Lab VII: Introduction to Sky Gazing
Objective:
To build an astrolabe and compass rose
To measure altitude and azimuth
To use angles to calculate distance
To appreciate the challenge of measuring astronomic distances

Introduction:
When viewing the sky, it appears as a dome to an observer on Earth. In addition, celestial objects such as the sun, moon and stars, appear to move. Historically, astronomy has made use of different **coordinate systems** to map the night sky, but the arc of the night sky, without knowing distances to various stars, made it impractical to use Cartesian (x-y-z) coordinates. Therefore, various tools such as the astrolabe, compass rose, and backstaff were developed to help philosophers, mariners, and mapmakers to mark the seasons and geographic locations. These tools use trigonometry (mathematics of triangles and lengths) to measure the **altitude** and **azimuth** of celestial objects.

Imagine a half-sphere around and above you as you stand under the night sky with a friend. You see the red planet Mars in the West and you point at it with your finger. Your arm is pointing a certain angle upward (the altitude) and in a direction (the azimuth). The **azimuth** is the **angular distance** of an object from due north measured eastward; the **altitude** is the angular distance of an object above the horizon. The altitude and azimuth of an object in the sky are **local coordinates**, i.e. the coordinates depend on the time and the location of the observer. **Global coordinates** of a star, for example, do not change with time and are not dependent on the location of the observer. Global coordinates may be calculated from altitude and azimuth using advanced mathematics, which will not be discussed here.

In this lab, students will build a simple astrolabe and compass rose. An astrolabe can measure altitudes above the horizon as an angle in degrees. All students have likely seen a compass rose showing the cardinal directions on a map or a compass, but few have likely used a compass rose to measure the azimuth of objects in the sky. However, students should appreciate that early mariners and philosophers, to perform advanced calculations, use complex astrolabes and compass roses.

Terms:
Astrolabe, Compass Rose, Altitude, Azimuth, Angular Distance, Coordinate Systems, Latitude, Longitude, North Star, Zenith, Perpendicular, Parallel,

Supplies:
6 inch Protractors with small hole at center (one per student)
Straws
Tape
Kite String (or thin string)
Washers or paper clips

Tape Measure (non-metric measurements are permissible for this lab)
Meter stick (optional)
Pen, pencil, or fine-tipped marker
***1/2 × 19* Wire nails** (1/2 in. thin nails that fit in the center hole of protractor, *e.g*. Hillman brand #532392)
Scissors
1"× 6", or 1"x 8", **board**, sawed into 7 inch lengths and 3/8" hole drilled in its center
3/8" dowel rod, cut into 8 ½ inch lengths
Hammers (May be shared)
Compass
Scientific calculators

Teacher Prep:

• Students will build sturdy astrolabes that they may keep. This week will require simple preparation with a saw and a drill. If necessary, find a handyman parent who can help. These instructions are for use with 6-inch protractors with a hole at the origin (center). Smaller protractors would also be fine, but the origin hole is essential.

• Incidentally, individual protractors, *i.e*. not in a kit, are difficult to obtain at department stores in the middle of the school year and might be better purchased online.

• At the end of the lesson, there is summary of the Galileo controversy, in which Galileo was tried by a Church Tribunal and found guilty of heresy. A variety of rumors and half-truths are commonly circulated about this historical event. While the tribunal was mistaken in rejecting the heliocentric theory, the details of the story help to explain why the Church condemned Galileo's ideas. The heliocentric model was certainly not proven in Galileo's time, but Galileo proceeded to state it as an established fact, and he even re-interpreted parts of the Bible based on his scientific conclusions. An essay by Patrick Madrid is quoted at length. We hope you find this summary useful in leading a discussion with your class.

A full version of Patrick Madrid's essay may be viewed online at:

http://www.catholiceducation.org/en/controversy/common-misconceptions/the-papacy-and-galileo.html

<u>Board preparation</u>

Menards typically sells inexpensive "Value wood" with imperfections that is excellent for this project. A 1x8 is better than a 1x6 because there is more space for the students to make the East and West markings, but a 1x6 is typically more affordable. If you mention that this is for education, Menards, Home Depot, etc. might even cut the lumber for you for free.

1. Saw a 1x6 board into 7-inch segments, one per student. (Note: If you must use a 1x4 board, then you may need to use a smaller protractor.)

2. In the <u>exact center</u> of each board, drill a 3/8-inch hole <u>most of the way</u>, but ***not*** completely, through the center of the board.
3. Ensure the dowel rod stands in the hole vertically and can be rotated by hand.

<u>Dowel rod</u>

1. Saw the 3/8" dowel rod into ≈8 ½ inch segments (one per student). Smooth any rough edges with sandpaper.
2. At 3 inches from one end (the "top") and pre-drill a **shallow** 1/16 inch hole straight into the rod. Do <u>not</u> drill very deep. In class, students will drive a nail into this hole to hang their protractor in place. A shallow hole leaves wood to drive the nail.

Cheaper option 1:
Use a protractor to mark angles onto a quarter-circle of cardstock from 0-90 degrees. Be sure to mark the origin. This will save the protractor from becoming a permanent part of the astrolabe, and the student will read the angles directly without having to subtract from 90.

Cheaper option 2:
Construct a simple astrolabe as in **Part B** below, but instead of using a dowel rod, affix the astrolabe to a cardboard tube, *e.g*. a paper towel roll, with a pushpin. Next make a compass rose using a paper plate. Use the protractor to mark 360 degrees on an upside down paper plate. Cut a hole for the cardboard tube in the center of the plate. Point the 0° mark on the compass rose due north. Stand the astrolabe in the compass rose. Students will be able to give both horizontal and vertical angles of their measurements.

Students:
Part A: Build the compass rose
Procedure

1. Use a pen, marker or pencil to make a dot in the bottom of the 3/8" hole of the board.
2. **Place the center of a protractor on the hole of the board so that the flat edge of the protractor is perpendicular to the short, ≈5.5 inch sides and parallel to the 7 inch sides.** Ensure that the dot in the hole (from Step 1) is directly below the origin hole of the protractor. Immediately **mark the 0° and 180° angles.**
3. Without moving the protractor, mark the board every 10° working clockwise on the top of the board. You may need to use the inner scale of the protractor to mark points near the edge of the board. Flip the protractor to mark the other half of the circle. Do not number the marks yet. Make the special marks N, E, S, W at 0°, 90°, 180°, and 270°, respectively. Now your board should look like the image in Figure 1, below.

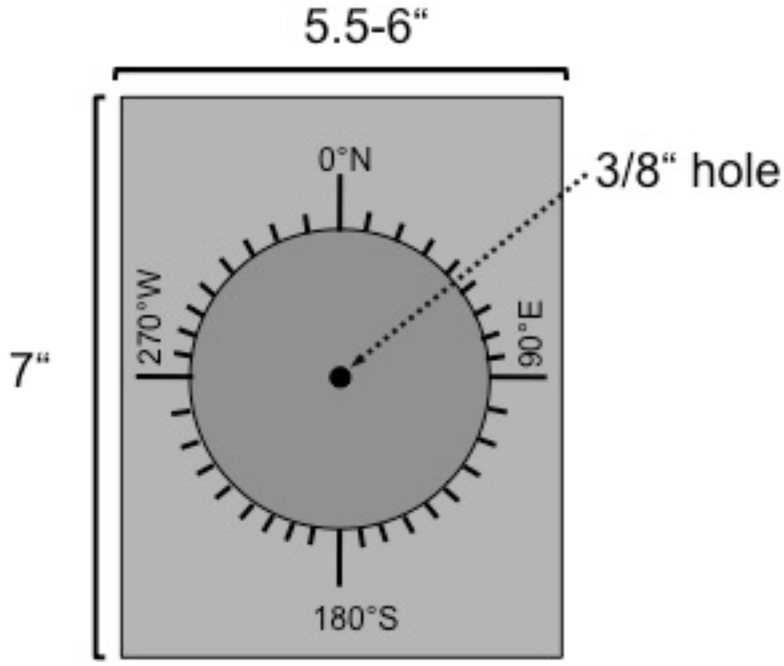


Figure 1. Compass Rose

4. Now, **mark the numbers of degrees for each mark from 0-350, counting by tens**.
5. Optional: **Use a straight edge to draw lines connecting points on opposite sides of the origin**. For example, draw a single line through 0°N, the origin, and 180°S. Likewise, draw a second line through 10° NE, the origin, and 190°SW, and so on.

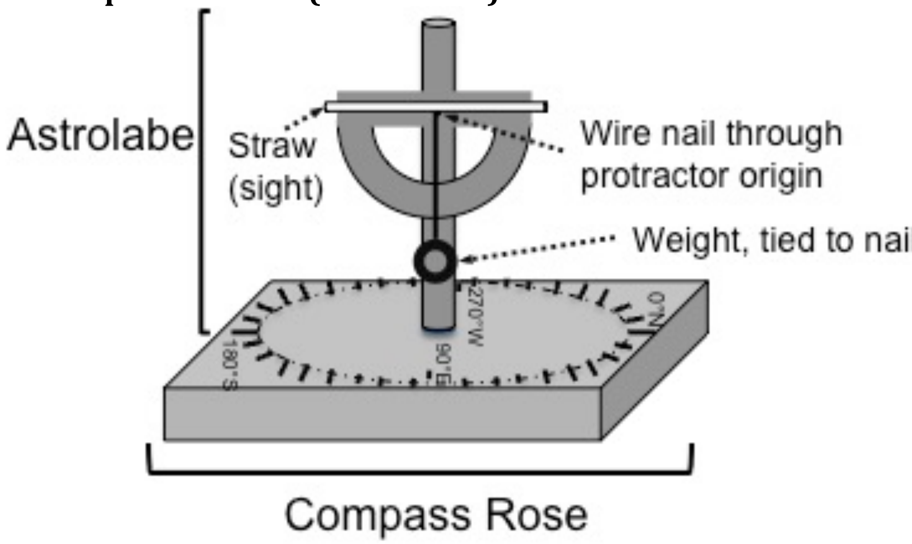
Part B. Build the Astrolabe

Important: Do this section only after completing Part A unless you have a second protractor.

1. **Tape a straw straight along the baseline of the protractor**. If it is a bendable straw, cut off the flexible part. The bottom edge of the straw should align with the baseline, but it should not block the origin hole. Optional: Cut a tiny hole out of the bottom of the straw where it would touch the nail. This better allows the straw to align with the baseline.
2. Lay the 8 ½ inch dowel rod on a flat surface with the pre-drilled hole facing up. **Align a small wire nail through the center hole of the protractor and into the pre-drilled hole of the dowel rod.** Ensure that the numbers are facing up and not backwards. If tape covers the hole, poke a hole through the tape with a wire nail.
3. **Use a hammer to drive the nail most of the way into the dowel rod while keeping the nail threaded through the protractor**. <u>Do not smash your protractor!!!</u> Leave a few millimeters of the head of the nail sticking out so that the protractor swings freely.

4. I**nsert the long end of the dowel rod into the hole of the compass rose** from Part A.
5. **Tie a short string between a washer and the nail**. The string should be just long enough to let the washer dangle below the arc of the protractor, but does not rest on the board of the compass rose. It should look like the image in Figure 2, below.

Figure 2. A Simple Astrolabe (not to scale)



6. **Check your astrolabe by looking at the horizon through the straw**. The horizon should be at the bottom of the straw interior. Have your partner measure the angle of the string relative to the protractor. With the weight of a washer, the string should point straight down. It should read 90° when the protractor is level. This means that the horizon is perpendicular to an angle straight down from where you stand.

Congratulations! You have finished your Astrolabe/Compass Rose.

Part C. Using your Astrolabe to calculate the heights of persons and objects.

<u>Objective</u>: You will determine the angle from the horizon, which we will call θ (theta). You will use the angle θ to calculate the height of an object or person. Then you will directly measure the height of the object and compare it to your calculation for its accuracy. You may use Figure 3 to help understand the trigonometry of the astrolabe.

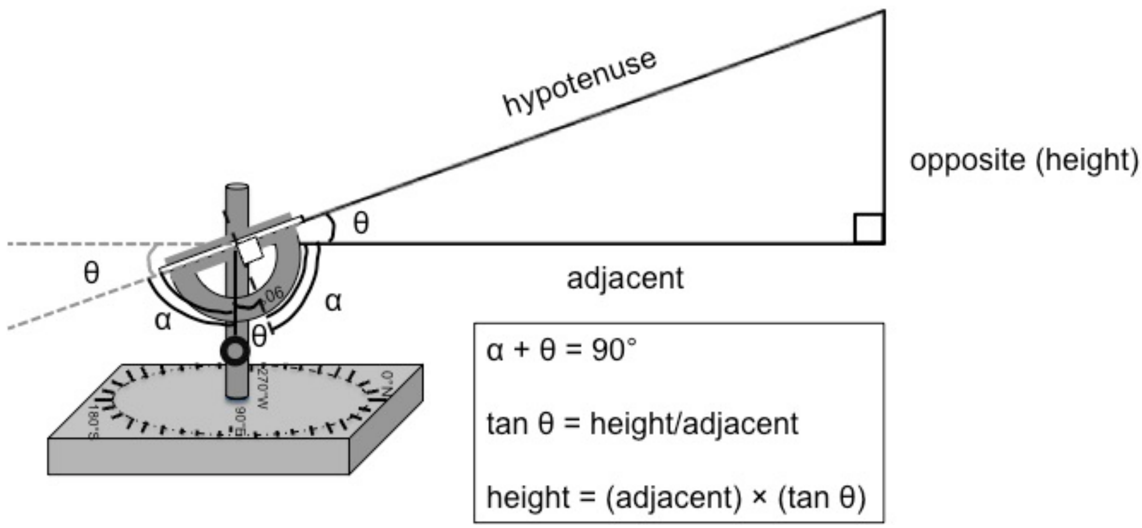


Figure 3. Using the astrolabe to determine the altitude (θ) from the horizon.

1. **Select an object or a person** whose height you could realistically measure, but do not measure its/his height yet. If it is a person, he/she must not move until all measurements have been made. Likewise, keep the astrolabe in one place. **Place your astrolabe on the ground or on a low flat surface away from the object.**
2. **Use a tape measure or meter stick to measure the distance along the ground from the dowel rod of your astrolabe to the bottom center of the object**.
3. **Look through the straw and align the top of the object with the bottom of the straw interior. Have your partner read the angle of the string relative to the protractor**. <u>Hold still!</u> The value should be less than 90°. If it is not, then use the other scale on the protractor. We will call this angle α **(alpha)**.
4. **Subtract the value in Step 2 from 90° to obtain the angle (θ) from the horizon**. **Equation 1: θ = 90° - α**
5. **Calculate the height of the object using the ground distance, the angle θ, and Equation 2: height = (adjacent) × (tan θ). Remember the units!**
6. **Now use the tape measure to directly find the height of the person.** Be sure to consider the height of the astrolabe during the measurement! You must subtract the height of the protractor origin from the calculated height of the object. The height of the astrolabe matters more with shorter objects.
   For example, if the origin of your protractor is 5.5 inches from the bottom of the compass rose, and the astrolabe was placed upon a table 13 inches from the ground, height you calculated may be 18.5 inches shorter than the height determined with a tape measure.
7. **Repeat the procedure with your partner's astrolabe and with different objects.**
8. **Attempt to calculate the height of an object you cannot measure directly, such as a house, power line pole, radio tower, etc.**

Part D: Calculate the accuracy of your astrolabe.

Objective: Your astrolabe will have accuracy within a certain number (±) of degrees. You will use your results from Part C and inverse tangent function on your calculator to determine its accuracy.

1. **Divide the measured height** of the object **by the adjacent distance** from the astrolabe.
2. Calculate the inverse tangent (also called $\tan^{-1}$, or arctan). Be sure your calculator is set on *deg* and not on *rad*. This is the expected angle of θ.
3. Find the difference between the measured θ and the expected θ. This is one measurement of the error (y) of your astrolabe in degrees (**θ**± y°).

Part E: Using your Astrolabe/Compass Rose to map a cloud.

Objective: Your astrolabe/compass rose may be used to describe the precise location of an object in the sky, such as a planet or star. In this exercise, you will practice using your compass rose in the daytime.

1. Place your compass rose outside on a flat object such as a picnic table. Use a compass to align the 0°N mark on the compass rose with Magnetic North, or True North if you know it. Record which North you are using.
2. Record the time and your location.
3. Locate an object in the sky, such as a cloud or the moon. (Do not look directly at the Sun!)
4. Rotate the astrolabe, but do not move the compass rose. With the help of a partner, use the astrolabe to collect the angle of altitude above the horizon (θ) as in Part C. At the same time, use a flat edge or thin book to determine the angle from 0°N that you are viewing the object. Draw a rough sketch of the object, and collect data for at least 4 points on the object, including its center and several features along its perimeter. For example, if viewing a cloud:

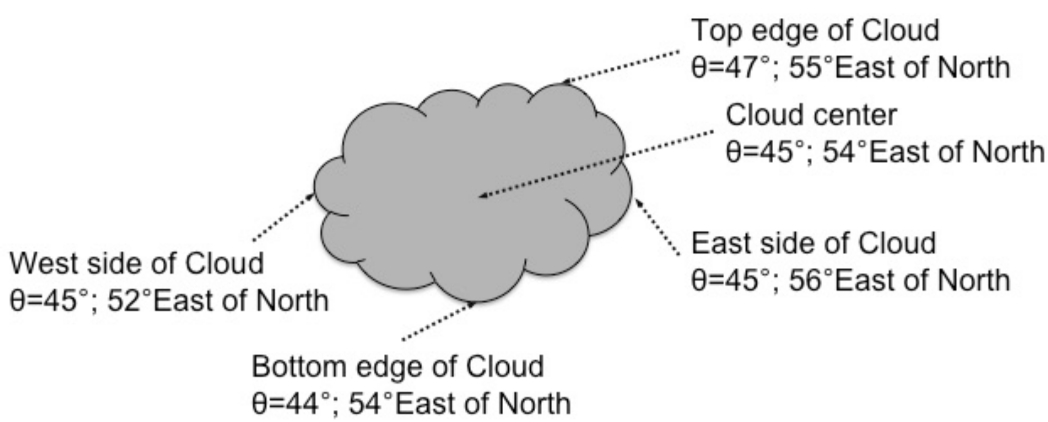


Figure 4. Example of using an astrolabe to describe the locations of objects in the sky.

Lab Homework and Write-up

1. Do you understand the trigonometry of the astrolabe in Figure 3? Explain to your lab partner which angles in the figure are similar and how to discover the angle of θ.
2. Why does the height of the astrolabe more greatly affect the measurement of short objects? Could you reasonably neglect the height of the astrolabe when viewing

objects in space? Could you reasonably neglect the elevation of the observer's location? Explain your answers.

3. **What was the error of your astrolabe in degrees?** Express your answer as "measured θ± y°". **Name some reasons that your astrolabe may not be completely accurate.**
4. **Could you use your astrolabe to approximate the size of a cloud**? Give it a try. Explain any assumptions you make. **Draw a diagram of the problem with right triangles.**
5. Why must you mark your location and time when you use your astrolabe and compass rose?

Possible Answers:
1. Hints: The straw is at a 90° angle to the protractor's 90° mark, and the angle from the horizon to the string is 90°. Inverse angles are similar.
2. When measuring a person's height, the height of the astrolabe, e.g. 6 inches, is a significant percentage of the height of, say, a 5'6" person (10%). For celestial objects such as the moon, which is 239,00 miles away, even an astrolabe held at 72 inches above the ground would be a small percentage of the distance. However, the elevation of an observer holding an astrolabe atop a mountain in Colorado would be a more significant height than that of an observer at sea level. This is why it is important that you record your precise location when making measurements of celestial objects.
3. Answers may vary, but some possible answers are that: it is difficult to hold still the astrolabe during measurement; it is difficult to tape the straw perfectly straight on the protractor; the string may not be still during the measurement; errors in tape measurements will compound the error in the astrolabe; perhaps the dowel rod is not perfectly vertical in their compass rose, etc.
4. Answers may vary, but students may make reasonable assumptions about the ground distance to the cloud by distances to known landmarks.
5. Altitude and azimuth are local coordinates. Celestial bodies may move throughout the day and night, and they may appear at different angles depending on your location.

Home Enrichment Activities:

1. Latitude can be determined by measuring the incline of the North Star at night. Use your astrolabe to determine your latitude by measuring the altitude of the North Star. Does your measurement match the latitude of your location on a map or GPS?
2. Use a map of the night sky to find a constellation. Use your astrolabe to map the positions of the stars in the constellation.
3. Do a little research into one of the following topics and explain it to your class.
    a. How was the diameter of the earth initially calculated? How has it been measured in modern times?
    b. How is the distance to the Sun calculated? Were the ancient philosophers such as Aristarchus correct in their calculations? Explain.
    c. How are distances to planets and stars determined? (Do not get too deep into the math, but try to get the general idea.)

<u>The arrangement of the solar system and the Galileo controversy</u>

The shape and arrangement of our solar system was one of the most important and difficult questions in astronomy. Copernicus (1473-1543) is often credited with the heliocentric model, which places the Sun at the center of the solar system, but Aristarchus of Samos (*ca*. 310-230 B.C.) was likely the first to propose the idea. However, it was the geocentric model of Ptolemy (*ca*. 100-170 A.D.), with Earth at the center of the solar system, which gained popular acceptance for approximately 1300 years. We now know that the heliocentric model is correct, but why was the incorrect geocentric model popular for so long? The answer lies in the difficulty of making accurate measurements of the stars.

Do the following mini-experiment. Extend your arm in front of you and stick up your thumb. Close one eye and describe what is behind your thumb, then repeat with the other eye closed. Your thumb appears to have moved, but you know it has not. Likewise, if the Earth is moving around the Sun, then a particular star in the sky would appear to move ever so slightly from the summer to the winter, when the Earth is on opposite sides of the Sun. This kind of change is called **stellar parallax**. However, the distances to even the nearest stars are yet so vast that stellar parallax is impossible to observe without a good telescope and some knowledge of light refraction and diffusion through the atmosphere. It was for this reason, among others, that most philosophers and scientists considered the heliocentric model to be false.

In 1610, Galileo Galilei (1564-1642) made use of a new instrument called the telescope. The telescopes he used were not even as powerful as a good pair of binoculars today, but he was able to make a number of important observations such as the orbits of moons around Jupiter, the phases of the planet Venus, and the rotation of Sun by watching sunspots. (Galileo did go blind five years before his death (Gerard, 1909) from staring at the sun through his telescope (Rhatigan & Newcomb, 2003, p. 27).) Galileo realized that his observations were *consistent* with the heliocentric model of the solar system, and he openly supported it as true.

However, the problem was that Galileo's observations neither *proved* the heliocentric model nor explained the lack of stellar parallax. (In fact, stellar parallax could not be demonstrated for another 200 years.) In addition Galileo seemed to ignore the proposal by his contemporary Johannes Kepler that planets moved in elliptical, not circular, orbits, even though elliptical orbits made the heliocentric model more plausible. Nevertheless, Galileo represented his view of heliocentrism as *fact*. To make matters worse, Galileo began to redefine how some passages of the Bible should now be understood in the face of his discoveries. Naturally, this excited concern among some important persons of the clergy, including the pope. Consider the following excerpt from an essay by Catholic apologist, Patrick Madrid.

"What, then, caused the row with the Church? The first thing to remember is that Galileo's heliocentric theory, although sternly opposed by theologians who embraced the Ptolemaic model (according to which, all heavenly bodies, including the sun, revolve around the Earth), wasn't the real source of his ecclesiastical difficulties. Rather, the cause of his persecution stemmed from a presumption to teach the sense in which certain Bible passages should be interpreted (using science as the ultimate criterion) and from charges that he claimed God was merely accidental and not substantial.

"Galileo confused revealed truths with scientific discoveries by saying that in the Bible 'are found propositions which, when taken literally, are false; that Holy Writ out of regard for the incapacity of the people, expresses itself inexactly, even when treating of solemn dogmas; that in questions concerning natural things, philosophical [i.e., scientific] should avail more than sacred.' Hence we see that it was Galileo's perceived attack on theology (which is the unique domain of the Magisterium and not of scientists) that elicited the alarmed response from the Church" (Madrid, 1999, pp. 181-2).

Some modern references erroneously dismiss the Galileo controversy as a dispute between a rational scientist and science-fearing clergymen whose faith was threatened by science, but the full story is more complex. Some even assert that Galileo was tortured until he recanted his claims, but there is no evidence that Galileo was ever tortured. He was eventually placed under a sort of house arrest, but during this time, he lived in comfort and not as a prisoner (Gerard, 1909). Nonetheless, in 1825 and again in 1992 the Catholic Church, through an official document and the words of Pope Saint John Paul II, apologized for the harsh actions taken against Galileo (Madrid, 1999, p. 188).

References:

Gerard, J. (1909) Galileo Galilei. In The Catholic Encyclopedia. New York: Robert Appleton Company. Retrieved December 29, 2015 from New Advent: http://www.newadvent.org/cathen/06342b.htm

Madrid, P. (1999) Pope Fiction. Basilica Press.

Rhatigan, J., and R. Newcomb. (2003) Out of This World Astronomy: 50 amazing activities and projects

Lab VIII: Space Exploration using Light Spectra

Objectives:
To learn about stellar spectra
To measure light intensity
To use a spectroscope to distinguish different types of light bulbs
To make inferences about the interior of planets and stars

Introduction:
Scientists have identified the chemical compositions and densities of planets in our solar system and even of numerous stars through the study of light spectra. Different elements and compounds absorb and emit different wavelengths of light, and reactions in different types of stars produce unique patterns and frequencies of energy. In fact, even refraction of light around planets can aid scientists to predict the types and quantities of different elements, compounds, and gases that are present.

In this experiment, students will use a spectrosope and photometer to distinguish different types and intensities of light emanating from candles, compact fluorescent light (CFL) bulbs, light-emitting diode (LED) bulbs, and incandescent light bulbs. CFL bulbs contain a fluorescent coating of different **phosphors**, compounds that fluoresce visible light after absorbing the ultraviolet light produced inside the long, twisted tube[1]. The phosphors may vary in different kinds of CFL bulbs, resulting in a different, **discontinuous spectra** in the visible light range. Other types of light sources tend to have **continuous spectra** in the visible light range. The spectra emitted by different light sources serve as a sort of signature to help identify the compounds and elements that are present.

In addition, students will explore different kinds of lenses to create a rudimentary, refracting telescope as was used by Galileo to investigate Jupiter, Venus, and the Sun.

References:

1. Retrieved December 30, 2015 from https://www.mineralseducationcoalition.org/sites/default/files/uploads/mec_fact_sheet_fluorescent_light_bulbs_0.pdf

Terms:
Phosphors, wavelength, frequency, visible light spectrum, ultra-violet light, infrared light, light-emitting diode (LED), fluorescent, refraction, light intensity, spectroscope, continuous photometer.

Supplies:
Candle and matches (or gas lighter)

***Quantitative* Spectroscope** (EISCO Premium Quantitative Spectroscope. $5-10 on Amazon; or #OP-SPEQUAN on Hometrainingtools.com for $9.50 +shipping)

Assortment of white light bulbs in fixtures (incandescent, CFL, LED, preferably all of the same style & approximately equal lumen rating)

Tablet, iPad, or smartphone with a photometer App (several free apps, such as LuxMeter, are available, but use one with units in lux.)

Flashlights, LED and incandescent (optional)

Assortment of Convex and Concave lenses, (Bag of Lenses by Science Kit Inc. on Amazon.com or American Educational 6 piece glass lens set)

Cardboard tubes (empty wrapping paper or paper towel rolls)

Lint-free cloth (to clean lenses)

Diagram of lens types

Ruler or tape measure

Optional Diagrams
- Full light spectrum showing visible and invisible light (recommended)
- Emission spectrum from the sun and the absorption spectra of helium & hydrogen
- Infrared absorption by greenhouse gases.

Teacher Preparation
For Part A:
You will need a space that you can make as dark as possible. Pitch black is not necessary. Students will use a spectroscope and a photometer app to view several sources of light: a candle, an incandescent light bulb, a LED, a CFL, and sunlight. They may also test incandescent or LED flashlights. The spectroscope will reveal that a CFL has a discontinuous spectrum, showing distinct and separate bands, of colored light. The spectroscope <u>must</u> have a quantitative scale within it that denotes which wavelengths (in nm) of light are present. The exact wavelengths of light make it possible to predict which kinds of phosphors are present in the CFL tube. White LED and incandescent light bulbs will likely have continuous light spectra.

For Part B:
Students will be allowed to experiment somewhat freely with refracting lenses. A simple protocol is provided, but the instructor should allow students some free time to practice using the lenses. It is important that a variety of convex and concave lenses are available. **Tip**: Combining a convex objective lens (FL 20cm) with an ocular concave lens (FL 10cm) should produce a slightly magnified image.

Students should be reminded (1) to handle the lenses only from the sides (2) of the shapes of convex and concave lenses, (3) how convex and concave lenses refract light; (4) to return lenses to their correct places for the next student or student pair; and (5) lenses will break if dropped.

As lenses are somewhat expensive, it may be worthwhile to investigate if a set may be borrowed. However, here is a short review of some options available for purchase.

<u>Bag of Lenses by Scientifics Online (Recommended)</u>

-Pro: Works well in this exercise, many good-quality lenses available for large groups; good value per lens.
- Con: greater up front cost of $12.95 + $5.95 S&H as of 12/2015
- 20 lenses, 5 sets of 4 lenses;
- Pro: each is wrapped and labeled with lens type, diameter, and, usually, with focal length
-Con: no guarantees on specifically which lenses will arrive
- One sample order: four 65mm Plano Convex lenses, eight 50-mm double concave lenses, focal lengths of 10- or 20-cm; four 38-mm double concave lenses, FL=15 cm; four 50-mm double convex lenses, FL=20-cm.

<u>American Educational 6 Piece Glass Lens Set by Amazon.com LLC</u>

- $9.93, S&H will vary on Amazon.com
- 6 lenses of adequate or good quality
- Will work in this exercise
- Con: Lenses are not labeled as concave, convex, *etc*. Instructor must identify each. Focal lengths are not reported.

<u>United Scientific LSTA50 Acrylic Demonstration Lens Set, 6 Pieces, 50mm Diameter (not recommended)</u>

- $16.75, S&H will vary on Amazon.com
- 6 thick lenses of low quality
- Good for demonstration of lens shape, but not good for this exercise
- Lenses are sorted by type, but focal lengths are not included.
- Instruction sheet for laboratory exercises is included.
- Not a good value for the cost.

If you know of other sources of good, affordable lenses, please let the publishers of Catholic Schoolhouse know. We are always seeking ways to improve the experiences of our tutors and students.

Student Procedure:

Part A: A study of the quality and quantity of light

Background: Incandescent, CFL, and LED lights generate light in different ways. Incandescent bulbs heat a metal filament, typically made of tungsten, which excites electrons and emits large amounts of infrared light (invisible heat) and a smaller amount of white visible light. CFL bulbs generate ultraviolet light that is absorbed by an assortment of chemicals called phosphors, which then emit a blend of visible light that our eyes see as white light. LEDs contain a semiconductor filament that passes electricity in only one direction. Excited electrons in the LED emit a wavelength(s) of light specific to the semiconductor filament.

Here you will use a spectroscope to aid in distinguishing CFL bulbs from other light sources and to help predict the types of phosphors they contain. This type of spectroscopy is similar to that used by astronomers to predict the chemical make-up of different planets and stars. You will also use a photometer to measure the intensity of light from each source. Light intensity is useful to astronomers in determining the relative abundance of different elements or compounds in celestial bodies. Intensity is also an important consideration regarding the size and distance of a star.

<u>Optimally, students should work in pairs.</u>

1. Turn off every light in the room and make the room as dark as you are allowed. **Light a candle**.
2. **Use a spectroscope to view visible light from a candle**. Look through the eyepiece and point the spectroscope so that the vertical slit points directly at the flame. On the opposite side of the slit, the light should be split into its prismatic colors.
3. **Record the prismatic colors on the light scale** (roughly 390-740nm) in the chart. Make a rough sketch of the scale in the column on the right. Are there separated bands of different colors (a discontinuous spectrum), or is there a range of colors with no gap between them (a continuous spectrum)? If it is a discontinuous spectrum, **measure the wavelengths (nm) of each band and record it and the color above each band.** If the spectrum is continuous, **measure the minimum and maximum wavelengths, and make note of anything distinctive.** For example, do any specific colors seem present in greater or lower intensities?
4. **Use the photometer to measure light intensity in units of lux**. Intensity increases the closer the photometer camera is held to the light. Therefore, select a distance (10-15 cm, or about ¾ the length of your hand) that you can easily and repeatedly measure for each light source. **Record that distance here ________cm.** *Be careful not to burn yourself!* The camera must be lined up directly with the light for the highest reading.
5. **Record the light intensity in your chart**.
6. **Qualitatively assess the production of infrared light,** which is invisible. Put your hand near the light source and record whether it is hot, warm or cool.
7. **Now get a background reading in the room**. Extinguish the candle and point your

photometer camera away from any existing light still in the room. This is the ambient light in the room. Record this number in the chart in the **Ambient** row.

8. Now **repeat steps 2-6 with the different light sources** your instructor has provided. Record your data as you go.
9. **Point the photometer at the Sun** through a window or by going outside, and get a reading of its intensity. Do not look directly at the Sun. Record your data.
10. Use a white sheet of paper to reflect the sunlight, or view the light reflected from a white cloud. **Use the spectroscope to record the prismatic colors of reflected sunlight**.

Table 1. Wavelength Emissions of Fluorescent Lamp Phosphors

Shorthand	**Phosphor**	**Colors and Peak Wavelengths**
A	Sb^{3+}, Mn^{2+}-activated Calcium halophosphate	Blue (480nm) and Orange-red (580 nm)
B	$Y_2O_3:Eu^{3+}$	Red (611 nm)
C	$LaPO_4$:Ce, Tb	Green (543nm)
D	$CeMgAl_{11}O_{19}:Tb^{3+}$	Green (550)
E	$Sr_3Gd_2Si_6O_{18}:Pb^{2+},Mn^{2+}$	Green (550)
F	$BaMgAl_{10}O_{17}:Eu^{3+}$	Blue (450)
G	$(Sr, Ba, Ca)_5(PO_4)_3Cl:Eu^{2+}$	Blue (450)

Reference for data in Table 1:

Srivastava, Alok M. and Sommerer, Timothy J. (1998). The Electrochemical Society Interface. Fluorescent Lamp Phosphors: Energy saving, long life, high efficiency fluorescent lamp products.

Table 2. Quality of common light sources

Source	Intensity (lux)	Infrared light? Hot, warm, or cool?	Continuous (C) or Discontinuous (D)?	Wavelengths (nm) Make a sketch of the bands on the scale, and record exact sizes of each band above the sketch.
Ambient				400 450 500 550 600 650 700
Candle				400 450 500 550 600 650 700
CFL				400 450 500 550 600 650 700
LED				400 450 500 550 600 650 700
Incandescent				400 450 500 550 600 650 700
LED flashlight				400 450 500 550 600 650 700
Incandescent flashlight				400 450 500 550 600 650 700
Reflected Sunlight				400 450 500 550 600 650 700
				400 450 500 550 600 650 700

Part B: Introduction to building telescopes

In this exercise, you will be allowed to practice using lenses to build a simple telescope. Be sure to heed the specific instructions by your tutor when handling the lenses.

A short review on lenses:

Concave lenses have a rounded side like the inside of a bowl. Convex lenses have a side rounded out like the bottom of a bowl. Each lens has two sides, so a lens can be a combination of concave and convex, or have one flat side, called plano.

Three shapes x two sides = 6 general styles of lenses: **double convex, double concave, plano-convex, plano-concave, concavo-convex and convexo-concave**.

Lenses also have focal lengths, which give the distance from the lens that an image is in focus.

1. **Make observations with a few different lenses**. Record your observations in a table (an empty table is provided). Be sure to record which type of lens you are observing.
   Are images through the lens: upside down or right-side up?; magnified or diminished?; in focus near or far from the object?; in focus near or far from your eye?; and so on.
2. **Take a cardboard tube and make a straight cut along one side of the tube**. This will be your telescope. Select a lens that seemed to magnify images. Open the tube a little at the far end of the tube, and **align a lens in it**. This will be your **objective lens**.
3. **Slide the objective lens forward and backward** while viewing something "far off". This something may be 20 cm away, or out the window and across the street. It is <u>your experiment</u>.
4. **Select another lens**. Place it in the tube closer to you. This will be your **ocular lens**. Slide it forward and backward in your tube while viewing your selected object. **Try to get an image to magnify <u>and</u> be in focus**. If something isn't working, slide the both lenses, swap out one of your lenses, or look at a different object.
5. When you have found a combination that you like, **make some measurements** with a ruler or tape measure. How far apart are your lenses? How far is the ocular lens from your eye? How far away is the object you are viewing?
6. **Share your findings with your classmates**. Who has the best telescope? Is it yours? If not, how is it different from yours?
7. **Return the lenses** to your instructor.

Table 3. Properties of Lenses

Lens	Observations

Table 4. Building a Telescope

Ocular	Objective	Observations

Lab Write-up:

1. Create a bar graph to compare the light intensity of each light source. Compare and contrast each type of light from your graph and data table.
2. How can a study of light spectra help determine the components of a star or planet?
3. How would a discontinuous spectrum affect how you see colors? How do the makers of CFL bulbs try to create "white light"?
4. Attempt to qualitatively evaluate the light from each bulb. Which kind(s) of light bulb would be best in an art gallery? Which would be worst?
5. What kinds of phosphors might be in your CFL bulbs? Use **Table 1** to help you. Keep in mind that your spectroscope, like all instruments, has some degree of error and your wavelengths will have some degree of error.
6. How many of the following atoms are in "Phosphor G": Y; P; O? Which atoms do these symbols represent?

Advanced:

7. Consider what NASA has learned about Pluto (or another planet or start) recently. Write a short report about the findings. How do they know its temperature, density, and molecular composition? (Answer: Studying these compounds in isolation on Earth reveals their properties, and satellites have detectors that look for these properties as they fly by.)
8. Use the internet to look at the full visible light spectrum, the emission spectrum of the Sun, and the absorption spectra of hydrogen and helium. How could you make conclusions about the composition of the Sun?

Answers

1. *Answers may vary. Sunlight should be most intense and display fullest range of visible light.*
2. *The light spectra are determined by the optical properties of the elements and compounds.*
3. *Answers may vary, but a full light spectrum would have a higher* ***color rendering index****.*
4. *A continuous spectrum would be better at showing the true colors of art.*
5. *Answers may vary, but their data should correspond with the options in Table 1.*
6. *Y, yttrium, 1 atom; P, phosphorus, 3 atoms; O, oxygen, 12 atoms. Subscripts of atoms within parentheses must be multiplied by the subscript of the parentheses.*
7. *Answers may vary. Check that they have researched well.*
8. *The emission spectrum of the sun has small gaps that correspond to the absorption spectra of hydrogen and helium, indicating these elements are present in the Sun. These are called Fraunhofer lines.*

Lab IX: Engineering the Reentry and Splashdown

Objectives:
To build a “module” that will make a safe landing by parachute

Introduction:

Consider the Apollo missions to the moon. A return from space, and especially from the moon, represents a lot of potential energy due to the great height from which the astronauts are falling. Great scientists and engineers considered many variables to ensure that the command modules of these missions could safely return to planet Earth. For example, an ablative heat shield protected the command module by burning itself away in the atmosphere and dispersing some of its kinetic energy. The astronauts also needed to land in a particular area in the Pacific Ocean so that ready U.S. ships could rapidly recover them.

Imagine you are on a team that is designing a module to make a return landing on Earth from the Apollo moon missions. For the Apollo missions, the astronauts made water landings in their command modules, but your team has been assigned to develop a module that could make a terrestrial landing. Your superiors have insisted that the module have at least a parachute system. However, you believe a parachute system alone might not be enough, and you make a few more innovations to ensure a safe landing for the astronauts, whose body shapes are strangely oval.

Supplies per team:

1 Medium Grade A Egg (55-60g each)
1 Sandwich bag
Two Sheets Wax Paper, in 12x24 inch rectangles
Four Strings, (67 cm apiece)
1 Balloon, un-inflated
4 straws (5mm diameter, 21cm long)
4 small popsicle sticks (1 cm x 11.5 cm)
Scotch tape (Used sparingly for securing joints only; not as a structural component)
Optional: Images of different parachute designs

Other supplies:
Copies of scoring sheets (1 × #students × #modules to be judged)
Optional: Tape measure (if measuring distances from target or height of drop)

Teacher Instruction:
Students will design an egg parachute and landing component that will safely land without cracking the egg. They may select from the components you provide in the quantities listed above. With the components in the list above, a landing module could be created that would protect a medium, white Grade A egg from a drop from a height of 4 meters or

higher. Students do not need to use all the components, but if they use only a parachute and if the landing surface is hard (and it should be), the egg will very likely break.

Give the students 20-30 minutes to construct their parachute & module. Then take them outside to some high point (treehouse, 2nd story window, balcony, playground equipment, etc.) where the eggs will be dropped. Points will be awarded in several categories.

DO allow them to be creative. Do NOT tell them how to make it.
DO give them some tips (see below).
DO tell them how the contest will be performed (how high, where, and who will release the egg, and who will judge it).
DO discuss the considerations for a landing.
DO allow the students to help judge the modules. Encourage objectivity.
DO encourage students to think of a clever name for their design. They should be proud of it!

Options for variation:
• Make it sporting. Challenge the students to use as few of the materials as possible.
• Alter the list of supplies for the students. Allow them to be more creative.
• Test different types of materials. For example, different groups could substitute wax paper with plastic, fabric, or paper. Use a stopwatch to measure the rate of descent.
• Design a landing zone and give points to modules that landed closest to the target. Discuss how a greater distance from the targeted landing site rapidly increases the area that the recovery team must search. If it were a water landing, more ships would have to be deployed, thereby increasing expenses.
• Use different kinds of eggs. Large Grade A eggs are about 5 g more massive than medium eggs, and brown eggs seem a little tougher, in general, than white eggs.
• Make designs for a water landing in a small swimming pool, large puddle, etc.

General tips for a safe landing

- A parachute with a greater surface area will descend more slowly.
- An egg with too much kinetic energy (falling fast) will break.
- Even a slow-moving egg (low kinetic energy) will crack against a hard surface.
- During a fall, potential energy is changed to kinetic energy. Therefore, a part of your module that is designed to bend or break upon landing will absorb kinetic energy and soften the landing.

Egg drop rules

The objective is to design a landing module that combines a slow descent with a soft landing on a hard surface.

1. Landing module must deploy a parachute.
2. Components may be selected from only the materials supplied by the instructor.
3. The egg must be completely inside the sandwich bag at the point of release. To facilitate judging of the egg integrity after the drop, at least half of the egg must be visible in the finished module. After all, the astronaut needs room to breathe.
4. Components may be placed in the sandwich bag with the egg as long as Rule #3 is not violated.
5. Contestants may cut the materials to smaller sizes.
6. Tape may be used only to connect materials. Tape may not be used as a major structural component. Tape may NOT be placed directly on the egg.
7. Components may be attached to the sandwich bag.
8. Each egg must be dropped from the same height. Parachutes may be spread open prior to release and from above the drop height, but the egg must not be lower than the drop height at the moment of release.
9. The parachute and module must be released at the same time.
10. Unused components may be returned to the instructor for bonus points in the judging, at the instructor's discretion.
11. Any component that has been cut, taped, or in any way used in construction has been used fully and may not be returned for credit as an unused component.

Scoring Sheet for Module Entry Entitled: ______________________

Circle a score for each category.

		Dull				**Clever**				
A. Title of Design		**1**	**2**	**3**	**4**	**5 pts**				
		Drab				**So-So**				**Stylish**
B. Aesthetics		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10 pts**
		Clumsy				**So-So**				**Elegant**
C. Ease of Release		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10 pts**
		Ineffective				**Useful**				**Effective**
D. Parachute		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10 pts**
		Ineffective				**Useful**				**Effective**
E. Module		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10 pts**

	Yolk broken in a yellow mess			**Egg white leaking**		**Large crack**		**Small crack**		**Good egg No cracks!**
F. Landing	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50 pts**

Circle one of the following only if the egg suffered no more than a small crack.

G. Number of	**1**	**2**	**3**	**4**	**5 or more**
unused components	**1**	**2**	**3**	**4**	**5 points**

Add up the total number of points you awarded.

Total Score _______/100

What elements of design made this module succeed or fail? Why?

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