1 per group) Intro and Part 1 (page 1). You can attach this sheet to the whiteboard with a magnet.
- (1 per student) Part 2 (page 2). Hand this out to the class after the apple sorting activity. This page contains a continuous reference spectrum so this page needs to be reproduced in colour. Alternatively, create a sheet of reference spectra, print a number of copies (but only once), cut them into strips and hand out one strip per student. Be sure the reference spectra are the same size as the boxes on Page 2 (7.5 in $\times$ 1 in).
- (1 per student) Part 3 (page 3): Questions. Hand this to each student as he/she finishes their "catalogue" of spectra.

As usual, invite the students to form groups of 2–3 as they arrive and ask them to come and pick up one diffraction grating slide.

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Part 0: Introduction and Motivation	5–10 minutes

It's never a bad idea to let the students know why they are doing this, or any other, tutorial. Why should they care? Why should they invest the time and energy? The answer should be more than the marks they'll receive. Here's the big idea:

> We know the colour of a gas tells us its temperature: blue flames are hotter, red flames are cooler. There's a lot more than temperature 'encoded' in the light, though. By 'cracking the code', we can figure out what chemicals and elements are in the gas. This is what they do on TV shows like *CSI* and what astronomers do with glowing gases in space – like nebula and stars.

To get the students engaged with spectra (and figure out how to use the diffraction slides), put the incandescent light bulb on the overhead and turn on the light bulb. It might help to have the front of the room dark. Ask the students to look at it and get someone to describe it, to check that they all see a continuous spectrum. Now ask them to look up at the fluorescent lights and get someone to describe it. It's completely different: they'll see multiple copies of the lights, each in a different colour. Don't overwhelm them with technical terms like "continuous" and "emission". Just let them look around.

Part 1: The Sunripe Apple Sorting Machine	10 minutes

This activity assumes students have already seen how the electrons in atoms have quantized orbits and that light with certain energies and colours can be absorbed and emitted. To remind them of this "filtering," but without repeating the lecture about how light and matter interact, we give the students an "invention" activity to get them thinking about how to select certain objects from a collection. **Don't tell them** (at this stage) they're about to create a model of atoms absorbing and emitting light.

Put up the overhead of Page 1 containing the apple sorting maching. Tell them (read them) the story about how Sunripe needs special *Extraordinary Selection*© apples for their pies: the apples with diameters 60–65 mm and 80–85 mm. Page 1 overhead

Invite the student to take 5 minutes to design the sorting machine, using the whiteboards so they can share the results with the class. This won't take long and we're not expecting every group to produce blueprints! A common invention is a sequence of holes which allow apples below a certain size to pass through.

When their attention is starting to drift, get the class' attention and ask a couple of groups (maybe groups with good but different ideas that you spotted earlier) to share their designs. Encourage comments from other students if they seem eager.

Now comes the important part: linking this invention to the formation of spectra. Put up the apple sorter overhead. Ask them (and write on the overhead) what sizes of apples they find in the different bins: apple sorter overhead

Sunripe apples: apples of all sizes

Extraordinary Selection: only apples with diameters 60–65 mm and 80–85 mm

Absent Selection: apples with all sizes *except* 60–65 mm and 80–85 mm. They're likely to say, "all the ones you don't want" so prompt them to tell you the sizes: "Right, and which are those?" We want someone to say "except" or "everything but" or...

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And now, the key to determining chemical composition: looking at what's missing. Put up the histogram overhead and give a quick description of the "architecture" of the graph. In other words, don't assume that the students can interpret the graph.

> This is a graph showing the apples in the Absent Selection bin at the end of the conveyor belt. The horizontal axis has ranges of sizes and the vertical axis shows how many apples are in each range.

Be careful not to interpret the graph for them, though. Don't say, "...and you can see that all the 80−85 mm apples have been used." Instead, just ask them what the factory made that day.

The missing 60−65 mm apples mean the factory made pies that day. Pies also use 80−85 mm apples, which are also missing from the histogram (consistency check.) What about the missing 90−95 mm apples? They are used in sauce which also uses 80−85 mm apples (again, consistent with the histograms.)

Now we switch to the formation and decryption of spectra. While invention and analogy activities can be very powerful, students notoriously fail to make the connection(s) between the analogy and the actual phenomenon being studies. They often think they did one thing, then another, unrelated thing. You have to explicitly make the connections for them.

Put up the overhead showing the apple sorting and spectra overhead . Compare the bins and spectra in the diagrams:

apple sorting and spectra overhead

1. The star produces a continuous spectrum of light with all energies. This is like the bin of apples of all sizes at the factory.

2. Some of the light passes through the star's outer layers. There, atoms absorb light with certain energies and colours. This gas is like the sorting machine (not the Extraordinary Selection bin, though – the sorting machine itself.)

3. The light we observe (at the far right) has dark absorption lines because it contains light with all the colours/energies *except* the light absorbed in the gas. This is like the Absent Selection bin that contain all apples *except* the ones used for apple pies.

   If it comes up, you can add the absorption lines are not perfectly black: some "special energy" light escapes from the gas – either because it made it through or it was absorbed but re-emitted, just like some special apples might slip through the sorting machine.

4. If you could look just at the light coming from the gas, you would see an emission spectrum – just the light with the energies (colours) matching the energy levels of the atoms in the gas. That's like looking in the Extraordinary Selection bin.

5. The key point to wrap it up: when we see light that has passed through a gas, we see an absorption spectrum. By determining what colours are *missing*, we can figure out what atoms are in the gas. In other words, what the star is made of.

Psst! Did you notice the **E***mission* **S***pectrum matches the* **E***xtraordinary* **S***election and the* **A***bsent* **S***election matches the* **A***bsorption* **S***pectrum? A little bonus for the keen students...*

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Part 2: A Catalogue of Spectra	10 minutes

Share the main idea for this Part with the students:

> The key to making this work is knowing which atoms absorb which colours. We do that by first building a "catalogue" of emission spectra of various atoms, so when we look at an absorption spectrum later, we'll know which atoms are in the gas.

Hand out Page 2

It's important that the emission lines the students colour are at the right position in the spectrum. That's why they have the reference spectrum. However, it seems they need a little extra help, so demonstrate using the overhead fluorescent lights. Put up the "Catalogue entry for fluorescent lights" overhead and ask the students to look up at the lights through the diffraction grating slide. You should all see bright red, fainter orange, then bright green, blue and purple lights. Using the 5 dry erase markers, demonstrate how you look at the red emission line, locate that colour in the reference spectrum and draw a red line at the corresponding position in the empty rectangle. Do the same for the other colours. You won't get the lines in exactly the right place but emphasize the number of lines, their approximate location and their relative spacing.

fluorescent lights overhead

With that demonstration finished, invite the students to visit each of the 4 stations around the room. They're not working in groups anymore – each student should make the catalogue. They should look at the gas through their diffration grating slide and then use the crayons to sketch the emission lines. It's true that you don't really need the crayons and colours, black lines in the lines' locations would do, but the students seem to be more engaged (and have a better study aid) when they use the crayons.

You might need to switch off the overhead lights in the room (though you'll have to switch them back on again because we ask the students to look at the overhead lights in Part 3...)

Part 3: Questions	Remainder of tutorial

As students finish collecting the four emission spectra, hand out the Question sheet. When they're finished, ask them to return their diffraction slides to the baskets.

Hand out Questions as needed

1. This question asks them to determine chemical composition is an overly-simplified, idealized case, just so they can get the hang of matching collections of lines. (In earlier versions of this activity, the first question was the Mystery Stars question and students were sometimes unable to use their own emission catalogues because there was too much going on: colours, locations, bright coloured lines, dark lines,...) The answer is 2 elements, hydrogen and helium. Notice the distractors, though: 7 is the number of lines in the star's spectrum, 9 is the number of unique lines in the 3 emission spectra. Yes, so of the lines have been shifted slightly to make them line up - again, part of the idealization.
2. This question is the final step in the process of spectroscopy – determining the composition of the gas. If the crowd surrounding the mystery gases on the walls is too big, we might have to make 2 copies of each mystery gas.
3. This question relates the learning goal, students will be able to distinguish between continuous, absorption and emission spectra. Then we ask them to do some near-transfer of the concept: to identify the chemicals in the fluorescent lights, first build a bigger catalogue.

Notes

4. This question is adapted from the ClassAction collection of peer instruction questions at `astro.unl.edu`. In the notation of continuous (C), absorption (A) and emission (E), since A+E=C, the correct answer is C-E=A.

Clean up

We'll leave the power supplies and gas discharge tubes set up for the duration of the week but put away the crayons and other materials.

Credits

This work is supported by the Carl Wieman Science Education Initiative at the University of British Columbia. See `cwsei.ubc.ca` for more information.

If you have comments or suggestions, please contact

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14 September 2011