

ASTRONOMY LAB MANUAL



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Chabot College

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This text was compiled on 10/06/2026

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Glossary

Detailed Licensing

Licensing

A detailed breakdown of this resource's licensing can be found in **Back Matter/Detailed Licensing**.

1: Mapping the Night Sky

Lab Overview

This lab is an introduction to the night sky. In this lab, we will examine different stars on a static night sky. In groups you will discuss how to locate those stars, estimate and compare relative magnitude of the stars, and identify constellations. You will also practice using a star wheel as a guide to the night sky.

Lab Goals

As a result of this lab, you should be able to:

- Identify the location of a star in the sky using astronomical coordinates
- Use a starwheel to identify the constellation of different stars in the sky
- Predict the apparent magnitude of a star based on comparison stars

Equipment and Setup

This lab requires the following equipment:

- Planetarium (or Planetarium software)
- Starwheel
- Red lights / lasers (optional)

Submission Instructions

Submit a brief lab report that includes the following sections:

Methodology

Include your methods for locating and communicating the location of stars and your reflection on those methods.

Results

Data tables for your group focus stars

Discussion

Responses to the discussion questions

Part 1 - Star Location

Background Information

We will begin our night sky learning journey by using our planetarium to simulate a starry sky in Hayward, CA. When the planetarium is on, please refrain from using cellphones, laptops, tablets, or any other device that produces light. We have special red flashlights that allow us to see without disrupting the dark adaptation of our eyes.

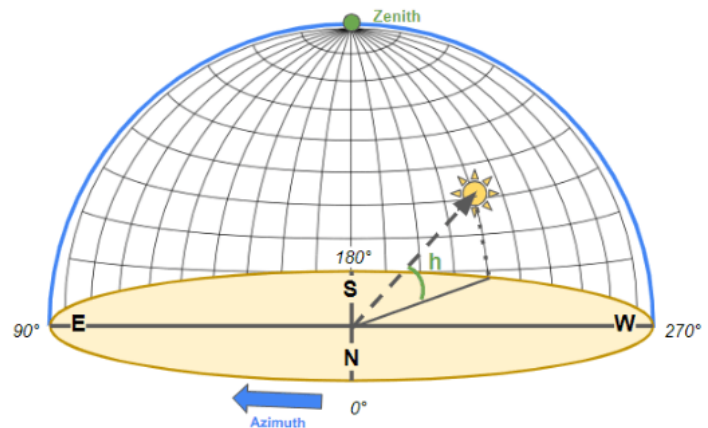
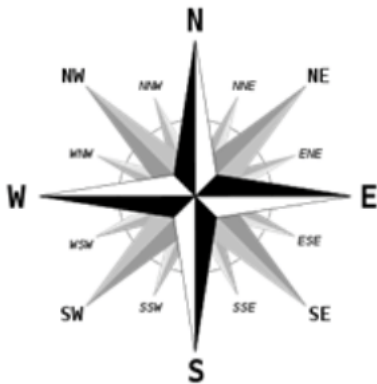
Lab Instructions

1. Choose a star in the sky. Do not point to it or give away its location.
2. Write instructions for how to locate that star.
3. Share your instructions with your group. Each member of the group should guess the location of your star.
4. Write down some ideas on how you could make the process of identifying each other's star easier.
5. In collaboration with your partners, select a **Focal Star** that the entire group will use.
6. If you were to make a constellation out of the pattern of stars near the star you have chosen, what would it look like?
 1. Draw your imagined constellation below with a label to designate your focal star. Each group member may have a different response.

Part 2 - Star Measurements

Background Information

We can identify the location of a star or a point in the sky by imagining a curved grid superimposed on the sky. Grids have two axes. For star locations, we can describe the **Cardinal Direction** of the star along the horizon and the **Altitude** of the star above the horizon. We can add precision to our **cardinal directions** by identifying 360 degrees around the horizon with our 0o point as North. This measurement is called **Azimuth**.



Lab Instructions

1. **As a group:** Identify the following for your group's **Focal Star**:
 1. **Cardinal direction:** What direction should you face to see the star?
 2. **Altitude:** How high above the horizon is the star (in degrees)?
 3. **Apparent brightness:** Compare the brightness (Very bright, medium bright, dim) of your star to the brightest star you can see on the planetarium sky.
 4. **Any other identifiers.** Any other characteristics about the star or position that can help you identify the star?
2. Complete the table for 5 additional star choices agreed upon by your group. Choose stars that are not near each other in the sky.
3. Discuss the questions as a group, then respond in **complete sentences**:
 1. Why are **Cardinal Directions (Azimuth)** and **Altitude** useful concepts for astronomical observation?
 2. How else can astronomers communicate information about a star to help others locate the same star?

Results

Star	Altitude (degrees)	Cardinal Direction	Apparent Brightness	Other identifiers
Focal Star (1)				
Star 2				
Star 3				
Star 4				
Star 5				
Star 6				

Part 3 - Using a Starwheel

Background Information

This activity involves the use of a **Star Wheel**. Your instructor will demonstrate how to set the starwheel to our latitude and local time and how to orient it correctly. Note: On a starwheel, constellations are labeled in all caps (URSA MAJOR). Some of the brightest stars in the constellations are labeled with only a capital first letter (Vega).

The **apparent magnitude** of a star indicates how bright the star looks to the naked eye. The magnitude scale we use today was first developed thousands of years ago by ancient Greek astronomers and has since been adapted into a logarithmic scale by modern astronomers. Adapting a more robust mathematical scale to ancient naked-eye observations yields a more functional but less intuitive scale. **Negative magnitudes mean brighter stars!**

The relative brightness of stars on your starwheel is represented by the size of the dot. Larger dots indicate brighter stars. The brightest star visible in our sky is **Sirius** (Mag -1.5). Some other bright stars that should be labeled on your starwheel are **Arcturus** (Mag 0), **Vega** (Mag 0), **Deneb** (1.25), and **Antares** (Mag 1). Fainter stars are not specifically named on your starwheel except for **Polaris** (Mag 2). The naked eye limit (the faintest magnitudes that can be seen with the naked eye in very dark skies) is about Magnitude 6.

Your starwheel may include a magnitude chart on the back (and a section titled "The First Magnitude Stars").

Lab Instructions

- Keep the same stars and star numbers you used in the first table. Now, using your starwheel, identify the constellations of your 6 original stars.
 - Is your star not on the starwheel? Reasons could be:
 - It is too faint
 - It is not a star! It could be a planet.
 - If your star is not on the starwheel, give a constellation hypothesis based on general location and nearby stars.

2. Locate the stars mentioned in the **Background** section on your starwheel and compare their brightness and magnitudes to the stars on your table. Estimate an apparent magnitude for each of your 6 stars in the table (you don't have to be exact, just give it a good guess).
3. **Bonus Credit:** If you have completed your two tables, and you are waiting for your classmates to catch up. You can choose 5 additional stars and, using the same steps 3-6 fill out this table.
4. Your instructor will put up the outline and the name of each constellation. Discuss the questions as a group, then respond in **complete sentences**:
 1. Were you correct for each of your six stars? Explain below any corrections that need to be made to your table (but do not change your original answers)
 2. What would you change about your process next time if you had 6 different stars? Explain the reasons for those changes.

Results

Star	Constellation Hypothesis	Correct (Y/N)	Corrections / Notes
Focal Star (1)			
Star 2			
Star 3			
Star 4			
Star 5			
Star 6			

Star	Altitude Degrees	Cardinal Direction	Apparent Brightness	Other Identifiers	Constellation	Correct? Y/N
Star 7						
Star 8						
Star 9						
Star 10						

Star 11						
---------	--	--	--	--	--	--

2: Apparent Motion

Lab Overview

This lab explores the apparent motion of objects in the sky due to Earth's rotation.

Lab Goals

As a result of this lab, you should be able to:

- Collect observational data on the change in position of star patterns in the night sky over time
- Identify patterns relating latitude/longitude and visible star patterns.
- Identify patterns relating latitude/longitude and celestial sphere features (poles, equator, circumpolar regions, etc)

Equipment and Setup

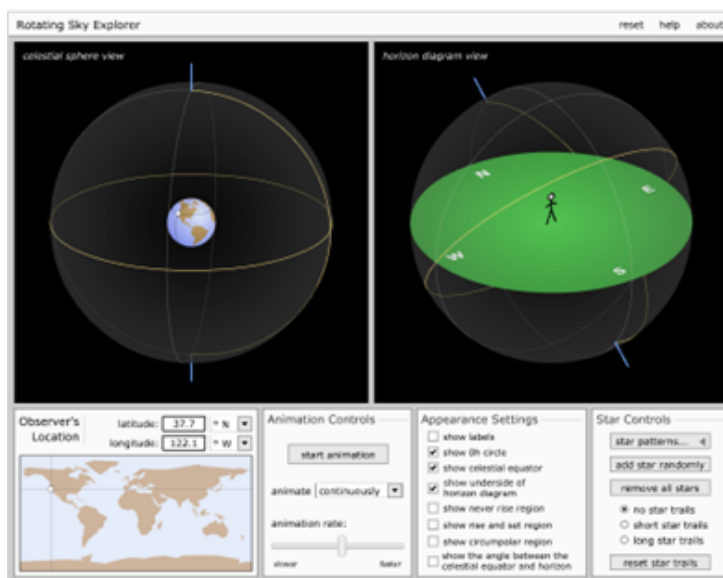
This lab requires the following equipment on each table.

- Computer/Tablet with internet access

Submission Instructions

Submit a brief lab report that includes the following sections:

1. **Results**
2. **Discussion**



Celestial Sphere Simulation

Background Information

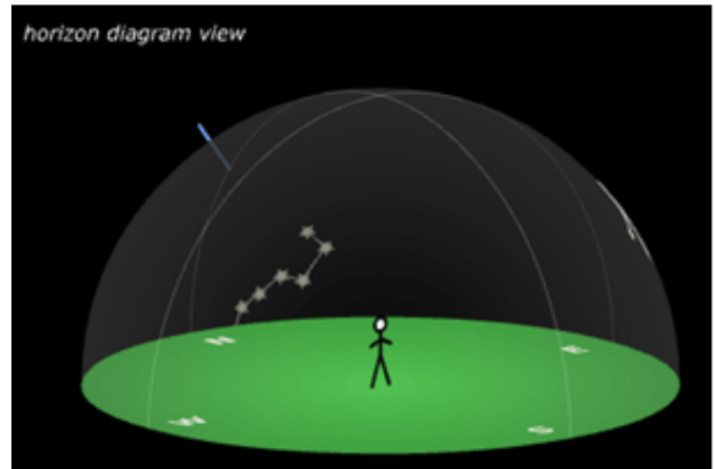
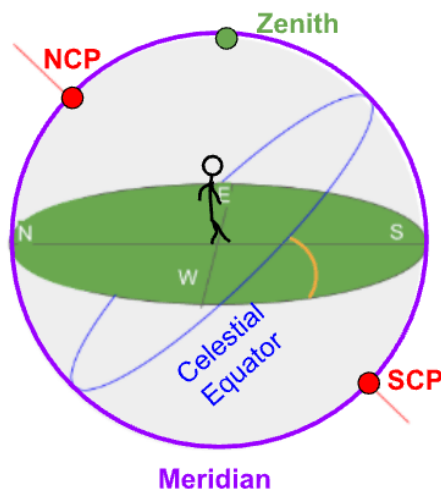
We will continue our exploration of the night sky using a computer simulation. This simulation will allow us to see the effect of

time on our sky maps. Open the University of Nebraska-Lincoln NAAP Rotating Sky Explorer Simulator:

- https://astro.unl.edu/naap/motion2/animations/ce_hc.html
- <https://tinyurl.com/Sky-Explorer>

The entire Earth has been mapped using coordinates of longitude and latitude. You use these coordinates every day, even if you are not aware of it. The GPS on phones and computer apps use these coordinates to pinpoint your position on Earth. Your position on Earth determines what objects are visible to you in the sky at a specific time. For this lab we will use our **current location** to make sense of our local view of the sky. Look up information about your latitude and longitude to set up the simulation.

Astronomical Coordinates are similar to Latitude and Longitude but they mark locations in the sky, not locations on Earth. We will explore the markings of this **Celestial Sphere** in this lab to make sense of sky maps and how they change over time.



The **North Celestial Pole (NCP)** and **South Celestial Pole (SCP)** will be marked on the simulation. These locations represent the projections of the north and south geographical poles on Earth on the celestial sphere model.

The **zenith** is also marked, which represents the point directly above the observer's head on the sky. The zenith is at an altitude of 90 degrees from the horizon. Lastly, the '**meridian**' represents an imaginary circle that passes through the north and south celestial poles. The meridian functions as a helpful way to think about the altitude of stars as the Earth turns.

The **green circle** represents the observer's horizon. The **horizon** marks the visible separation between the Earth and the sky and is at an altitude of 0 degrees. The observable sky is what is visible above your horizon. Your horizon is local to you; if two people are at significantly different positions on Earth, they have different horizons. This is due to the spherical nature of the Earth and the fact that you cannot see around a curve. Horizons also may be partially blocked due to trees, buildings, mountains, clouds, etc.

Setup Instructions

1. Use an internet resource to look up the longitude and latitude of Hayward, CA, and enter it in the "Observer's Location" section in the lower left area of the Rotating Sky Explorer simulation. This will replicate the sky in our area.
2. On the "**Star Controls**" panel, select the pull-down menu for '**star patterns**' and make sure all three options are checked (**Big Dipper**, **Orion**, and **the Southern Cross**). On the "Appearance Settings" panel, select the option for '**show labels**'.
3. On the "**Appearance Settings**" panel, select the box for "**show the angle between the celestial equator and horizon**."
4. In the "**Animation Controls**" panel, click "**start animation**" and adjust the animation controls as you like to observe the star patterns move over time.

Lab Instructions

Apparent Motion Patterns

1. Look at the “**horizon diagram view**”: Describe the visibility and motions of the three star patterns over multiple days.
2. Look at the “**celestial sphere view**”, Describe the visibility and motions of the three star patterns over multiple days.
3. Explain the differences in the visibility and motions of the three star patterns between the two different views. Also, describe what causes the apparent differences.

Effect of Location

1. Adjust the **Longitude** of the person by clicking on and dragging the white dot that is on the flat **Observer’s Location** map. Try to drag the dot back and forth **horizontally** while keeping the latitude the same. How does it affect the **Horizon View Diagram**?
2. Adjust the **Latitude** of the person by clicking on and dragging the white dot that is on the flat **Observer’s Location** map. Try to drag the dot up and down **vertically** while keeping the longitude the same. How does it affect the **Horizon View Diagram**? Is there a numerical relationship between the latitude and the angle
3. **Circumpolar stars** are defined as stars located near the North and South Celestial Poles. You can select “**show the circumpolar region**” in the Appearance Settings panel. Describe the motion of stars in these regions as seen from observers at a selection of different latitudes (try a latitude in the northern hemisphere, the equator, and the southern hemisphere).
4. Using as many of the “**Animation Controls**”, “**Appearance Settings**”, and “**Star Controls**” options as you like, explore the differences in the observable sky. Fill out the discovery table in the **Results** section of your report.
5. Select or change as many settings/controls as you would like to continue to explore the relationship between location, time, and the observable sky. ***Once you feel that you have mastered the concepts, answer the discussion questions in detail.***
 1. How does an observer’s **latitude** affect the angle that the celestial equator makes with the local horizon?
 2. What can an observer’s **latitude** indicate about the constellations that are visible to them?
 3. How does an observer’s **longitude** affect the constellations visible to them?
 4. Two students are observing the night sky at the same time but at very different **latitudes** on Earth. They are texting back and forth about what they see. One student is in Bozeman, Montana, and the other student is in Cusco, Peru. Explain the visibility and motion of each of the three “star patterns” constellations that you can select in the Star Controls panel for each observer.

3: Celestial Sphere Model

Lab Overview

This lab uses a celestial sphere model to identify mathematical patterns relating the North Star to latitude. You will also explore apparent motion using this model to see how the celestial sphere relates to star paths in the sky.

Lab Goals

As a result of this lab, you should be able to:

- Identify a mathematical relationship between the latitude of an observer and the altitude of Polaris (the North Star)
- Collect observational data on daily apparent motion of stars at different latitudes
- Describe and explain how latitude / longitude affects or does not affect the apparent motion of stars

Equipment and Setup

This lab requires the following equipment on each table.

- Physical Celestial Sphere Model

Submission Instructions

Submit a brief lab report that includes the following sections:

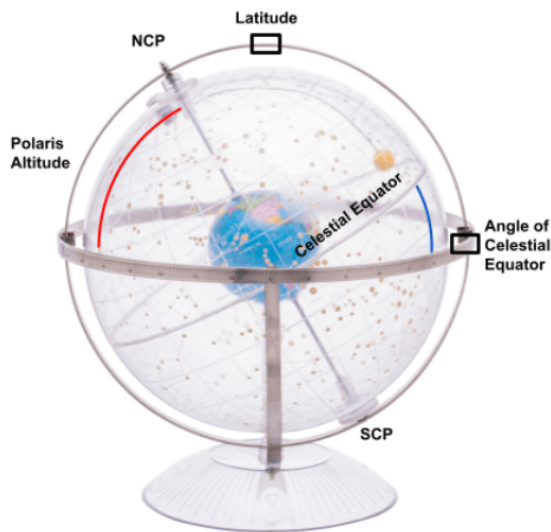
Results

Discussion

Using a Model Celestial Sphere

Background Information

Now that you have some experience with the position and motion of stars using the planetarium and an online simulation, we will continue our exploration with a 3D model of the celestial sphere. Each group has access to a physical Celestial Sphere Model. Please be very careful with this expensive model. Keep it on its stand if someone is not actively holding it. We will use the markings on the model to identify different latitudes. For the angle of Polaris, be sure to identify the angle between the North Celestial Pole (NCP) and the Horizon (horizontal metal ring). It might not match the number at the horizon.



Celestial Sphere Model Instructions

1. Spend time with your group carefully examining the celestial sphere. Hold it, look up closely at each part, and share your discoveries with each other.
 1. Rotate the **Earth Only** by turning the white knob that is at the **South Celestial Pole**. The Earth should turn towards the **East**.
 2. Now **hold onto that knob to keep the Earth from rotating**. Turn the clear sphere the opposite way as you rotated the Earth. This produces the same **relative motion** between a location on Earth and the stars in the sky.
 3. Decide as a group, which of the two previous version of rotation provide the more realistic representation of how things are actually moving?
2. The horizontal ring around the sphere represents your horizon from the **Horizon Model** in the simulation. Imagine you are on top of the Earth viewing the half of the sphere that is above this metal ring.

North Pole

1. Adjust the angle of the Earth to represent the observable sky for a person who is at the **North Pole**. Briefly sketch the appearance of your model with the Earth and the horizon marker in the appropriate position. Please label your sketch.
2. Determine the altitude of the North Star (Polaris) from this observer's position _____
3. As the Earth turns (you can reach in and rotate the Earth), how does the sky appear to change over the course of the night for an observer at **the north pole** (how do the stars appear to move)?

Equator

1. Adjust the angle of the Earth to represent the observable sky for a person who is at a location on the **equator**. Briefly sketch the appearance of your model with the Earth and the horizon marker in the appropriate position. Please label your sketch.
2. Determine the altitude of the North Star (Polaris) from this observer's position _____
3. As the Earth turns (you can reach in and rotate the Earth), how does the sky appear to change over the course of the night for an observer at the **equator** (how do the stars appear to move)?

South Pole

1. Adjust the angle of the Earth to represent the observable sky for a person who is at the **South Pole**. Briefly sketch the appearance of your model with the Earth and the horizon marker in the appropriate position. Please label your sketch.
2. Determine the altitude of the North Star (Polaris) from this observer's position _____
3. As the Earth turns (you can reach in and rotate the Earth), how does the sky appear to change over the course of the night for an observer at **the south pole** (how do the stars appear to move)?

30°N

1. Adjust the angle of the Earth to represent the observable sky for a person who is at a location at a latitude of **30 degrees in the Northern Hemisphere**. Briefly sketch the appearance of your model with the Earth and the horizon marker in the appropriate position. Please label your sketch.
2. Determine the altitude of the North Star (Polaris) from this observer's position _____
3. As the Earth turns (you can reach in and rotate the Earth), how does the sky appear to change over the course of the night for an observer at **30 degrees North** (how do the stars appear to move)?

60°N

1. Adjust the angle of the Earth to represent the observable sky for a person who is at a location at a latitude of **60 degrees in the Northern Hemisphere**. Briefly sketch the appearance of your model with the Earth and the horizon marker in the appropriate position. Please label your sketch.
2. Determine the altitude of the North Star (Polaris) from this observer's position _____
3. As the Earth turns (you can reach in and rotate the Earth), how does the sky appear to change over the course of the night for an observer at **60 degrees North** (how do the stars appear to move)?

Choose your Latitude: ____° N / S

1. Move the horizon marker that surrounds Earth to represent the observable sky for a person who is at a location at a latitude that **is different from any of the previous ones**. Briefly sketch the appearance of your model with the Earth and the horizon marker in the appropriate position. Please label your sketch.
2. Determine the altitude of the North Star (Polaris) from this observer's position _____
3. As the Earth turns (you can reach in and rotate the Earth), how does the sky appear to change over the course of the night for an observer at ____° N/S (how do the stars appear to move)?

Discussion

Your discussion should summarize your responses to the questions throughout the lab manual. You might choose to group some questions together in this response. Each paragraph should be organized in a **Claim-Evidence-Reasoning** format:

- **Claim:** A succinct one-sentence answer to the question.
- **Evidence:** A sentence or two that selects and summarizes measurements, descriptions, or patterns from your lab. Be as clear as possible. You might want to add labels or color-coding to your models to make it easy to refer to specific parts or components.
- **Reasoning:** Explain how the specific evidence you selected supports/justifies your claim. Imagine you are explaining it to someone who is not in this lab so they do not have the background information that you have.

Discussion Questions

1. How does an **observer's latitude** affect the constellations and stars they can see over the course of a night.
2. Propose a connection between an observer's latitude and the altitude of Polaris (the North Star).
3. How does an **observer's longitude** affect the constellations and stars they can see over the course of a night.

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4: Sun Path

Lab Overview

In this lab you will use a Celestial Sphere model to explore the path of the sun for observers at different latitudes at different times of the year. You will focus on where the sun rises and sets (if at all), how long the sun is above the horizon (hours of daylight), and differences in the actual path of the sun, including its altitude at local noon.

Lab Goals

As a result of this lab, you should be able to:

- Identify how latitude and seasons (time of year) affect the rise and set azimuth of the sun
- Identify how seasons and latitude affect the hours of daylight
- Identify how latitude and seasons affect the overall path of the sun in the sky

Equipment and Setup

This lab requires the following equipment on each table.

- Celestial Sphere Model that you can manipulate

Submission Instructions

Submit a brief lab report that includes the following sections:

1. **Results**

Include drawings of the sun path as viewed from the celestial sphere models and tables of data for sun measurements at different times of the year.

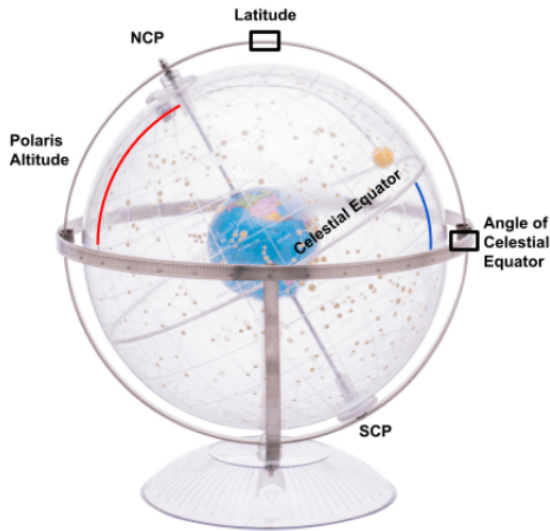
2. **Discussion**

Use the CER format to identify multiple patterns relating the sun position and sun path during the day from different latitudes at different times of the year.

Using a Model Celestial Sphere

Background Information

Recall that you can set the latitude of the observer's horizon by adjusting the latitude value to be at the top of the sphere. You can also use patterns relating the altitude of Polaris and/or the angle of the celestial equator to set the latitude.



There is a sun model on the sphere. Adjust the sun to match the month of the year that you want to model. You can create a sun path by starting the sun on the **Eastern** horizon, placing a dry erase marker on the celestial sphere at the sun location. Rotate the **sphere** and watch the sun rotate as well. Keep the marker at the spot on the Eastern horizon so that a curve is traced out as you rotate the celestial sphere.

Once you have your path drawn, you can measure that path. The celestial sphere has curves that resemble longitude with 1-hour spacings. Using these markings, you can estimate how many hours the sun is above the horizon.

Sun Path Instructions

1. Adjust the angle of the Earth to represent the observable sky for a person who is at each of the following locations:
 1. 40° N
 2. 40° S
 3. Equator
 4. North Pole
 5. South Pole.
2. Use different color markers to identify the sun path for the following months on the 21st of each month. If you finish all locations early, go back and add in the missing months:
 1. March
 2. June
 3. September
 4. December
3. Record the **rise and set azimuth** for each path. If the sun never rises or never sets, write N/A.
4. Measure the **declination** and the **altitude** of the sun at **local noon**.
5. Measure the number of **hours of daylight** for each path
6. **Draw the paths** on the Horizon Diagram Sketch

Discussion Questions

1. Are there any months that have the same values for rise/set azimuth or sun declination?
2. What affects sun declination more? Latitude or time of year (month)?
3. Are there any months when the **latitude** does not significantly affect the **rise and set azimuth**?
4. Are there any months when the **latitude** does significantly affect the **rise and set azimuth**? If so, what patterns do you notice about those azimuth values?

Discussion

Your discussion should make evidence-based claims about patterns, models, or other insights from your experiment. You likely have identified multiple claims that you can make and should write a separate (3-5 sentence) paragraph for each claim. Each paragraph should be organized in a **Claim-Evidence-Reasoning** format:

- **Claim:** A succinct articulation of a pattern or concept that you can support with data/observations.
- **Evidence:** A sentence or two that selects and summarizes measurements, descriptions, or patterns from your lab. Be as clear as possible. You might want to add labels or color-coding to your models to make it easy to refer to specific parts or components.
- **Reasoning:** Explain how the specific evidence you selected supports/justifies your claim. Imagine you are explaining it to someone who is not in this lab so they do not have the background information that you have.

Sun Path Question: How does the time of year affect the path of the sun at different locations on Earth?

- Discuss all of your ideas, then organize them into multiple small patterns.
- Write a CER for each small component of your answer to the overall question.

5: Discovering Kepler's Laws

Lab Overview

Lab Goals

The goal of this lab is to develop the scientific practices of identifying patterns/relationships between variables and making scientific claims based on evidence with clear reasoning. You will develop these lab skills while developing/reviewing your understanding of Kepler's Laws for gravitational orbits. As a result of this lab, you should be able to:

- Restate **Kepler's Laws** as claims and support those claims with evidence and reasoning.
- Identify additional patterns relating orbital shape to other orbital parameters (speed, semi-major axis, orbital orientation, etc).

Equipment and Setup

This lab requires the following equipment on each table.

- Computers with PhET Simulator

Submission Instructions

Submit a brief lab report that includes the following sections:

Methodology

Write a **Methodology** section that details the steps you took in the simulation to generate the data in your results section. Be sure to include information about what boxes were checked in each simulation. Include any description of how you adjusted parameters (position, velocity, etc) and measured values (if any). If your data was visual, describe what you look at in the visual when you made your changes.

Results

Include screenshots from the simulation. This might include orbits, graphs, or other data. If you have a collection of numerical data, make organized tables that are clearly labeled. All images should have a caption with numbers increasing throughout the paper. See example below:

Figure 1. [One sentence description]

Discussion

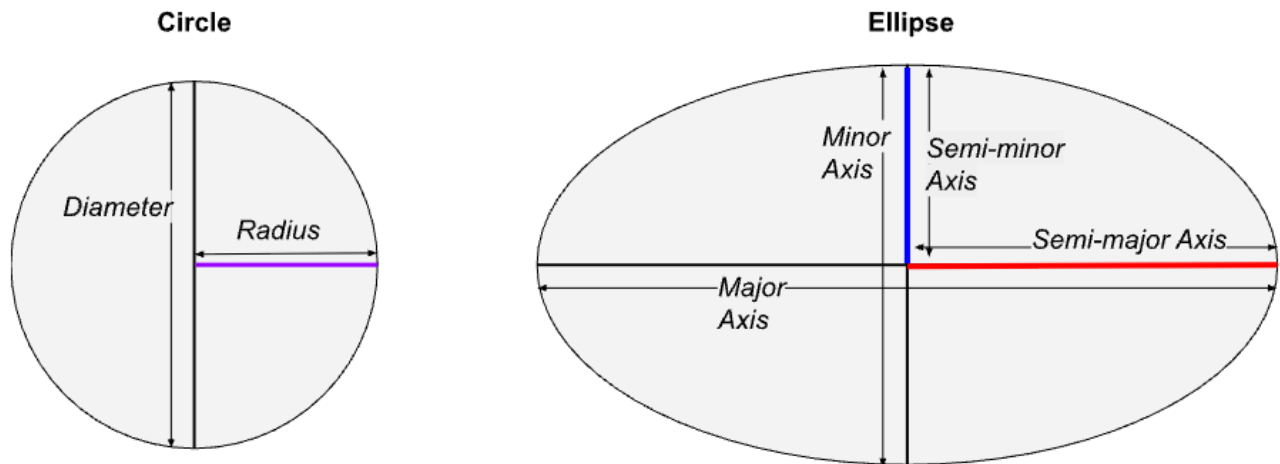
Write/type your answers to the **Discussion Questions** using the **Claim-Evidence-Reasoning** format. If it makes sense, you might group responses to multiple questions into a single claim.

Background Information

When orbits are circular, we can describe them based on their diameter or radius. The diameter is the length of a line that goes from one part of the circle, through the center, to the other end. A radius is the length of a line from the center to any point on the circle. The radius is half the diameter

Most orbits are more of an oval than a circle. These orbits can often be described by the major axis, which is the length of the

long axis and their minor axis, which is the length of the short axis. Since we often describe circular or rotational motion based on radius, rather than diameter, we define a **semi-major axis** as the “long radius” and **semi-minor axis** as the “short radius” of an orbit. The mathematical name for this shape is an **ellipse**.



Lab Instructions

Simulation Setup

Open the Kepler Laws Simulation from the *University of Colorado, Boulder* PHET Interactive Simulations website:

- https://phet.colorado.edu/sims/html/keplers-laws/latest/keplers-laws_all.html

Start with the **First Law** tile.

- Check the box for **Foci**
- Check the boxes for **Axes** and **Semiaxes**

Play around with the simulation for 3-5 minutes. Explore the different menus (on this tile) and different orbits you can make. Then move on to the procedure on the next page.

Part 1 - Orbital Shape

Procedure

1. Check the box for **Always Circular** to simplify the first exploration. Move the planet to different distances and **search for a pattern** between radius and speed for circular orbits. Uncheck the box for **Always Circular** to make the simulation more complex and more realistic.
2. Try adjusting the velocity by changing the green vector. Search for patterns based on the discussion questions.

Discussion Questions

1. For a **circular orbit**, what is the pattern between orbital radius and orbital speed?
2. For an **elliptical orbit**:
 1. How can you make the orbit larger/smaller?
 2. How can you adjust the orientation of the major/minor axes in the orbit?
 3. What can you say about the location of the star as you make these changes? Use terminology about circles/ellipses.

3. What (if anything) results in an incomplete (dashed line) orbit? What happens to the planet in such an orbit?

Part 2 - Orbital Wedge Areas

Move to the **Second Law** tile.

- Check the box for **Apoapsis** and **Periapsis**
- Check the boxes for **Axes** and **Semiaxes**
- Set **Period Divisions** to **6**
- Check the boxes for **Area Values** and **Time Values**

Procedure

1. Check the box for **Always Circular** to simplify the first exploration.
 1. Compare the **area** of each wedge. Are they the same? If not, is there a pattern for where they are bigger/smaller?
 2. Compare the **period** of each wedge. Are they the same? If not, is there a pattern for where they are longer/shorter?
 3. Compare the **arc length** of each wedge. Are they the same? If not, is there a pattern for where they are longer/shorter?
 4. Change the radius: How are the areas, periods, and arc lengths affected (or not affected) by a bigger/smaller radius?
2. Uncheck the box for **Always Circular** to make the simulation more complex and more realistic. Drag the planet out (or change the velocity) to make the orbit an ellipse instead of a circle.
 1. Compare the **area** of each wedge. Are they the same? If not, is there a pattern for where they are bigger/smaller?
 2. Compare the **period** of each wedge. Are they the same? If not, is there a pattern for where they are longer/shorter?
 3. Compare the **arc length** of each wedge. Are they the same? If not, is there a pattern for where they are longer/shorter?
 4. Change the radius: How are the areas, periods, and arc lengths affected (or not affected) by a bigger/smaller radius?

Discussion Questions

The wedges are all created to show **equal periods**. Everything else is a reflection of this fact. Write CERs based on the following:

1. Make a claim about wedge area and arc length for each period portions of a circular orbit.
2. Make a claim about wedge area and arc length for each period portions of an elliptical orbit.
3. For anything that has different values, identify a trend for when/where those values are greatest/least.

Part 3 - Semi-major Axis and Period

Move to the **Third Law** tile.

Procedure

1. Adjust the orbit in and out. This should create a graph that shows how the period relates to the semi-major axis in an orbit. You can play the animation at a few points to understand what this graph represents.
2. Examine the line/curve:
 1. Is there a positive or negative correlation between semi-major axis (a) and orbital period (T)?
 2. Is the relationship linear or nonlinear?
3. If the orbit curves away from an axis, increase the **power** of that variable (eg, select a^2 if the graph curves away from a or select T^2 if the graph curves away from T). Repeat until you get a straight line. Record an equation that states your y (vertical) selection is equal to your x (horizontal) relation.

Discussion Questions

1. Use the following sentence frame to make claims about the relationship between the semi-major axis and the orbital period. Only include your selection from each option in parentheses for the first and include your equation for the straight line graph in the second.
 1. *There is a **(positive/negative)** **(linear/nonlinear)** relationship between the semimajor axis and the orbital period.*
 2. *In an orbit, the orbital period and semi-major axis are related by the equation ...*

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6: Kepler Models

Lab Overview

Lab Goals

The goal of this lab is to develop the scientific practices of taking measurements, identifying patterns and relationships between variables, and making scientific claims based on evidence with clear reasoning. You will develop these lab skills while reinforcing/furthering your understanding of Kepler's Laws for gravitational orbits. As a result of this lab, you should be able to:

- Explain your methodology for performing measurements with explanations for the choice of precision in measurement and analysis of how finer/coarser measurements might affect results.
- Make scientific claims about orbital characteristics/values that are based on evidence with clear reasoning/analysis of that evidence to support those claims.

Equipment and Setup

This lab requires the following equipment on each table.

- [Orbit Templates \(3\)](#)
- 3-5 different types (sizes) of beans/legumes
- Centimeter rulers
- Graph paper
- Calculator

Submission Instructions

Submit a brief lab report that includes the following sections:

Methodology

Write a **Methodology** section that details the steps you took to create your Kepler Orbital Model. This section should include your responses to the **Methodology Reflection Questions** as well as a narrative of how you used the beans to create the model. Your audience is someone who knows a little about Kepler's laws but was not present in the lab and does not have this lab activity handout.

Results

Organize your data tables, orbital models, and any other measurements or calculations. Include a brief introduction/explanation before the tables/models/measurements. Include captions that have a number and description. Consider any annotations or color coding that will be helpful to reference in the discussion.

Discussion

Write/type your answers to the **Discussion Questions** using the **Claim-Evidence-Reasoning** format with a separate (3-5 sentence) paragraph for each question.

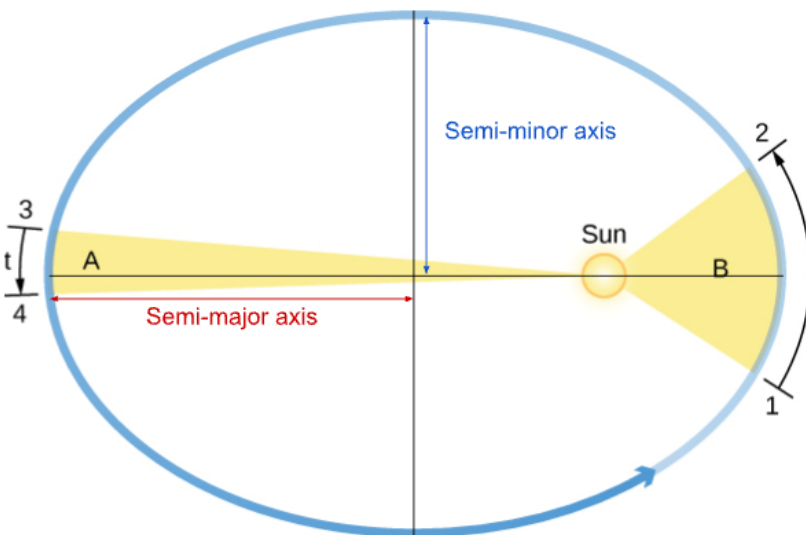
Kepler Orbits

Background Information

Gravitational orbits of objects, such as a planet around a star, follow **Kepler's Three Laws of Planetary Motion**:

1. Each planet moves around the Sun in an orbit that is an ellipse, with the Sun at one focus of the ellipse.
2. The straight line joining a planet and the Sun sweeps out equal areas in space in equal intervals of time.
3. The square of a planet's orbital period is directly proportional to the cube of the semimajor axis of its orbit.

In this lab we will explore those elliptical orbits by primarily exploring the second law, which relates to area and time. We will create a diagram similar to the one on the right but with more detailed measurements.



Lab Instructions

Measuring the area of the wedges (A or B) on an ellipse can be challenging. In this lab, we will use beans as a way to approximate areas and build the wedges from these beans. Beans should be in a **single layer**.

Measurement Calibration

1. Identify the area of a 4x4 grid and 16x16 grid: 4x4 grid: ____ in² 16x16 grid: ____in²
2. Identify the number of beans that fit in a 2x2 grid and a 10x10 grid for each bean type.
3. Record those values below, then identify the average area of a bean is in in² for each bean type. Area of 1 bean is Area of Grid divided by # of Beans.

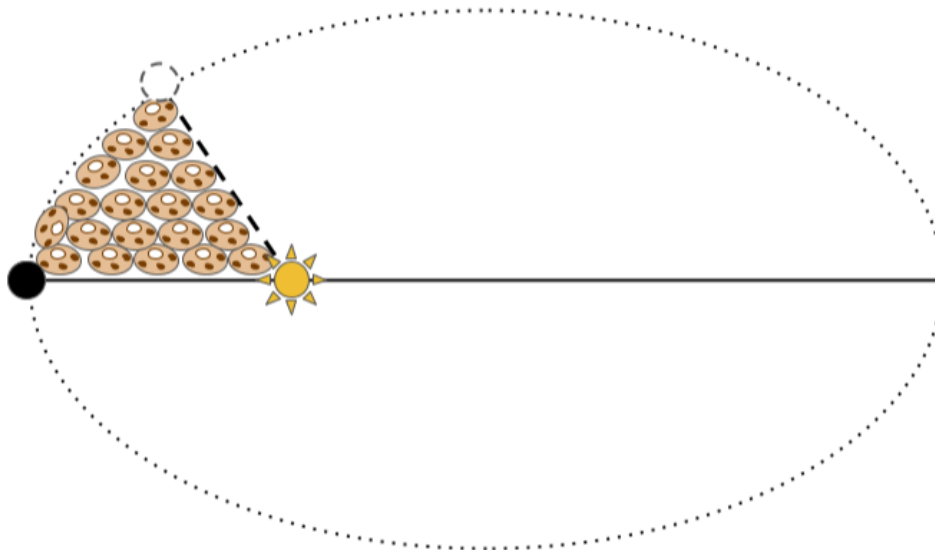
Bean Type	# Beans in 4x4	Area of 1 Bean	# Beans in 16x16	Area of 1 Bean

4. Are your results different for the 4x4 grid and the 16x16 grid? If so, decide as a group which you think is more accurate and circle those measurements on the table. Briefly explain your reasoning below.

Make an Kepler's 2nd Law Orbital Model

Goal: Use beans to identify **equal area** wedges along the orbit to show the position of the orbiting planet at equal time-intervals. For an accurate model, you should have enough beans to make a clear wedge throughout the orbit.

1. Decide as a group **which type** of bean to use and **how many** beans you will use (it doesn't need to be the whole bag). Consider the following to make the **best selection** for this lab:
 1. You want to use enough beans that they form a wedge even at the largest distances between the planet and star
 2. Using fewer beans will give you more positions of the planet (ie, more data) and more data makes patterns easier to find and minimizes error.
 3. Use an amount of beans that is less than $\frac{1}{4}$ of the overall area to create more than 4 total wedges
2. Align the beans along the line between the planet and the star so that they form a wedge. Try to make both sides of the wedge as straight of a line as possible.
3. Draw a line along the edge of the beans. Use a ruler and try to be as exact as possible. Put a big dot at the edge of the line where it hits the elliptical orbit.



4. Shift the beans to the other side of the line you drew, then continue to repeat steps 2-3 until you have gone around the entire orbit. **Make sure to always use the same beans for each wedge.**

Methodology Reflection Questions

As a team, discuss and record notes for the following questions:

1. How did the different bean types compare in area? What bean type did you use and what were the benefits/drawbacks of that selection?
2. How many beans did you use for each area wedge? Why did you choose that number? What were the benefits/drawbacks of that choice?
3. What might be the benefits/drawbacks of using a **much larger** object (like an orange) instead of a bean?
4. What might be the benefits/drawbacks of using a **much smaller object** (like sand) instead of a bean?
5. What actions did your group take to make measurements as accurate as possible?
6. Were there any challenges to taking accurate measurements? If so, what could you do (possibly with different materials) to be more accurate?

Apply Kepler's 3rd Law to a Larger/Smaller Orbit

Kepler's 3rd law relates the period of orbit to the distance of the semi-major axis:

$$P^2 \propto a^3$$

And for our solar system using years and AU as units:

$$P^2 = a^3$$

Using this relationship, we can identify that for the same amount of time, the area swept out (ie, number of beans) for planets is proportional to the square root of the semimajor axis:

$$\text{Area} \propto \sqrt{a}$$

We can then identify the number of beans to use in the larger/smaller orbit to make a Kepler's Second Law Orbital Model that is consistent with the first. For this process, **Orbit 1** is the orbit you previously modeled. Use the table below to make this conversion:

1. Measure the semimajor axis of each orbit
2. Divide the result for Orbit 2 by Orbit 1
3. Take the square root of that number
4. Fill in the number of beans used in Orbit 1, then multiply that number by the previous column ($\sqrt{a_2 / a_1}$). Round to the nearest whole bean and put that result in the last column.
5. Repeat the process you used in part 1 of the lab to create a Kepler Orbital Model for this second planet.

Semimajor Axis (a)		Ratios		Number of Beans	
Orbit 1	Orbit 2	a_2 / a_1	$\sqrt{a_2 / a_1}$	Orbit 1	Orbit 2

Semimajor Axis (a)		Ratios		Number of Beans	
Orbit 1	Orbit 3	a_3 / a_1	$\sqrt{a_3 / a_1}$	Orbit 1	Orbit 23

Lab Extension Options

- Repeat the experiment with a different number of beans (same bean type) and compare the differences as part of your methodology section.
- Repeat the experiment with a different bean (or other object) choice and compare the two bean choices as part of your methodology section.
- Something else! Make a proposal and check in with your instructor. Be sure to identify if the extension will relate to your methodology section, discussion section, or both!

Lab Analysis

Use your orbits to answer the discussion questions below as a group. Write your responses as a separate paragraph for each question. Each paragraph should include:

- **Claim:** A succinct one-sentence answer to the question.
- **Evidence:** A sentence or two that selects and summarizes measurements, descriptions, or patterns from your lab. Be as clear as possible. You might want to add labels or color-coding to your models to make it easy to refer to specific parts or components.

- **Reasoning:** Explain how the specific evidence you selected supports/justifies your claim. Imagine you are explaining it to someone who is not in this lab so they do not have the background information that you have.

Discussion Questions

1. Is the speed of the planet always the same? If not, make a claim about any patterns related to the speed of the planet at different parts of the orbit.
2. Is the period (how much time it takes for one complete orbit) of two planets orbiting the same star the same or different? If not, make a claim about any patterns related to the period of planets with different orbits
3. Does the size of an orbit seem to affect the speed of a planet? If so, make a claim about any patterns related to the speeds of planets with different orbits.

7: Optics and Telescopes

Lab Overview

Lab Goals

As a result of this lab, you should be able to:

- Describe how concave and convex lenses and mirrors affect light rays
- Identify a mathematical pattern related object distance, image distance, and focal length for a double-convex lens (thin lens/mirror equation)
- Use scale-model diagrams to explain how a simple refracting telescope uses two lenses to form an image that the eye can see.

Equipment and Setup

This lab requires the following equipment on each table.

- Pasco Optics System (or similar)
- Pasco Optics Track (or similar)
- Graph Paper

Submission Instructions

Submit a brief lab report that includes the following sections:

Results

Include all data tables and calculations. Make sure everything is properly labeled with clear and accurate units.

Discussion

Your discussion should summarize your responses to the questions throughout the lab manual. You might choose to group some questions together in this response. Each paragraph should be organized in a **Claim-Evidence-Reasoning** format:

- **Claim:** A succinct one-sentence answer to the question.
- **Evidence:** A sentence or two that selects and summarizes measurements, descriptions, or patterns from your lab. Be as clear as possible. You might want to add labels or color-coding to your models to make it easy to refer to specific parts or components.
- **Reasoning:** Explain how the specific evidence you selected supports/justifies your claim. Imagine you are explaining it to someone who is not in this lab so they do not have the background information that you have.

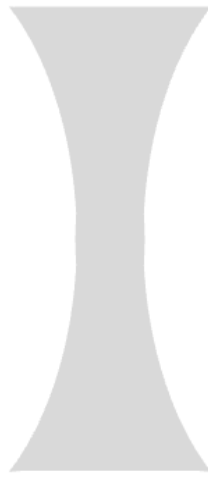
Part 1: Single Optic Systems

Background Information

Lens and mirror surfaces can be flat or curved with two different types of curvatures: **Concave** and **Convex**.



Convex



Concave

The material a lens is made from and the way a lens/mirror is curved will influence the way that optical component bends light. This bending of light is what allows a telescope to **brighten** and **enlarge** our view of an object.

Concave and Convex Lenses and Mirrors

Lenses

Explore how lenses affect incoming, parallel light rays and determine which type of lens **converges** light.

1. Set up the optical track with the **parallel laser emitter** pointing towards higher numbers on the track.
2. Position one of the free lenses (not one in a black holder) so that it is flat on the track with a curved edge facing the lasers. Draw a picture of the setup, including the beams before and after they go through the lens. Repeat for the other lenses.

Discussion Questions:

1. How do the different shapes of the lenses affect the way they bend light?
2. Which lens **converges** light to a point?

Mirrors

Explore how mirrors affect incoming, parallel light rays and determine which type of mirror **converges** light.

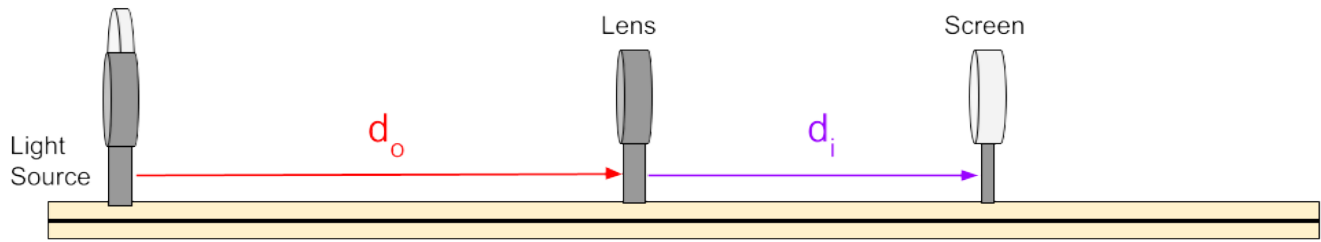
1. Set up the optical track with the **parallel laser emitter** pointing towards higher numbers on the track.
2. Position one of the free mirrors (not one in a black holder) so that it is flat on the track with a curved edge facing the lasers. Draw a picture of the setup, including the beams before and after they go through the lens. Repeat for the other mirrors.

Discussion Questions:

1. How do the different shapes of the mirrors affect the way they bend light?
2. Which mirror **converges** light to a point?

Focal Length and Image Creation

Now we will explore how lenses affect all of the light from an object by constructing the setup shown below:



1. Remove the **parallel laser emitter** and replace it with the light source.
2. Return the free lenses and take out the lenses that are in black holders. These holders allow the lenses to snap into the optical track and slide to different positions.
3. Add a screen near the end of the track. You will slide this around later.
4. Choose one lens **that is the type that converges light** and put it between the light source and the screen at a position of 30cm in front of the light source. This is called the **object distance** (d_o).
5. Move the screen back and forth until you get a clear image on the screen. Record the distance between the lens and the screen as the **image distance** (d_i)
6. Add the two distances together ($d_o + d_i$) to calculate the total distance from the object to the image.
7. Repeat the above steps for 4 different object distances.

d_o	d_i	$d_o + d_i$
30 cm		

Discussion Questions:

1. Describe any patterns you notice in your data
2. When the **object distance** increases, does the **image distance** increase or decrease?
3. Were there any object distances that **did not** form a clear image? Were they large or small distances?

Some quantities have reciprocal relationships. Calculate the reciprocals of your data and fill in the table below. Round to two decimal points.

$1/d_o$	$1/d_i$	$1/d_o + 1/d_i$
30 cm		

Discussion Questions:

1. Describe any patterns you notice in your data
2. Try to construct an equation relating the object distance and image distance

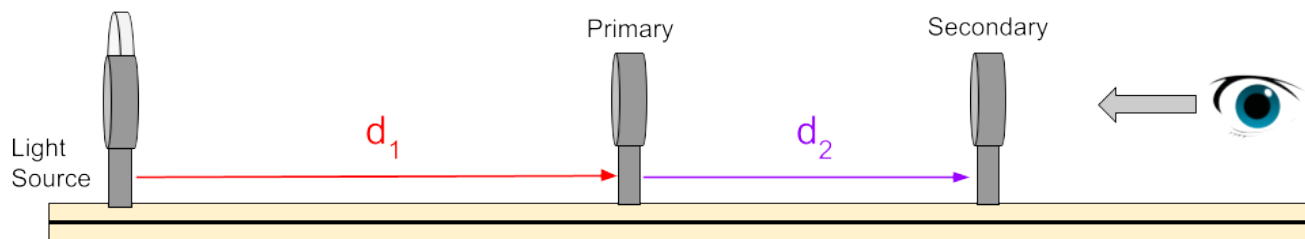
Thin Lens/Mirror Equation

The relationship between the location of an object, a lens/mirror, and the image that is formed by that object/mirror is given by the **thin lens/mirror equations**:

Part 2: Primary and Secondary Optics

Background Information

Two different optical components (lenses/mirrors) can be used in combination with one another. The first component that the light interacts with is called the **primary** and the next is called the **secondary**. On the lab bench, count starting with the component that is closest to the light source (object).



Lab Instructions

Shorter Focal Length Primary and Larger Focal Length Secondary

Use the shorter focal length double convex lens as your primary lens and the larger double convex lens as your secondary lens. Start with the Primary lens 50cm from the light source ($d_1 = 50\text{cm}$).

1. Place the secondary at the end of the track and look through the secondary to see the light source on the other side of the primary lens. Make sure everything is lined up (the light source might be blurry).
2. Adjust the secondary lens until the image first becomes clear. Record the distance between the primary and secondary lenses (d_2).
3. Move the primary to 2-3 other positions (ie, change d_1) and then move the secondary to create a focused image. Record all positions.
4. Use your data to create a **scale model** of the optical system for each position of the primary lense:
 1. Draw a line at the positions of the **object**, the **Primary Lens** and the **Secondary Lens**. Label them.
 2. Use the **thin lens** equation to identify the position of the image that is created from the primary lens (d_i).
 3. The **image** from the primary becomes the **object** for the secondary. Identify the distance between this image/object and the secondary lens (d_o).
 4. Use the **thin lens** equation to (try to) identify the position of the second image that is created from the secondary lens.

d_1	d_2	d_i	d_o
50 cm			

Larger Focal Length Primary and Shorter Focal Length Secondary

Now switch to use the larger focal length double convex lens as your primary lens and the shorter double convex lens as your secondary lens. Start with the Primary lens 50cm from the light source ($d_1 = 50\text{cm}$).

1. Place the secondary at the end of the track and look through the secondary to see the light source on the other side of the primary lens. Make sure everything is lined up (the light source might be blurry).
2. Repeat the process as before to collect data on the locations of clear images in this new configuration

d_1	d_2	d_i	d_o
50 cm			

Discussion Questions

1. What patterns do you notice in your tables for the two telescopes that you made?
2. Where does the image formed by the primary need to be in relation to the primary/secondary lens?
3. Where is the secondary image? Why is this a good location?
4. If you want to make a **larger** image of the object compared to what you would see without a telescope, which should be bigger, the primary or the secondary?
5. Summarize how a **Simple Refracting Telescope** works. Draw an example diagram to go along with your description that includes the **primary lens**, **primary image**, and **secondary lens**.

8: Spectroscopy

Lab Overview

Lab Goals

As a result of this lab, you should be able to:

- Record spectral lines from known sources
- Use spectral patterns to identify mystery gases
- Explain the cause of spectral lines by referencing atomic energy levels

Equipment and Setup

This lab requires the following equipment on each table.

- Spectrum Tube Power Supply
- Spectrum Analyzers
- Spectrum Keys
- Spectrum Tubes containing:
 - Hydrogen
 - Helium
 - 3-4 other gases

Submission Instructions

Submit a brief lab report that includes the following sections:

Methods

Describe the lab setup and the process that you used throughout the different parts of the lab. Include both written explanations and visuals/diagrams. Add a short description of your diagrams after each figure caption.

Results

Include measured spectra, spectrum keys (when relevant) and predicted spectra.

Discussion

Write clear paragraphs that answer the discussion questions throughout the lab. When relevant, be sure to cite evidence from the results section and explain how that evidence supports your claims.

Part 1: Observing Gas Spectra from Known Sources

Background Information

When energized, gases emit light at specific, discrete wavelengths. These result in **emission spectrum lines** that are unique to each gas, based on the energy levels present in the electron orbital structure of the element/molecule. Molecules are more complex because they also have energy levels based on vibrational modes.

Hydrogen and Helium

1. Start with a **Hydrogen Spectrum Tube** set in the power supply, turn the power supply on:
 1. Observe the spectrum tube using the Spectrum Analyzer.
 2. Draw a line at the measured location for each line you see through the spectrum analyzer
 3. Color your lines to match (approximate) the color of the spectral line.
 4. Color the tube graphic to match the (approximate) color of the spectrum tube when observed with the naked eye.
2. Turn off the power supply and ask your instructor to remove the spectrum tube (they get very hot!). It should be replaced with a **Helium Spectrum Tube**. Then, repeat steps a-d above.

Discussion Questions:

1. Do different gases have the same or different spectral lines?

Part 2: Applying Known Spectra to Unknown Sources

Simplified Solar Spectrum

Lines are drawn for a simplified solar spectrum. Using your key for Hydrogen and Helium, complete the following:

1. Identify any lines on the solar spectrum that match the lines on the hydrogen or helium spectrum.
2. Label lines that match as either **Hydrogen** or **Helium**. It is possible some lines will not match either
3. Color the hydrogen/helium lines to match the color of those spectra
4. Write a few sentences stating the lines that matched and the unmatched lines

Discussion Questions:

1. Is the sun made out of hydrogen? Helium? Both? Neither? Make a claim and support it with evidence.

Predicted Complete Solar Spectrum

If an element is present in the atmosphere of the sun, **all of that element's lines** are likely present. Identify any lines on the solar spectrum that match the lines on the hydrogen or helium spectrum.

1. Based on the simplified solar spectrum, draw in all of the spectral lines you predict should be present on the sun.
2. Label lines that match as either **Hydrogen** or **Helium**.
3. Color the hydrogen/helium lines to match the color of those spectra

Explanation

Explain your reasoning for the prediction you made about the solar spectrum.

Identifying Mystery Gases

Scientists have followed a similar process to what you did for Hydrogen and Helium to record spectra of different elements. A key for several gases is provided to each table. Additionally, each there are cutouts of each individual gas spectra for use in this lab.

1. Obtain a mystery spectrum tube and record the spectrum number on your writeup.
2. Observe the mystery gas through the analyzer and record its spectrum on your paper. Include color.
3. Use the keys to identify the mystery gas. Tape/glue the key below your recorded spectrum to show the match
4. Repeat for additional mystery gases.

Discussion Questions

1. Explain the process for which scientists can identify what a gas is made of using spectrum analyzers.

Part 3: Causes of Spectra

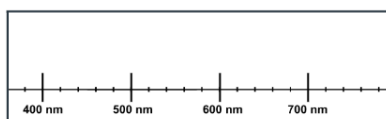
1. Open the Hydrogen Spectrum simulation from PHET and click on the Energy Levels Tile: https://phet.colorado.edu/sims/html/models-of-the-hydrogen-atom/latest/models-of-the-hydrogen-atom_all.html
2. Show the **Spectrometer** and select **De Broglie Model**
3. Press the **red button** on the laser to shine light on the hydrogen atom and start collecting data
4. Watch the energy level diagram and identify transitions that are **colors of light** (visible). You do not need to identify other transitions.
5. After some time has passed, record the spectrometer data

Discussion Question

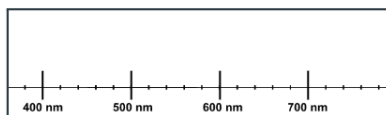
1. Explain the causes of spectroscopy and/or any patterns you noticed about spectral lines, energy levels, and atomic orbitals.

Templates

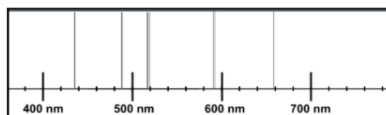
Hydrogen



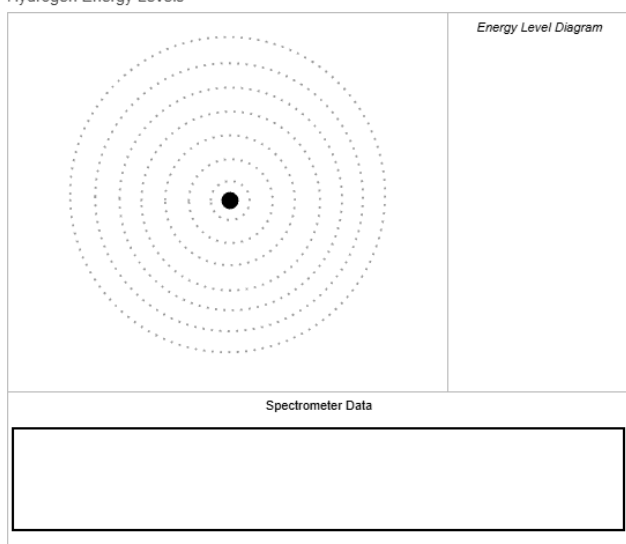
Helium



Simplified Solar Spectrum



Hydrogen Energy Levels



9: Exoplanet Detection - Doppler Method

Lab Overview

Lab Goals

The goal of this lab is to develop the scientific practices of collecting and interpreting data:

- Make connections between measured data and planetary orbit positions/velocities
- Identify patterns relating mass (planet and star), orbital distance, orbital speed, and measured light properties for doppler measurements

Equipment and Setup

This lab requires the following equipment on each table.

- Computers with internet for simulator

Submission Instructions

Submit a brief lab report that includes the following sections:

Results

- Doppler Graphs

Discussion

Write your answers to the **Discussion Questions** using the **Claim-Evidence-Reasoning** format.

Background Information

Gravity and Orbits

The orbital speed of an object depends on the mass of the star and the distance between the planet and the star. For elliptical orbits, planets move faster when they are closer to the star in such a way that results in the planet moving through equal area wedges in equal amounts of time (Kepler's 2nd Law).

Doppler Shift

When the source of waves moves toward you, the wavelength decreases a bit. If the waves involved are visible light, then the colors of the light change slightly. As wavelength decreases, they shift toward the blue end of the spectrum: astronomers call this a blueshift (since the end of the spectrum is really violet, the term should probably be violetshift, but blue is a more common color). When the source moves away from you and the wavelength gets longer, we call the change in colors a redshift. The greater the motion toward or away from us, the greater the Doppler shift. If the relative motion is entirely along the line of sight, the formula for the Doppler shift of light is

$$v = (\Delta\lambda/\lambda) c$$

where λ is the wavelength emitted by the source, $\Delta\lambda$ is the difference between λ and the wavelength measured by the observer,

c is the speed of light, and v is the relative speed of the observer and the source in the line of sight. The variable v is counted as positive if the velocity is away from the observer, and negative if it is towards the observer.

Lab Instructions

Simulation Setup

Open the Radial Velocity simulation from the *University of Nebraska* Astronomy Education website:

- <https://astro.unl.edu/naap/esp/animations/radialVelocitySimulator.html>

Part 1 - Doppler Measurements

Setup - Theoretical

- Set **eccentricity** to zero
- Start the animation
- Adjust the **animation speed** as needed
- Adjust the video of the orbit as needed

Discussion Questions

1. What is happening in the orbit at the following velocities:
 1. Max (most positive)
 2. Min (most negative)
 3. Zeros (if any)
2. How do the maximum and minimum velocities compare?

Part 2 - Planet and Star Parameters

Setup

- Set **eccentricity** to zero
- Start the animation
- Adjust the **animation speed** as needed
- Adjust the video of the orbit as needed

Procedure

1. Play around with the slider to increase and decrease the **planet mass**. Identify changes (if any) to the following:
 1. Orbital Period
 2. Max/min velocities
 3. Closeness of data points to theoretical curve
2. Play around with the slider to increase and decrease the **star mass**. Identify changes (if any) to the following:
 1. Orbital Period
 2. Max/min velocities
 3. Closeness of data points to theoretical curve
3. Play around with the slider to increase and decrease the **semimajor axis**. Identify changes (if any) to the following:
 1. Orbital Period
 2. Max/min velocities
 3. Closeness of data points to theoretical curve

Discussion Questions

1. Make a claim about how orbital period and max/min velocities relate to:
 1. Planet Mass
 2. Star Mass
 3. Semimajor Axis
2. Propose a proportional relation for max/min velocity by putting variables in the numerator or denominator:

Part 3 - Eccentricity

Setup

- Set **eccentricity** to zero
- Start the animation
- Adjust the **animation speed** as needed
- Adjust the video of the orbit as needed

Procedure

1. Change the eccentricity to values between **0** and **0.8**. Identify the following at different eccentricities:
 1. How does the shape of the doppler plot change?
 2. Does the planet spend more/less time at fast/slow speeds?
2. Set the **eccentricity** to some value **above 0.5** and change the **longitude** in the system orientation box.
 1. How does your view of the system affect the measured doppler plot?

Discussion Questions

1. Identify a pattern relating eccentricity to the shape of the doppler plot. Explain the cause of this change.
2. Explain how your view point (longitude) of an orbit with high eccentricity affects the doppler plot

Part 4 - Data Quality

Setup - Actual

- Check the **show simulated measurements** box
- Adjust different amounts of **data** and different amounts of **noise**. As you explore, trying turning on/off the **show theoretical curve** box. Consider the following as a starting point:
 - High Noise, Low Data
 - High Noise, High Data
 - Low Noise, Low Data
 - High Data, Low Noise
 - Medium Data with High and Low Noise
 - Medium Noise with High and Low Data
- After exploring those options, continue exploring the relations between these two measurement parameters.
- Draw four Doppler Plots (with the dots for data) that show differences between them and identify the effects of low, medium, high noise and data.

Discussion Questions

Overall Question: How does the amount of data and the noise in data affect the ability to “see” the doppler curve and determine planetary properties?

Subquestions that might help:

1. Does it seem better to have more or less data? More or less noise?
2. How does the amount of data affect the clarity of the pattern?
 1. Is there a minimum number where the data do not clearly represent the theoretical curve?
 2. Does the amount of noise affect this minimum?
3. How does the level of noise affect the clarity of the pattern?
 1. Is there a maximum amount of noise that loses the pattern?
 2. Does the amount of data affect this maximum?

10: Exoplanet Detection - Transit Method

Lab Overview

Lab Goals

The goal of this lab is to develop the scientific practices of collecting and interpreting data:

- Make connections between measured data and planetary orbit positions/velocities
- Identify patterns relating mass (planet and star), orbital distance, orbital speed, and measured light properties for transit measurements

Equipment and Setup

This lab requires the following equipment on each table.

- Computers with internet for simulation

Submission Instructions

Submit a brief lab report that includes the following sections:

Results

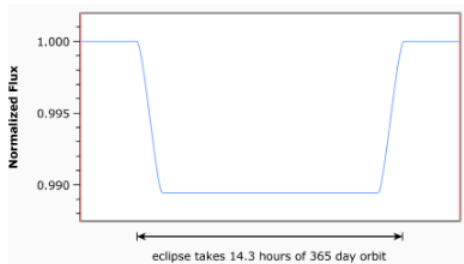
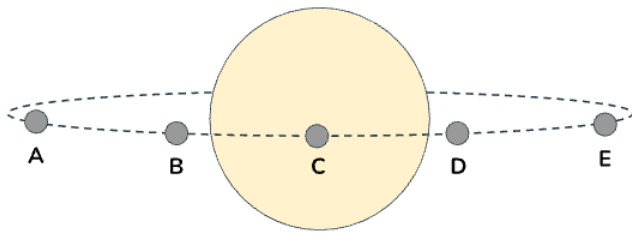
- Light Curve Drawings
- Data

Discussion

Write your answers to the **Discussion Questions** using the **Claim-Evidence-Reasoning** format.

Background Information

Light Intensity



We can see and measure the light from other stars in our galaxy. Planets are smaller and darker, so we cannot see them directly. However, we can detect them when they pass in front of a star and cast a small shadow that reduces the total amount of light our telescopes receive. The transit method detects planets and uses the characteristics of the light curve to infer properties about the planet and its orbit. A Normalized Flux of 1.000 is the full star light. The other values on the graph can identify the percent of starlight that reaches us ($0.990 = 99\%$ of the light or 1% of light is blocked).

Lab Instructions

Simulation Setup

Open the Transit simulation from the *University of Nebraska Astronomy Education* website:

- <https://astro.unl.edu/naap/esp/animations/transitSimulator.html>

Part 1 - Transit Measurements

Procedure

1. Animate the orbit by moving the **phase** slider from one end to the other.

Make sense of the model

1. Where is the planet when the normalized flux is 1.000?
2. Where is the planet when the normalized flux is below 1.000 and a flat line?
3. Where is the planet when the graph slants down or up?

Part 2 - Planet Properties

Procedure

1. Set **inclination** to 90o
2. Choose one slider in the **Planet Properties** controls at a time and make changes. Examine effects on the orbit, the light curve, and the period of the eclipse
3. Repeat for the other slides

Discussion Questions

1. Make a claim about the effect of each planet property on each of the following:
 1. Light Curve depth
 2. Light Curve eclipse time
 3. Total Orbital Period

Part 3 - Star Properties

Procedure

1. There is only one star property (mass). Change it without changing anything else and examine effects on the orbit, the light curve, and the period of the eclipse

Discussion Questions

2. Make a claim about how the mass of the star does/does not affect:
 1. Light Curve depth
 2. Light Curve eclipse time
 3. Total Orbital Period

11: HR Diagram and Stellar Evolution

Lab Overview

Lab Goals

As a result of this lab, you should be able to:

- Describe and compare the phases of stellar evolution for low, medium, and high mass stars
- Identify trends on an HR diagram relating to luminosity, temperature/color, and stellar radius
- Identify a directional relationship between stellar mass and main-sequence life-time.

Equipment and Setup

This lab requires the following equipment on each table.

- Computers with internet for simulation

Submission Instructions

Submit a brief lab report that includes the following sections:

Results

HR Diagram sketches with annotations and values plotted

Discussion

Write clear paragraphs that answer the discussion questions throughout the lab. When relevant, be sure to cite evidence from the results section and explain how that evidence supports your claims.

Part 1: HR Diagram and Stella Origin Point

Simulation Setup

- Open the simulation at <https://astro.unl.edu/naap/hr/animations/hrExplorer.html>
- The red line represents the **Main Sequence** and can be thought of as the starting point of a star's life

Collecting Data

1. Click on different parts of the red line to see a visual of the different stars
2. Draw circles on your results HR Diagram that show:
 1. Size
 2. Color
3. Click around near where you drew your circles and write the value for **Radius** next to them. A radius of 1 means the radius of our sun.
4. **Nearest Stars**
 1. Select **Nearest Stars** and put dots on your diagram to show the general star locations plotted (you do not need to copy every dot exactly)
 2. Click around on some of them to look for common trends about color and size. Add labels to your diagram based on the

trends

5. **Brightest Stars**

1. **Select Brightest Stars and put dots on your diagram to show the general star locations plotted (you do not need to copy every dot exactly)**
2. **Click around on some of them to look for common trends about color and size. Add labels to your diagram based on the trends**
3. **Add radius values next to some of the points to help show trends.**

6. **Isoradius Lines**

1. **Make sure the show isoradius lines box is checked**
2. **Sketch these lines with their radius values on your diagram**
3. **Draw arrows between lines in the direction that radius increases.**

Discussion Questions:

1. Where on an HR Diagram are the hottest (most blue) and coldest (most red) stars?
2. How does the size of a star change based on location on an HR diagram?

Part 2: One Stellar-mass Star

Simulation Setup

- Open the simulation at <https://www.starinabox.net/> and select **Advanced**
- Set the **Mass** to **1** (should be the default)
- Play the simulation (you can adjust speed if you want)
- Replay the simulation as needed at different speeds. You can also click on the diagram to show that point in time (best when simulation is paused)

Collecting Data

1. Sketch the “path” of the star on from the simulation
2. Highlight parts of the path different colors to match the color of the star
3. Add labels on the path to identify if **radius** is **increasing** or **decreasing**
4. Add the **stage** labels on the different parts of the stellar evolution path
5. Place dots at transitions from one stage to the next and put the **age** of the star next to those dots.

Identify Trends

Try to **identify trends on the diagram** (locations or directions) for the following:

1. Star Color
2. Star Size
3. Where the most time is spent (you need to use the years because the animation speed is not constant).

You can add information about these trends on the diagram or on the lines below the diagram

Discussion Questions:

3. What stage is a star in for most of its lifetime? How does the mass of the star affect the time spent in this stage?
4. When a star gets **bigger** does it get **more red** or **more blue**? Identify patterns in changing size to color and temperature.

Part 3: Lower and Higher Mass Stars

Simulation Setup

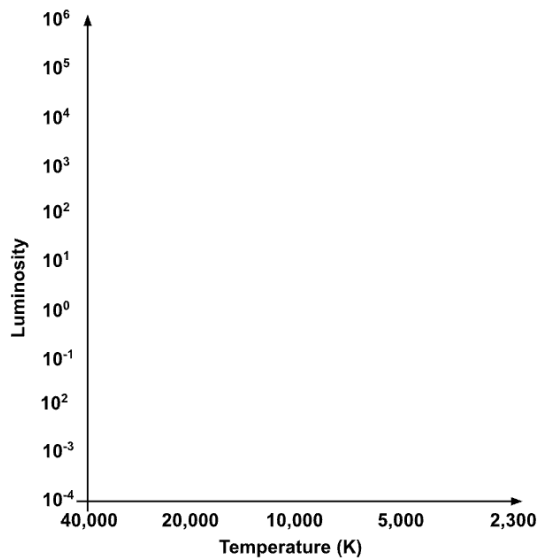
- Set the **Mass** to each of the following values: 0.5, 8, 30
- Follow the same set of instructions as for the one solar-mass star.
- You can explore other mass stars if you finish early

Discussion Questions:

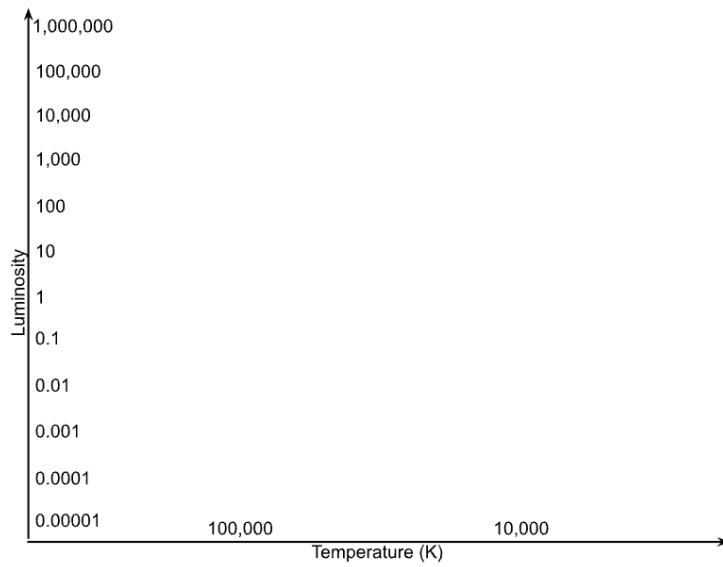
5. What are the different possible **end states** of stars? What determines which end state a star will reach?

Templates

HR Diagram



Stellar Evolution



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12: Planetary Evolution

Lab Overview

Lab Goals

As a result of this lab, you should be able to:

- Predict the composition and relative mass of different planets in a solar system based on the location of their formation and data on temperature in the protoplanetary disk.
- Construct explanations for why different planets have such different masses and compositions using Condensation Theory
- Explain general trends for planetary characteristics based on condensation theory.

Equipment and Setup

This lab requires the following equipment on each table.

- Colorful Dot Stickers
- [Group Graph Templates and Planetary System Data Handouts](#)

Submission Instructions

Submit a brief lab report that includes the following sections:

Introduction

Describe the process of planetary formation. In particular, discuss what determines which materials are or are not a part of the early planetesimal formation and why planets in different regions are made of different materials.

Results

Sketches of your dot-graphs that show the relative amount of each type of material for each planet in the sample system.

Discussion

Write clear paragraphs that answer the discussion questions throughout the lab. When relevant, be sure to cite evidence from the results section and explain how that evidence supports your claims.

Conclusion

Summarize your results to explain the trends we expect to see in most planetary systems if we assume similar characteristics of the original dust cloud (eg, total abundance, relative abundance, temperature profile).

Part 1: Planetary Formation in the Planetarium

Planetary Formation

Observe the video with a focus on the following questions:

1. What material do early planetesimals form from? What do they not form from?
2. Where are the planetesimals bigger/smaller?
3. When does hydrogen gas start to play a role?

Part 2: Estimating the Composition and Mass of a Planetary System

Temperature and Types of Materials

In your group handouts are some data on the temperature at the time of formation at the location of several planets.

1. This planetary system has 8 planets (Planets A-G). Based on the temperature of each planet, decide as a group which substance(s) that planet it made up of.
2. Identify a color (from the dot stickers) for each substance. Make a key.
3. For each planet, place a dot of that color and arrange them vertically to make a bar chart on the group template. This represents the amount of mass and which type of material(s) that the planet is made of.
4. Underneath each group, write a **descriptive statement** about your data. Imagine you want to communicate the content to someone who cannot see the graph.

Discussion Questions:

1. Identify patterns between planetary formation location (ie, proximity to the star) and diversity of planet material.
2. According to these data, which planet(s) should be the largest (most mass) and which should be the smallest (least mass)? Why?

Types of Materials + Relative Abundance

In your group handouts are some data on the temperature at the time of formation at the location of several planets.

1. The **Relative Abundance** chart tells you how the amount of metal, rock, water, and methane/ammonia compare in the protoplanetary disk. For each type of material that each planet is made up, place dots to make a new set of vertical columns. This time, place the number of dots that matches the relative abundance (eg, if the planet is formed from water, place 5 water dots). Start with metal on the bottom and work up to lower condensation temperature substances.
2. Underneath each group, write a **descriptive statement** about your data. Imagine you want to communicate the content to someone who cannot see the graph.

Discussion Questions:

1. According to these data, which planet(s) should be the largest (most mass) and which should be the smallest (least mass)? Why?
2. Generalize a pattern: Where in this solar system do the largest (most mass) and smallest (least mass) planets form? Why does this happen?
3. What separates big planets from small planets? Where in space would this line separating the two groups of planets be?

Types of Materials + Total Abundance

In your group handouts are some data on the temperature at the time of formation at the location of several planets.

1. The **Total Abundance** chart tells you how the amount of metal, rock, water, and methane/ammonia compare in the protoplanetary disk **at different distances in that disk**. Take the amount of dots you used previously and **multiply by the total abundance value** at the location of each planet. Round answers to the nearest integer.
2. Underneath each group, write a **descriptive statement** about your data. Imagine you want to communicate the content to someone who cannot see the graph.

Discussion Questions:

1. According to these data, which planet(s) should be the largest (most mass) and which should be the smallest (least mass)?

Why?

2. Generalize a pattern: Where in this solar system do small, medium, and large planets form? Why does this happen?

Part 3: Conclusions about Planetary Systems

Conclusion sections differ from discussion sections. A discussion is an interpretation of your specific results. Conclusions generalize to describe more than just the findings of this investigation. You started this in the second discussion question for each section, but you focused on generalizing based on the single graph. In your conclusion section, use all of your discussion claims to make a general claim about planetary systems across the universe.

Generalize a pattern: Where in **any solar system** should the largest (eg, most mass) planets form? Why does this happen and why do we expect this to be similar across all (or most) systems?

INDEX

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GLOSSARY

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