Telescopes and Spectra

To solve problems, scientists ask scientific questions. They determine the best methods to answer the question, collect the data, and analyze it to draw evidence-based conclusions that answer the question. You will be practicing these steps in the **process of science** in this lab.

Learning objectives:

- Students will be able to describe characteristics of telescopes and what they can see.
- Students will be able to interpret what spectra can tell us.
- Students will be able to apply and analyze steps in the **process of science** (scientific literacy).
- Students will be able to **read graphs** (quantitative literacy).
- Students will be able to calculate **percentage** (quantitative literacy).
- Students will be able to distinguish between **observations and interpretations** (scientific literacy).

Materials needed:

- Access to Telescope Simulator (https://astro.unl.edu/classaction/animations/telescopes/telescope10.html)
- Access to AstroSims Spectrum Constructor Simulator (https://foothillastrosims.github.io/Spectrum-Constructor/)
- Access to Solar System Simulator (http://space.jpl.nasa.gov)
- Ruler, lined paper, or print this paper or trace it to use the "ruler" below. You can use any unit of measurement.

|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|

Telescope (source: ZAIDoopro on pixabay.com)

Part 1: Navigating the Telescope Simulator

Examine the Telescope Simulator. Play around with the settings for aperture size, eyepiece size, and target. To put the object in focus, adjust the focus setting. As you try different settings, note how the Magnification in the Readouts box changes.

1. What type of telescope is shown?

- ○ A telescope that uses mirrors
- ○ A telescope that uses reflection
- ○ A telescope that uses polished metal
- ○ A telescope that uses glass lenses
- ○ It cannot be determined

2. What aperture and eyepiece settings result in being able to see Saturn the largest?

__________ -inch aperture and __________ mm eyepiece

The resolution describes the smallest features the telescope can detect. To determine this number, use the Readouts at the bottom.

3. What gives the best resolution?

- ○ Largest aperture; smallest eyepiece
- ○ Largest aperture; largest eyepiece
- ○ Largest aperture; eyepiece size does not matter
- ○ Smallest aperture; smallest eyepiece
- ○ Smallest aperture; largest eyepiece
- ○ Smallest aperture; eyepiece size does not matter

Telescopes with larger apertures allow more light to be collected, giving them a higher resolution. To compare the light-collecting capabilities of two telescopes, you can calculate the percentage of light a small telescope collects compared to a larger telescope.

Scientists calculate **percentages** to make data easier to compare and communicate. Percentages show how big something is relative to the total number. To calculate a percentage, take the number that you identified (the part you want to know about) and divide it by the total number identified, and multiply that by 100.

A telescope that has a diameter of 4 in has an area that collects light that is 12.5 in^2 (Area = πr^2). A telescope that has an aperture twice that size has a diameter of 8 in and an area that is 50 in^2.

To calculate the percentage of light a small telescope collects compared to a larger one, take the part you want know about (area of the 4-inch lens) and divide it by the total (area of the 8-inch lens), and multiply that by 100.

Note the two numbers below that you need to calculate the percentage of light collected by a 4-inch aperture telescope compared to a telescope with twice the aperture:

Your note: The part you want to know about ______________ Total number ______________

4. Calculate the **percentage** of light collected by a 4-inch aperture telescope compared to a telescope with twice the aperture?

- ○ 4%
- ○ 10%
- ○ 25%
- ○ 50%
- ○ 75%
- ○ 100%
- ○ 400%
- ○ 800%

5. The field of view describes the size of the patch of sky in the view, measured in degrees. What gives the largest field of view (meaning the telescope captures the largest amount of the sky)?

○ Largest aperture; smallest eyepiece
○ Largest aperture; largest eyepiece
○ Largest aperture; eyepiece size does not matter
○ Smallest aperture; smallest eyepiece
○ Smallest aperture; largest eyepiece
○ Smallest aperture; eyepiece size does not matter

To see the most detail, it helps to have an object fill much of the field of view. Set the Aperture to 4-inch, the Eyepiece to 40 mm, and the Target to "Moon". Adjust the focus. You will calculate the percentage of the field of view covered by the Moon.

Use a physical ruler (or regularly spaced lines) to measure the diameter of the Moon and the diameter of the field of view on your screen.

Diameter of Moon: __________ Diameter of field of view: __________

Next, you will determine the area of each by calculating the area of the circle. Divide the diameter by 2 to determine the radius (r). Then square the radius and multiply by pi (π = 3.14) (Area = πr^2).

Area of Moon: __________ Area of field of view: __________

6. Calculate the **percentage** of the total field of view area that is covered by the area of the Moon in this scenario.

○ 4%	○ 25%	○ 75%	○ 400%
○ 10%	○ 50%	○ 100%	○ 800%

In Part 1, we examined how the characteristics of a telescope impact what you can see. In particular, we found that doubling the aperture means that four times the light is collected. In Parts 2 and 3, you will explore what different bodies in space look like with telescopes with different apertures.

Part 2: Navigating the Solar System Simulator

Examine the Solar System Simulator. To see the Moon as you did with the Telescope simulator, set the "Show me" to …the Moon, set "as seen from" to Earth, and choose "I want a field of view of [1] degree". Don't forget to hit "Run Simulator" to show you the image. Continue to play with the different choices, then answer the following questions.

7. What happens when you make the field of view smaller?
○ You can see more of the sky, and the objects appear larger
○ You can see more of the sky, and the objects appear smaller
○ You can see less of the sky, and the objects appear larger
○ You can see less of the sky, and the objects appear smaller

8. Which scientific question would be best answered by a telescope with a larger field of view?
○ Do the features on Jupiter change in size over one month?
○ Are there asteroids that might hit Earth in the next 50 years?
○ How many planets orbit the nearest star?
○ How many volcanoes are there on Jupiter's moon Io?

9. After deciding on a scientific question, what is the next step in the **process of science**?
○ Ask a scientific question
○ Determine the methods to use
○ Make observations and collect data
○ Analyze data and develop conclusions
○ Share results and conclusions

10. Set the Solar System simulator to a field of view of 0.01 degree. This is similar to what a large observatory can see. Aim it at Neptune as viewed from Earth. Which of these is an observation you could make about Neptune?
○ It is not possible to see Neptune.
○ Neptune is a small dot.
○ Neptune has fuzzy blue-green bands, but details of the clouds are not visible.
○ Neptune has distinct bands with detailed white clouds around a large blue spot.

11. Set the Solar System simulator to a field of view of 1 degree. This is similar to what a home telescope can see. Aim it at Io (a moon of Jupiter) as viewed from Earth. Which of these is an observation you could make about Io?
○ It is not possible to see Jupiter or its moon Io.
○ Io is a small dot.
○ Io has fuzzy orange, yellow, and white splotches, but details of the splotches are not visible.
○ Io has detailed splotches with distinct, dark-colored volcanoes.

Part 3: Collecting data with different telescopes

What telescope is needed to observe features on Saturn and its moon Titan?

Very large telescopes tend to have smaller fields of view but higher resolutions than small telescopes. Here are some approximate numbers you can use with the Solar System Simulator to simulate different sized telescopes (from smallest to largest):

- To simulate what you can see with your eye, enter a field of view of 10 degrees.
- Home telescopes have a field of view of approximately 1 degree.
- A telescope in a small observatory has a field of view of approximately 0.1 degrees.
- A telescope in a large observatory has a field of view of approximately 0.01 degrees.

Fill in Data Table 1 with observations of Saturn and its moon Titan simulating different telescopes. Four observations have been filled in for you.

Data Table 1

Telescope	**Observation of Saturn and its rings***	**Observations of Titan****
Your naked eye field of view: 10 Degrees	Visible as a dot	Cannot see Titan
Home telescope field of view: 1 degree		Barely visible as a small dot
Small observatory field of view: 0.1 degree		
Large observatory field of view: 0.01 degrees	Bands of orange and white on Saturn with some storms visible; can see rings with breaks between them	

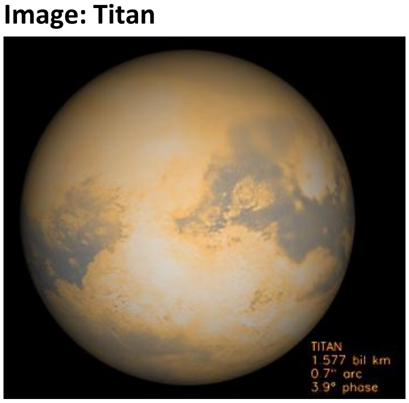
* Note that the tilt of Saturn's rings changes from our viewing point on Earth, so you may need to change the date by several years to better see the rings.

** Note that Titan may be blocked by Saturn, so you may need to change the date by several days.

12. What is the smallest telescope needed to make observations of the bands in Saturn's rings?

○ Your naked eye
○ Home telescope
○ Small observatory
○ Large observatory
○ None of the telescopes on Earth can see that

Image: Titan



13. Examine the image of Titan and compare it to the observations you recorded in Data Table 1. What telescope is needed to take a similar image?

- ○ Your naked eye
- ○ Home telescope
- ○ Small observatory
- ○ Large observatory
- ○ None of the telescopes on Earth can see that much detail

14. If you were able to put a telescope on Saturn, what telescope would be able to take a similar resolution image of Titan? (Change "as seen from" to Saturn)

- ○ Your naked eye
- ○ Home telescope
- ○ Small observatory
- ○ Large observatory
- ○ None of the telescopes on Earth can see that much detail

15. Why do NASA and other space agencies send spacecraft with small telescopes to orbit other planets (e.g. Galileo to Jupiter, Cassini to Saturn)?

- ○ There are not enough of our largest telescopes on Earth for scientists to observe other planets and moons.
- ○ Earth's atmosphere increases the field of view for telescopes, preventing telescopes on Earth from viewing small details.
- ○ Our largest telescopes on Earth cannot see the details that can be seen with a small telescope close to the planet.

Distinguishing between **observations and interpretations** is an important skill for scientists that you will practice below. Observations are what you can see or measure. Interpretations are explanations that make sense of observations. Observations are data, and interpretations are conclusions made from that data.

16. Think about the difference between **observations and interpretations**. What do telescopes provide?

- ○ Observations
- ○ Interpretations
- ○ Both observations and interpretations

17. Each choice below is either an **observation or interpretation**. What is an **interpretation** you can make if you observe the location of Jupiter's four brightest moons over time?

- ○ They look like dots.
- ○ They are orbiting Jupiter.
- ○ They are sometimes on the left and sometimes on the right of Jupiter.
- ○ They have different colors and brightnesses.

So far in this lab, we've focused on what we can see in the visible light range of the electromagnetic spectrum (400 nm to 700 nm) with a telescope. In the next parts of the lab, you will focus on specific wavelengths of light by using a telescope to look at the spectra bodies in space.

Part 4: Navigating the AstroSims Spectrum Constructor

Do some brief independent research to learn about the electromagnetic spectrum, the differences between continuous, emission, and absorption spectra, and how spectra can be used to detect different elements.

Examine the [AstroSims Spectrum Constructor Simulator]() and play around with the continuous, emission, and absorption spectra. Note that you can mouse-over or tap the graph to display the brightness at specific wavelengths.

18. What part of the electromagnetic spectrum is being shown?

○ Ultraviolet
○ Visible
○ Infrared

19. When using the AstroSims Spectrum Constructor Simulator, what two types of spectra together look like a rainbow with black lines through it?

○ Continuous and emission together
○ Emission and absorption together
○ Absorption and continuous together

20. If you were looking for sodium in a cloud of gas in space, what wavelength of spectral lines would you pay particular attention to?

○ 447 nm ○ 589 nm ○ 656 nm ○ 668 nm

Scientists use graphs to interpret data because they turn numbers into visual patterns that are easier to understand. They help communicate data by showing trends and patterns and making comparison easier. To **read a graph**, start by examining the labels to understand what the axes represent. Then look at the data points to identify trends, patterns, or comparisons.

21. When you **read the graph** on the AstroSims Spectrum Constructor Simulator, what does the left axis show?

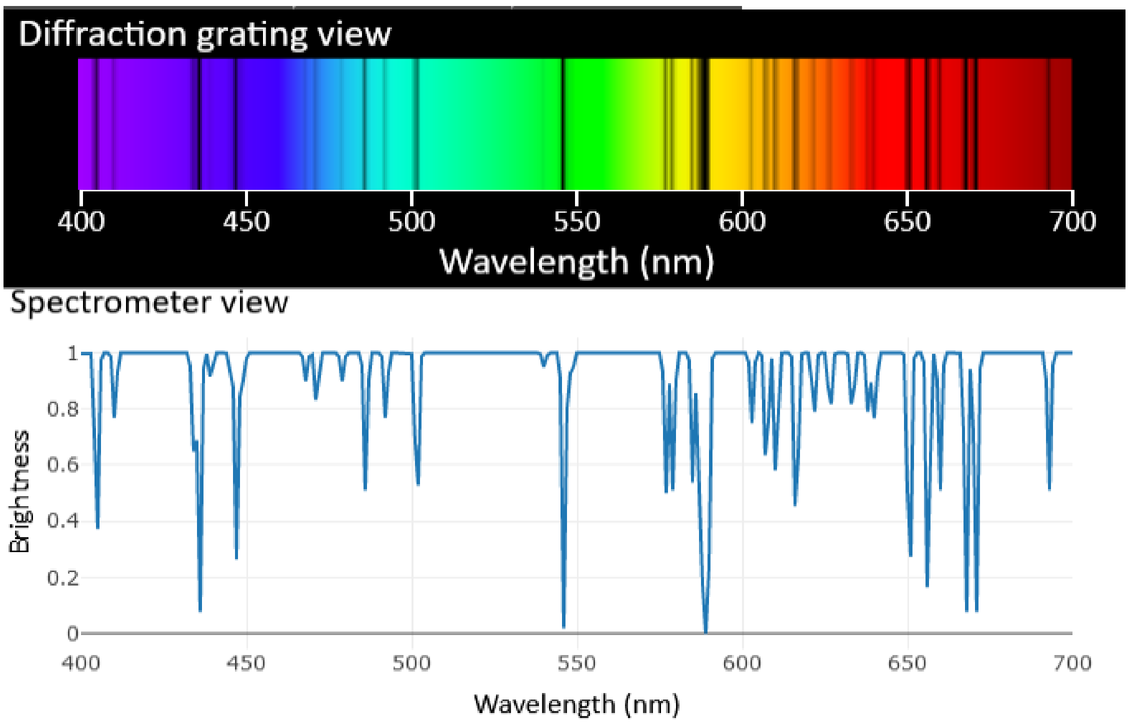
○ Wavelength, with 400 indicating full brightness and 700 indicating more absorption
○ Wavelength, with 700 indicating full brightness and 400 indicating more absorption
○ Brightness, with 0 indicating full brightness and negative numbers indicating more absorption
○ Brightness, with 1 indicating full brightness and lower numbers indicating more absorption

Part 5: Planning methods and collecting data to answer a scientific question

What information can be learned from spectral lines in this unknown spectrum?

The methods section of a scientific study gives the specific step-by-step strategy used to collect data to answer a scientific question. You are asked the above scientific question about spectra What methods would you use to collect data to answer the scientific question?

Unknown Spectrum



22. You want to identify what the spectrum is showing using the AstroSims Spectrum Constructor Simulator. What methods would you use to reproduce the unknown spectrum? Select **two** of the steps.

☐ Set the continuous spectrum to none.
☐ Set the continuous spectrum to visible.
☐ Set the continuous spectrum to thermal: 3,000 K.
☐ Select all the elements for emission spectra at once and see which ones are missing in the unknown spectrum.
☐ Select elements for absorption spectra, one at a time, and match them to the lines in the unknown spectrum.

23. Each choice below is an **observation or interpretation** about the unknown spectrum. What is an **interpretation** you can make about the unknown spectrum?

- ○ The largest absorption lines are at 546 nm and 589 nm.
- ○ There is neon present.
- ○ The continuous spectrum shows visible light.

Consider the scientific question above about the information that can be interpreted from spectra. Using the AstroSims Spectrum Constructor Simulator, you will collect data necessary to identify unknown spectra. In Data Table 2 below, fill in the wavelength of the one major spectral line for hydrogen, lithium and sodium. To get the exact wavelength, you can hover over the graph and read the wavelength in the black box at the bottom.

Data Table 2

Element	**Wavelength of major spectral lines (nm)**
Hydrogen	
Helium	447, 588, 668
Lithium	
Sodium	
Neon	651 (smaller lines at 585, 615, 660, 693)

A fellow student wrote the following about an unknown spectrum: "**I see major spectral lines at 447 nm, 588 nm, 656 nm, and 668 nm, along with other less bold lines.**"

24. Think about **observations versus interpretations**. What did the student write about?

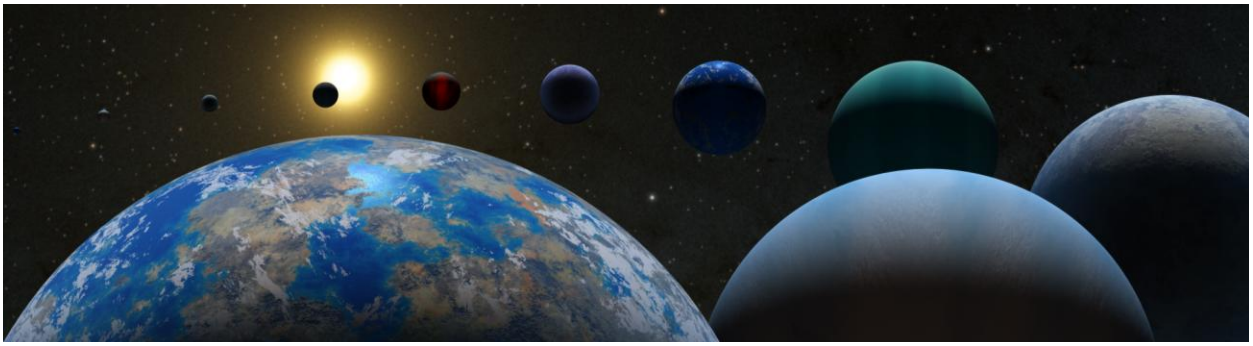
- ○ Observations
- ○ Interpretations
- ○ Both observations and interpretations

The student proposes the following conclusion statement about their unknown spectrum: "**Based on the spectral lines I observed, I interpret that hydrogen and sodium are present**."

25. How would you fix the second part of the student's conclusion statement, so the interpretation is supported by the data you collected?

- ○ I interpret that hydrogen and sodium are present. (No changes)
- ○ I interpret that hydrogen and helium are present.
- ○ I interpret that hydrogen and lithium are present.
- ○ I interpret that helium and sodium are present.
- ○ I interpret that lithium and sodium are present.
- ○ I interpret that hydrogen, helium, lithium, and sodium are present.

Part 6: Collecting data about spectra of planets



An artist's impression of what planets around other stars may look like, but how do we know? (source: NASA).

Several molecules are commonly found in atmospheres of planets.

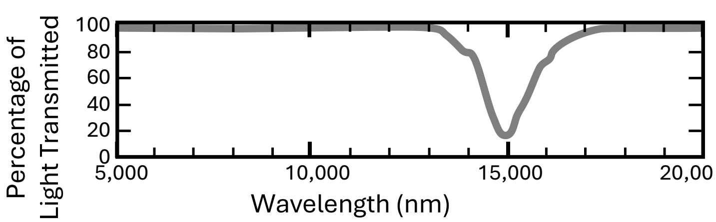
- Carbon dioxide is added to an atmosphere through a variety of processes (e.g. volcanoes).
- Water is naturally added to an atmosphere, and it is necessary for life.
- Oxygen and methane are considered to be signatures of life, meaning that they likely cannot be present in an atmosphere without life being present.

26. Based on the information above, which **two** molecules in an atmosphere indicate likely life?

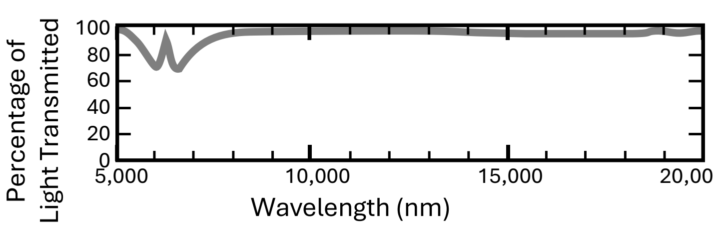
☐ Carbon dioxide ☐ Water ☐ Oxygen ☐ Methane

A planet gives off a continuous spectrum in longer wavelengths than our eyes can detect. As the light moves through the planet's atmosphere, some of it is absorbed by molecules in the atmosphere. Therefore, we can use a telescope on Earth to collect the spectra of light from a planet to identify the composition of its atmosphere. Below are spectra of some molecules found in atmospheres.

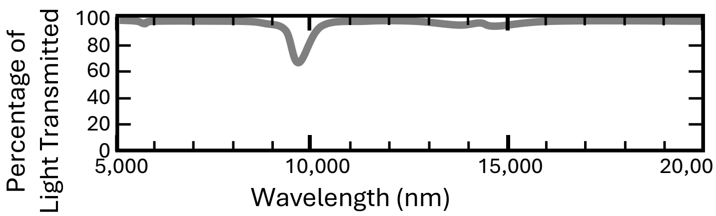
Spectrum for Carbon dioxide



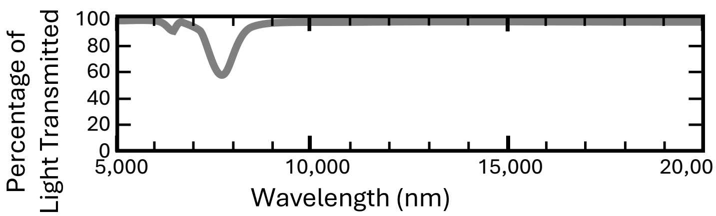
Spectrum for Water



Spectrum for Oxygen (ozone)



Spectrum for Methane



27. When you **read the graphs**, what does the height of the line show?

- O The wavelength of light. If the wavelengths are longer, the line is higher on the graph.
- O The percentage of light not absorbed by molecules in the atmosphere. If more light gets through, the line is higher on the graph.
- O The brightness for each wavelength of light. If the wavelength is dimmer, the line is higher on the graph.

28. Consider the part of the electromagnetic spectrum is being shown in the above graphs of the spectra of molecules. How does it compare to the part of the spectra shown for elements?

- O Ultraviolet for elements and visible for molecules
- O Visible for elements and ultraviolet for molecules
- O Visible for elements and infrared for molecules
- O Infrared for elements and ultraviolet for molecules

Read the graphs and determine how you would explain the difference between the spectra, such as the spectrum for water and the spectrum for methane. Would you point out the shape of the curve, the number of dips, the wavelength of the dips, etc.?

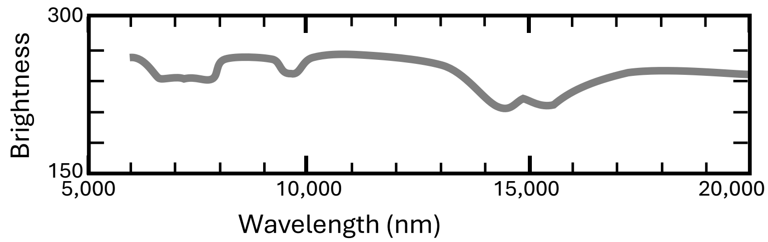
29. **Read the graphs**. Match the molecule with its absorption lines in each spectrum.

Oxygen (ozone) •	• 15,000 nm
Carbon dioxide •	• 9,600 nm
Water •	• 7,600 nm
Methane •	• 6,000 and 6,500 nm

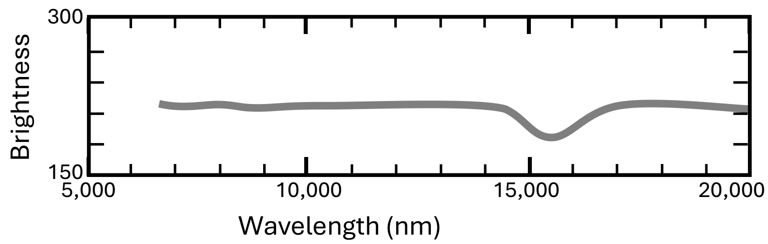
What molecules are present in the atmosphere of Earth, Mars and Venus?

Below are the spectra of three planets: Earth, Mars, and Venus. To answer the scientific question above about molecules in planet atmospheres, label the parts of the spectra where dips indicate oxygen (ozone), carbon dioxide, water, and methane.

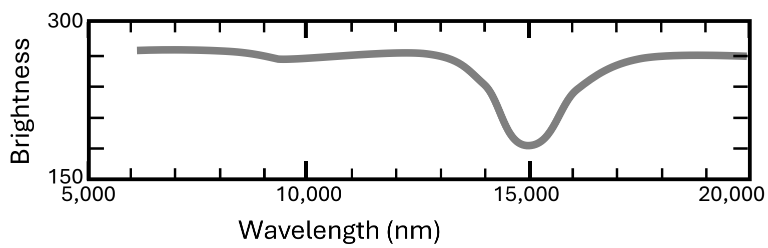
Spectrum for Earth



Spectrum for Venus



Spectrum for Mars



30. When you **read the graphs**, what is an observation you can make about the trends, patterns, or comparisons of the data?

- O The brightness is the same for the wavelengths of 10,000, 15,000, and 20,000 nm for Earth.
- O Venus has the largest dip in brightness, from 300 down to 150.
- O The wavelength is brightest at 20,000 nm and dimmest at 10,000 nm for Earth, Venus, and Mars.
- O Some dips in brightness are at different wavelengths for Earth, Venus, and Mars, but all have the biggest dip at 15,000 nm.
- O

Read the graphs and fill in this Data Table 1 by writing "yes" or "no" for the gasses found in each planet's atmosphere. There are one or two that may be uncertain.

Data Table 1

	Earth	Venus	Mars
Oxygen (ozone)			
Carbon dioxide			
Water			
Methane			

31. What molecule is present in the atmospheres of all three planets?

O Carbon Dioxide O Water O Oxygen (ozone) O Methane

32. When you **read the graphs** what numerical data are observations that support your interpretation in the previous question?

O All three spectra are relatively smooth, without too many dips or rises
O Dip in all three spectra at 6,000 and 6,500 nm
O Dip in all three spectra at 9,600 nm
O Dip in all three spectra around 15,000 nm
O The high parts of all three spectra extend from 6,000 to 14,000 nm

Atmospheres that have more of a particular molecule often have larger dips in the wavelengths they absorb. To get a sense of abundances of molecules in an atmosphere, you can calculate the percentage of that wavelength that is absorbed.

33. What percentage of light at wavelength 15,000 nm on Mars is absorbed by carbon dioxide? To calculate the **percentage**, use a brightness of 270 without carbon dioxide, with a dip of 90 caused by carbon dioxide.

O 3% O 10% O 33% O 50% O 75% O 300%

34. What molecules does Earth have that are not clearly present in the spectra of Mars and Venus?

O Carbon dioxide and oxygen (ozone) O Oxygen (ozone) and water
O Carbon dioxide and water O Oxygen (ozone), water, methane, and carbon dioxide

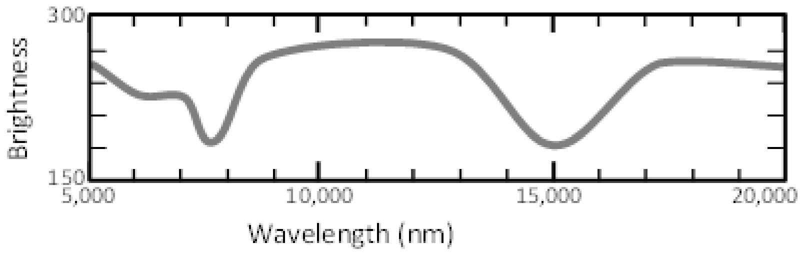
35. When you **read the graphs**, what numerical data are observations that support your interpretation?

O Rise in Earth's spectrum at 11,000 nm that is not found in Mars' and Venus' spectra
O Earth's spectrum has more dips and rises overall, with more wiggles
O Dips in Earth's spectrum at 6,000, 6,500 and 9,600 nm that are not found in Mars' and Venus' spectra
O Dips in Earth's spectrum at 6,000, 6,500, 9,600, and 15,000 nm that are not found in Mars' and Venus' spectra
O Earth's spectrum has a deeper dip at 15,000 nm than Mars' and Venus' spectra

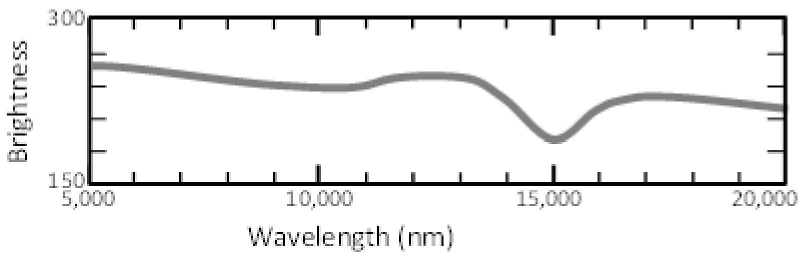
Part 7: Synthesizing the process of science

Which of these two planets would you explore to search for life?

Spectrum for Planet X



Spectrum for Planet Y



You observed these spectra of two planets (Planet X and Planet Y). You are asked to write a research report answering the above scientific question about life on other planets.

Here is the **first sentence** of your report:
Should we explore Planet X or Planet Y for signs of life?

36. What part of the **process of science** does this **first sentence** describe?

- O Ask a scientific question
- O Determine the methods to use
- O Make observations and collect data
- O Analyze data and develop conclusions
- O Share results and conclusions

Here is the **second sentence** of your report:
I examined the spectra of the two planets (Planet X and Planet Y) to determine what molecules were found in the atmospheres.

37. Which sentence is a good **third sentence** for your report?

- O For Planet X, I see a spectrum that overall has a lot of dips and rises. For Planet Y, the spectrum is much smoother, with only a couple broad dips and rises.
- O For Planet X, I see dips at 6,000-7,000 nm, 7,600 nm, and 15,000 nm. For Planet Y, I see a dip at 15,000 nm.
- O For Planet X, I see the highest parts at 9,000-13,000 nm. For Planet Y, I see the highest parts at 12,000-13,000 nm.

38. Why was this an appropriate **sentence** near the beginning of your report?

○ This sentence describes the data and observations, which is necessary to support the interpretations in the analysis.
○ This sentence makes an interpretation of the data, which is important to get to right away.
○ This sentence states the conclusion, which ties the interpretation of data to the original question being answered.

39. Which sentence is a good **fourth sentence** for your report?

○ I interpret this to mean that Planet X has water and methane, and Planet Y has carbon dioxide and an unknown molecule in the atmosphere.
○ I interpret this to mean that Planet X has a thicker atmosphere, and Planet Y has a thinner atmosphere.
○ I interpret this to mean that both planets have an atmosphere, but Planet X has a greater abundance and variety of gases in the atmosphere.
○ I interpret this to mean that both planets have carbon dioxide, but Planet X also has water and methane in the atmosphere.

40. Which sentence is a good **fifth sentence** for your report?

○ Carbon dioxide and oxygen are necessary for plants and animals.
○ Methane is a signature of life, and water is necessary for life.
○ A thick atmosphere with water is necessary for life.
○ A greater variety of gases could result in a greater variety of life.

41. Which sentence is a good **final sentence** for your report?

○ Therefore, I would explore Planet X to look for life.
○ Therefore, I would explore Planet Y to look for life.
○ Therefore, I would explore both Planets X and Y to look for life, as they are both likely to have it.
○ Therefore, I wouldn’t explore either Planet X or Planet Y, as neither are likely to have it.

42. Why is writing and publishing a report an important part of the **process of science**?

○ It is asking a scientific question.
○ It is determining the methods to use.
○ It is making observations and collecting data.
○ It is analyzing data and developing conclusions.
○ It is sharing results and conclusions.

Reflection

43. Which question in this lab connects to your personal experience? Consider the lab topic, math skills, and the process of science. You may also consider your lived experience or stories you’ve encountered. To earn credit, list the question number and explain how it relates in 2-3 sentences.