TA Guide for

ASTR 311 Tutorial: Decoding Light

ver. 100923

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 (subset of hydrogen, helium, neon, krypton, oxygen, mercury). 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

- describe the properties and behaviour of light when it is treated as a wave (wavelength, frequency, dispersion, colour,...) or as a particle (formation of spectra,...)

Set-up — 20 minutes

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.

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 and 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 stations (Post-it Notes on top of the power supplies, for example)
  - basket of crayons (4 baskets in total)
- Attach the absorption spectra of Mystery Star 1 and Mystery Star 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. Both stars have absorption lines from 2 gases.

  Just in case students are tempted to "reveal the secret" of the mystery gases to their friends in tutorials later in the week, we may have different combinations for each tutorial section. These sets of absorption spectra can all be prepared ahead of time.

Notes

- each group needs a whiteboard and coloured pens
- basket of diffraction grating slides, one for each student
- basket of reference spectra, one for each student. The students will use this reference spectrum to estimate where to draw the emissions lines on their worksheets (which have empty boxes the same size as the reference spectra.)
- incandescent light bulb (on square wooden base)
- overheads
  1. Page 1 (with apple sorting "story" and diagram)
  2. apple sorter diagram at the top, histogram of apples on the bottom
  3. apple sorter diagram at the top, diagram showing 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
- 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.
  - (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 slide and one reference spectrum each.

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

In class, they've already discussed 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. 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! 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 and how we use them. Put up the apple sorter and formation of spectra overhead but **with the bottom (histogram) covered**. Ask them (and write on the overhead) what sizes of apples they find in the different bins:

apple sorter and histogram 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..."

To get them thinking about how we use that information, and also how different sets of lines are superimposed, uncover the bottom of the overhead to show the histogram. First, a quick explanation:

> This graph shows how many apples of each size are found in the *Absent Selection* bin one day. This axis is the ranges of sizes, this axis is how many apples are in that range.
>
> Also, here is the "recipe" for different products the factory makes, pies, juice and so on.

Now, the big question:

> What did they make in the factory today?

We're looking for someone to say you can tell the factory was making apple pies and sauce because those are the apples that are missing. Not juice, though, because that would have used the 70–75 mm apples in addition to the 80–85 mm apples. In other words,

> We know what the factory was doing because of the apples they *didn't* use.

Put up the next showing the appler sorter on top, the formation of spectra below. Quickly match the corresponding parts:

apple sorter and spectra overhead

> The light bulb, and the core of a star, produces a continuous spectrum of light with all energies. This is like the bin of apples of all sizes at the factory.
>
> Some of the light passes through the cloud of gas like the star's atmosphere. There, atoms absorb light with certain energies and colours. The gas is like the sorting machine (not the Extraordinary Selection bin, though – the sorting machine itself.)
>
> 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.

> 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.

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...*

Part 2: A Catalogue of Spectra	10 minutes

Share the main idea for this Part with the students:

Hand out Page 2

> 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.

Notes

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 (again). 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. Of course, you might not get the lines in exactly the right places – what's important is the relative spacing between the lines.

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. There's one extra box on Page 2 in case they mess one up.

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 and reference spectra into the baskets.

Hand out Questions as needed

1. This question is the final step in the process of spectroscopy – determining the composition of the Mystery Stars. If the crowd surrounding the mystery stars on the walls is too big, we might have to make 2 copies of each mystery star.
2. This question tests the idea of the superposition of several sets of lines. There are 2 elements in the absorption spectrum. There are 7 lines, by the way, and 9 lines if you count hydrogen and helium seperately.
3. One more time: what kind spectrum is coming off the fluorescent lights: emission.

   The, can they transfer the process, not just their tiny catalogue, to other situations? We're looking for "create a bigger and bigger catalogue, perhaps with 'all' the elememts, until you can match it with the lights."
4. Tests the relationship between the spectra: A+E=C, so C–E=A.

Clean up

We'll leave the power supplies and gas discharge tubes set up for the duration of the week. Replace any reference spectra that are wrecked and put away the crayons and other materials.