

Emission Spectra of Excited Gases

Light Emission Energetics and Spectra

Lindsey Link, Matthew Peck
Published by *K20 Center*

This work is licensed under a Creative Commons CC BY-SA 4.0 License

Grade Level	8th – 12th Grade	**Time Frame**	2-3 class period(s)
Subject	Science	**Duration**	90 minutes
Course	Chemistry, Earth Science, Physical Science, Physics		

Essential Question

How do excited gas atoms emit specific colors of light? How can these specific colors be used to explore the composition of planetary atmospheres?

Summary

In this lesson, students will observe the colors in emission spectra for different excited gases. They will compare the specific emitted wavelengths and explain how these specific emitted wavelengths are the result of energetic and physical transitions by electrons in excited atoms. Then, they will apply this experience with emission spectra to predict and compare the spectra of atmospheres for planets in our solar system.

Snapshot

Engage

Students hypothesize about the origin of "neon" colors, what types of gases would allow a planetary atmosphere to support life, and how we measure the composition of planetary atmospheres.

Explore

Students view glass tubes filled with various gases before and while they are excited by electricity and use spectroscopes to observe and record spectra.

Explain

Students work with simple Bohr models to formulate a physical and energetic explanation for the emission of specific colors of light. Students explore the relationship between light wavelength and energy by correlating specific light colors emitted with specific energy changes. Optional video and kinesthetic activities help students explain their observations.

Extend

Extension options for students include predicting the emission spectra of gases from different planets in the solar system, exploring and explaining the Northern Lights phenomenon, and performing Algebra 1-level energy calculations.

Evaluate

Evaluation options for students include writing a data table title that effectively summarizes the key

lesson of the exploration, sharing the results of their extension research, or designing their own multi-colored electrified gas sign.

Standards

ACT College and Career Readiness Standards - Science (6-12)

IOD201: Select one piece of data from a simple data presentation (e.g., a simple food web diagram)
IOD301: Select two or more pieces of data from a simple data presentation
IOD403: Translate information into a table, graph, or diagram
IOD504: Determine and/or use a simple (e.g., linear) mathematical relationship that exists between data
IOD505: Analyze presented information when given new, simple information
SIN201: Find basic information in text that describes a simple experiment
SIN301: Understand the methods used in a simple experiment
SIN502: Predict the results of an additional trial or measurement in an experiment
EMI201: Find basic information in a model (conceptual)
EMI401: Determine which simple hypothesis, prediction, or conclusion is, or is not, consistent with a data presentation, model, or piece of information in text
EMI603: Use new information to make a prediction based on a model

Next Generation Science Standards (Grades 6, 7, 8)

MS-ESS1-3: Analyze and interpret data to determine scale properties of objects in the solar system.

Next Generation Science Standards (Grades 6, 7, 8)

HS-PS3-2: Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as either motions of particles or energy stored in fields.

Oklahoma Academic Standards (8th Grade)

8.ESS1.3 : Analyze and interpret data to determine scale properties of objects in the solar system.*

Oklahoma Academic Standards (8th Grade)

PS.PS3.2 : Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as either motions of particles or energy stored in fields.

Attachments

- Data Table—Emission Spectra of Excited Gases - Spanish.docx
- Data Table—Emission Spectra of Excited Gases - Spanish.pdf
- Data Table—Emission Spectra of Excited Gases.docx
- Data Table—Emission Spectra of Excited Gases.pdf
- Lesson Guide with Teacher's Notes—Emission Spectra of Excited Gases.docx
- Lesson Guide with Teacher's Notes—Emission Spectra of Excited Gases.pdf
- Lesson Guide—Emission Spectra of Excited Gases - Spanish.docx
- Lesson Guide—Emission Spectra of Excited Gases - Spanish.pdf
- Lesson Guide—Emission Spectra of Excited Gases.docx
- Lesson Guide—Emission Spectra of Excited Gases.pdf
- Lesson Slides—Emission Spectra of Excited Gases.pptx
- Sample Data—Emission Spectra of Excited Gases.docx
- Sample Data—Emission Spectra of Excited Gases.pdf

Materials

- Lesson Slides (attached)
- Lesson Guide (attached; one per student)
- Lesson Guide with Teacher's Notes (attached)
- Data Table handout (attached; one per student)
- Sample Data handout (attached; optional)
- Spectrum tubes (The Vernier set includes He, H2, Ne, Ar, N2, CO2, and Air. If you have access to a different set of tubes, use those.)

- Spectrum tube carousel (Vernier Carousel is available to check out upon request, but any electrification device that matches your available tubes will work.)
- Spectroscopes (Triangular spectroscopes sold by Flinn or tube spectroscopes sold by EISCO are good options, though other brands and homemade work as well.)
- Colored pens, pencils, or markers (one set per group of students)
- Poster paper (optional; one per group)

Preparation

You can choose to use the **Lesson Guide** handout or have students use their science or lab notebooks for this lesson.

Lab Setup Options

Before the Explore activity, assess your material supply and decide whether you will have students view the gas tubes as part of a whole-class demonstration or as a station activity. If you have access to only one spectrum tube carousel or excitation box, consider performing a demonstration or using this activity as one station in a lab with other rotations. For example, you could include this activity in a rotation that also includes a chemical flame test experience. If you have access to more than one carousel or excitation device, consider placing different gas tubes at different stations and having students rotate to view them independently. This approach has the advantage of making sure students who work at different speeds have sufficient time to record the spectra.

20 minutes

Engage

Teacher's Note: Lesson Background And Rationale

This lesson represents a core opportunity to lay the groundwork for a unit in astronomy, physics, chemistry, or physical science classes. It is designed to be flexible and provide you with options to best fit your students' needs.

Different atoms and molecules produce different colors of light when electrons become excited after absorbing energy from an outside energy source, such as the electricity used in the lab or by the heat generated within stars. Light is produced the same way when solid chemicals are exposed to flames in flame tests, fireworks, and neon lights used for signs on businesses (which are becoming rarer these days). By looking at the atomic details of light creation, this lesson presents an opportunity to demonstrate energy conservation within an atom.

Energy transformations are a disciplinary core idea found in the standards of nearly every science class. Electrons in their ground state (most common, lowest energy location) absorb specific amounts of energy to make specific physical and energetic jumps to excited states. Eventually, the electrons re-release this energy, and when they do, they can create electromagnetic radiation (that can be viewed as visible light of the proper energy).

For more advanced students, this demonstration can initiate a quantitative study of light, the frequencies and wavelengths of visible particular colors of light, and calculations using Planck's equation (E = hv). As you prepare to teach the lesson, first, choose the options that you will use. Then, go through the slides and the lesson handout to edit or remove unneeded content.

Use the attached **Lesson Slides** and **Lesson Guide with Teacher's Notes** as you guide students through the lesson. Briefly review **slides 2–4,** introducing the lesson title, essential question, and lesson objectives. The main goals of this lesson are for students to observe line emission spectra, explain how these spectra result from physical and energetic changes in atoms (electron transitions), and apply line spectra to astronomy as a tool for analyzing the composition of planetary atmospheres. Spectroscopy is a broadly used tool with applications throughout physics, chemistry, and biology. Depending on the course you're teaching, weigh the electronic structure and astronomy goals to fit your needs.

Pass out a **Lesson Guide** to each student and direct them to the Engage section of the handout. Move to **slide 5,** and let students consider questions 1 and 2 on their own or with Elbow Partners. Ask them to record their answers on the handout.

Teacher's Note: The Neon Color

As you review the answers, don't reveal which color is neon yet. Keep it secret for the upcoming activity.

Display **slide 6.** Introduce the spectrum tube carousel and gas tubes that you'll be using in the next activity. Demonstrate the use of a spectroscope and show students an example of a spectrum. Explain your plan for the lab workflow and discuss safety concerns. Have students record the answers from this discussion on their Lesson Guide handout.

Teacher's Note: Sample Data Handout

You might utilize the attached **Sample Data** handout. This handout can be used for your reference or to show examples to students.

30 minutes

Explore

Distribute the attached **Data Table** and spectroscopes to the students. Depending on your spectroscope supply, form groups as necessary. Ideally, you'll have one spectroscope for every 1–2 students, but the lesson can be done with a more limited supply and larger groups. The larger the group, the more you will need to manage turn-taking.

Teacher's Note: Safety

The glass tubes get very hot! If students are working in a station lab, remind them not to touch the tubes. If you are leading a whole-class demonstration using a single-tube electrification device, use caution if you have to replace a hot tube.

Have students turn to the Explore section of their handouts and minimize ambient and overhead lights. Display **slide 7** and let students get their bearings with the spectroscopes by following step 1 to view natural light and/or overhead lighting. Remind students not to look directly at the sun. The broad rainbow spectra are easier to see than the line spectra emitted by specific gases.

Use **slide 8** to show what spectra should look like as students work on their technique. It can be surprisingly tricky to see the spectra produced by a spectroscope, and seeing the example will help many students.

Teacher's Note: Activity Tips

Follow the tips below to help ensure that the activity runs successfully.

- **Lighting:** For the best results, work in the darkest room available with minimized ambient and overhead lights.
- **Spectroscope Troubleshooting:** Students sometimes have initial difficulties using a spectroscope. The spectrum appears to the side of the initial line of sighting. The key for most spectroscopes is to center the slit of the spectroscope on the gas sample and then, without moving the spectroscope, slide your eye to either side to find the spectrum. If you use the triangular spectroscopes, the top of the spectroscopes can be labeled so that all students will orient them the same way and can adjust using verbal directions. Projecting or showing students a sample spectrum can help them better understand what it should look like.
- **Choosing Gases:** If you decide to show fewer tubes to improve students' focus, pick gases based on what would interest your class the most. Some suggestions might include: Neon (to relate to the Engage question about neon colors and neon lights); Helium and H2 (to show off the two most abundant elements in the sun); air, CO2, and N2 (to talk about atmospheric composition that is consistent with life).
- **Recording Data:** Make sure students are recording data. By monitoring the data acquisition, you will also know whether you are providing sufficient time for students to gather their observations. If tubes are viewed as a whole-class demonstration, then be patient to allow most students to record data before moving onto the next type of gas.

Display **slide 9** and ask students to view the gas tubes with and without the spectroscopes, following step 2 in their handouts. If you are working with one carousel or excitation device, you will set the pace for viewing the tubes. Make sure to first show the tubes without electricity (under which conditions they will all appear colorless) to emphasize electricity's role in color production. Provide students with colored pens, pencils, or markers to create their data table.After the activity, return the ambient light to the room. Display **slide 10** and direct students to step 3 on their handouts, asking them to form peer groups to compare results and ensure that everyone has data.

Display **slide 11** to introduce principles of scientific titles, and then ask students to add a title to their data table. Have students share their titles with you and other classmates as a mid-lesson formative evaluation or an Exit Ticket for the first class session. Typically, it takes about one class period to introduce the lab and gather data.

30 minutes

Explain

Display **slide 12** and have students answer the Explain questions from the Lesson Guide. You can ask students to work individually or in small groups. Encourage them to take chances and make hypotheses using their own words.

Once students have completed answering the questions, discuss as a whole-class. Use **slides 13-14** to assist with this discussion. Questions 1–4 are close to the data and should be relatively easy for students to address. Questions 5–10 will require additional discussion.

Teacher's Note: Explaining Light Emission Using Bohr Diagrams (Questions 5–10)

To discuss energy transitions that lead to the light, it can help to visualize the change using Bohr models. The thin circles represent energy levels for electrons in atoms. Though the idea of orbiting electrons shown in this model has long ago been discarded, the idea that electrons exist at only specific energy levels is very powerful and remains a standard convention. It is easy to show energy changes in the Bohr model, though other diagrams could also be used. The diagram on slide 9 is also included in the Lesson Handout.

In step 1, excitation occurs using the energy supplied by the electricity to move an electron from an inner shell to an outer shell. In step 2, light emission occurs and the potential energy lost by the electron as it moves closer to the positive charge of the nucleus is released as light energy. Electricity is involved only in step 1, and light is released only in step 2.

Slide 14 shows a second Bohr diagram that explains why hydrogen makes a green and red color (but not orange or yellow). The green jump is higher energy, as it is a higher energy color (higher frequency) than the red jump. Electrons can move between quantized electron energy levels only, so the entire rainbow of colors is not made. Different atoms have different energy levels available, which changes the color and number of lines observed for each element/molecule type. Throughout, "light" is used to indicate the visible colors we can observe directly in the lab. It is important to note that the atoms make many frequencies of non-visible electromagnetic radiation too (question 10).

Optional Video to Support the Discussion

To help the class better understand the color changes at the electron level and see how the jumps apply to firework colors, unhide **slide 15** and consider watching the video titled The Science of Firework Color.

Embedded video

https://youtube.com/watch?v=dW5OBrB4MRM

Teacher's Note: Background For Discussion

Spectral lines were discovered by German scientist Joseph Fraunhofer. By 1814, he had cataloged nearly 500 lines in the solar spectrum (as absorption lines, which create specific black lines of missing colors instead of specific emitted lines as seen in this lab). Fraunhofer connected one of the dark yellow lines in the solar spectrum to the yellow color produced when salt is sprinkled in a flame. Electrons in the ground state (the most common, lowest-energy location in an atom) absorb specific amounts of energy to make specific jumps to excited states. The electrons then re-release this energy during relaxation, often as electromagnetic radiation (including visible light).

Optional Kinesthetic Reinforcement Activity

Try this activity to conceptualize and build a physical model for the energy transition for your students. Start by asking students why they don't stand up in class, and then invite students, if they prefer, to stand instead of sit (likely a few will, but not the majority). Explain that standing is the "excited state" for a student—it is less common but possible—while sitting is the "ground state."

Ask students when energy needs to be put into their bodies: when going up or coming down? (Going up.) Ask students when they will get to release energy. (Going down.) Light is released when electrons go back to the ground state—not when they are excited by the external energy. Then, ask what bribe (extra credit? candy?) it would take to get them to stand during class. Point out that this represents what happens when we add an external energy source (electricity in neon signs or thermal energy in fireworks) to move electrons to an excited state.

Or, introduce a "token," such as a balled-up piece of colored paper representing the color of the light photon released during relaxation, to represent the energy that is needed to move to the excited state (step 1) and then released as light (step 2) to allow the electron to return to the ground state. When students have a token, they are allowed to stand. When they release the token, they need to sit. To address why only a limited number of colors are made, ask students why they are not sitting/levitating at any level beneath their chair seat or above the floor to introduce the idea that only certain states are allowed (quantization). This is why we see only certain lines in the spectra.

If you have surfaces at different heights (desktops), you can use the higher surfaces to represent higher energy jumps. Surfaces at varying heights can also be used to represent different elements that have access to different energy jumps due to their varying electronic energy structures. Conclude by returning to the diagram included on the handout to make sure that students see how this physical analogy applies to the electrons drawn in the diagrams.

10 minutes

Extend

Direct students to the “Extend” section of their Lesson Guide handout. Assign specific questions from this section that best support your goals for the lesson. Students can complete the questions individually or in groups, in class, or as homework.

1. Core extension questions 1 and 2 give students a chance to see an astronomy application of the spectra observed in the Explore activity. Use **slide 16** to orient students to these questions.
2. Optional extension question 3 allows students to connect a natural phenomenon (the Northern Lights) to the gas emission observations and explanations. It is best suited for classes with the available time and interests in earth and space sciences. Use **slide 17** to introduce this question.
3. Optional extension question 4 gives students a chance to discuss qualitative and quantitative methods of measurement and scientific communication. This discussion is suitable for students at all math and science levels.

Optional extension questions 5 and 6 offer an opportunity for quantitative practice. The equation is a two-variable inverse equation (y=constant/x) that can be used in Algebra 1 and physical science classes. The equation is not introduced at depth in this handout, so it will be more suitable to students who have been previously introduced (at least qualitatively) to the relationship of energy and light frequency. Use **slide 18** to introduce these questions. **Slide 19** shows work for an answer to question 5.

15 minutes

Evaluate

Direct students to the Evaluate section of their Lesson Guide handout. Depending on your goals for the lesson, you can choose to have students complete one or both of the evaluation activities, which are described below. Both options are suitable for students at various math and science levels.

1. Extend question discussion. Use the Three Stray, One Stays strategy described on **slide 20** to have students share the results of their Extend question research in peer groups. Split the class into groups of four and assign each group one Extend question. Give each group time to discuss and take brief notes over their assigned question, coming to a consensus. Ask one student per group to stay, acting as a group representative to describe the group's answer and reasoning to other students as they move through the room. Ask each of the remaining group members to stray, each traveling to a different question group (that is, not all going to the same table). Ask students to interview the representative in their new group to gain a deeper understanding of the answer to the question. Students should take notes and then return to their original groups to share what they have learned. Ask each group to synthesize the information they learned and share it with the class.
2. Design a sign for the school. Invite students to get creative and design a sign that uses electrified gas tubes to produce the desired colors. Using the directions on **slide 21,** students should perform research to find gases that can make other colors that they haven't seen in the lesson, and then draw a diagram to show the design for their sign, making sure to label the gas used for each portion.

Resources

- K20 Center. (n.d.). Bell ringers and exit tickets. Strategies. https://learn.k20center.ou.edu/strategy/125
- K20 Center. (n.d.). Elbow partners. Strategies. https://learn.k20center.ou.edu/strategy/116
- K20 Center. (n.d.). Three stray, one stays. Strategies. https://learn.k20center.ou.edu/strategy/85
- NPR's Skunk Bear. (2017, July 3). *The science of firework color* [Video]. YouTube. https://www.youtube.com/watch?v=dW5OBrB4MRM