

OPTICS UNIT

2011



Inquiry into Physics of Optics and its Usefulness in Astronomy

Addressed standards and objectives for all levels of science in North Carolina

North Carolina Standards Addressed:

- Physics Competency Goal 7: The learner will develop an understanding of wave motion and the wave nature of sound and light.
 - Objective 7.02: Describe the behavior of waves in various media
 - Objective 7.03: Analyze the behavior of waves at boundaries between media
 - Reflection, including the Law of Reflection
 - Refraction, including Snell's Law
- Physics Honors: 7.06H: Design and conduct investigation of optics (mirrors and lenses) and the laws of reflection and refraction.
- Earth Science Competency Goal 6: The learner will acquire an understanding of the Earth in the solar system and its position in the universe
 - Objective 6.03: Examine the sources of stellar energies

- Hertzsprung-Russell diagram
 - Life cycles of stars
 - Objective 6.04: Assess the spectra of stars and our sun as indicators of motion and composition (the Doppler effect)
 - Objective 6.05: Evaluate astronomers' use of various technologies to extend their senses
 - Optical telescopes
 - Cameras
 - Radio telescopes
 - Spectroscopes
- Chemistry Competency Goal 4: The learner will build an understanding of energy changes in chemistry
 - Objective 4.01: Analyze the Bohr model in terms of electron energies in hydrogen atom
 - The spectrum of electromagnetic energies
 - Emission and absorption of electromagnetic energies as electron change energy levels

ACRE: North Carolina Essential Standards addressed:

- (Physics) Phys.2.2: Analyze the behavior of waves.
 - 2.2.2: Analyze wave behavior in terms of transmission, reflection, refraction, and interference.
- (Earth/Environmental) EEn.1.1: Explain the Earth's role as a body in space.
 - EEn.1.1.3: Explain how the sun produces energy and is transferred to the Earth by radiation

Objectives for the AP Physics Courses B/C addressed:

- IV: Waves and Optics
 - B. Physical Optics
 - 2. Dispersion of light and the electromagnetic spectrum
 - b. Know the names associated with the electromagnetic radiation and be able to arrange in order of increasing wavelength the following: visible light of various colors, ultraviolet light, infrared light, radio waves, x-rays, and gamma rays
 - C. Geometric Optics
 - 1. Reflection and Refraction
 - a. Determine how the speed and wavelength of light change when light passes from one medium into another.
 - b. Show on a diagram the directions of reflected and refracted rays.
 - 2. Mirrors
 - b. Relate the focal point of a spherical mirror to its center of curvature.
 - c. Locate by ray tracing the image of a real object, given a diagram of a mirror with the focal point shown, and determine whether the image is real or virtual, upright or inverted, enlarged or reduced in size.
 - 3. Lenses
 - a. Determine whether the focal length of a lens is increased or decreased as a result of a change in the curvature of its surfaces, or in the index of refraction of the material of which the lens is made, or the medium in which it is immersed
 - b. Determine by ray tracing the location of the image of a real object located inside or outside the focal point of the lens, and state whether the resulting image is upright or inverted, real or virtual.
 - c. Use the thin lens equation to relate the object distance, image distance, and focal length for a lens, and determine the image size in terms of the object size.

Detailed Lesson Plan Outline

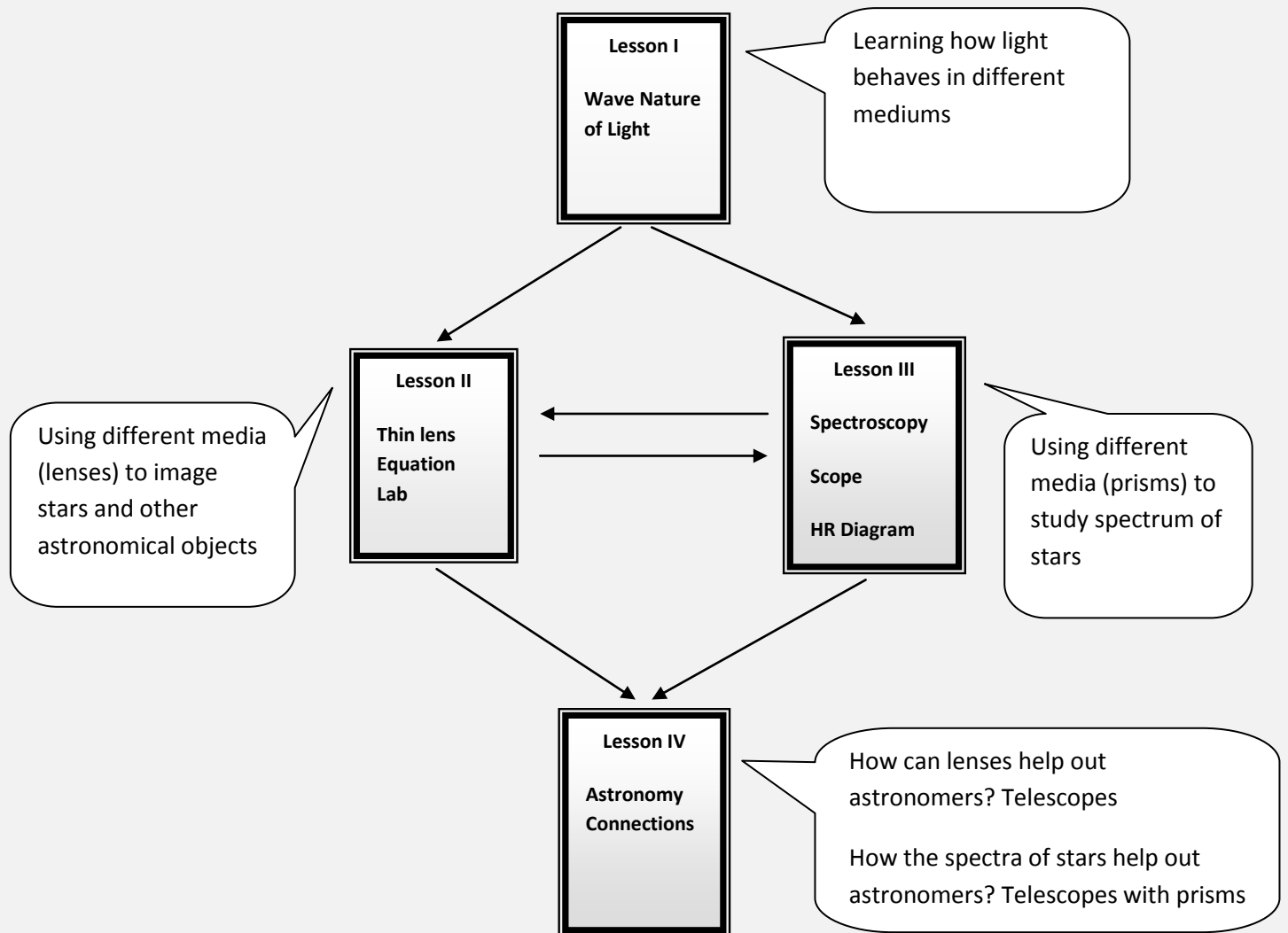
Background teacher information

This lesson plan will can be covered between 270-450 minutes and is best used during a block schedule because it is best divided into three or five equal 90 minute slots

The following lesson plan cover the standards addressed on the first page following guide lines from North Carolina. You will notice that there are two standards for NC, the first is being phased out and the second will be the only one used in the next few years.

This lesson plan is designed with astronomy in mind. The ultimate goal is to understand the math behind the thin lens equation and/or the use of spectroscopy in identifying stars, and the understanding of these uses in astronomy. This lesson focuses mostly on the visible light through lenses of optics but can be adjusted to include mirrors as well, however this will require more time than the allotted time above.

On the other hand you may decide to trim down this lesson. Each of the four parts can stand alone as an individual lesson.



Lesson I

Wave Nature of Light

Lesson I Wave nature of Light (90-120 minutes)

Main Topics

- 1. Light as a wave
 - Light is part of Electromagnetic spectrum
 - Light in different media
 - Bending of light through prisms
 - *Additional: Bouncing of light off mirrors*
- 2. Using prisms to create spectra → Intro to **lesson 3)**
- 3. Using lenses to focus image → Intro to **lesson 2)**

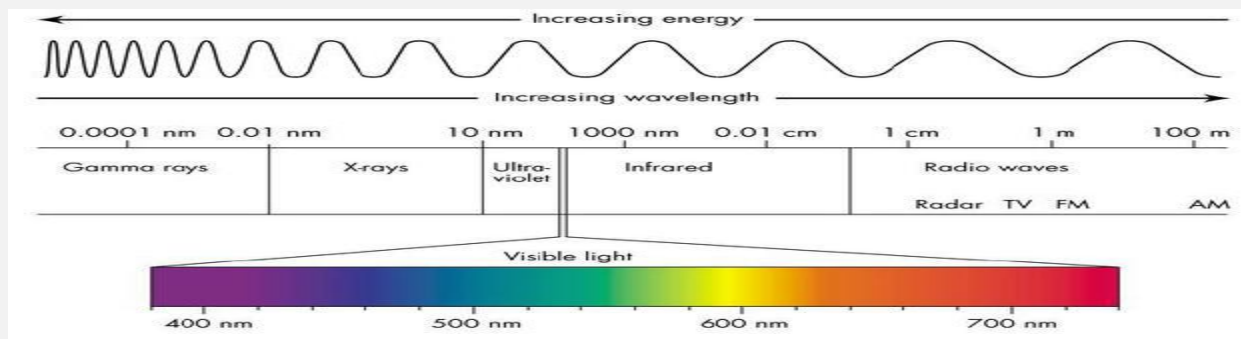
Materials Needed

- Computer
- Large paper
- Ruler

Instruction

1. Light as a wave

Light is a wave. Review the properties of all waves including wavelength, frequency, amplitude, and velocity. Review that visible light is only portion in the electromagnetic spectrum.



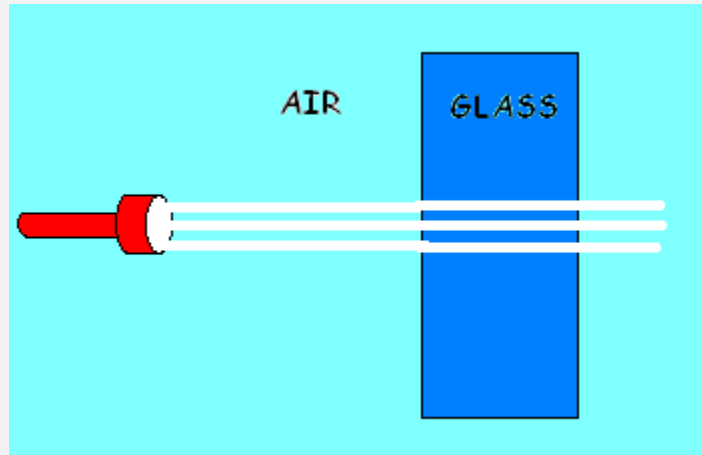
Review the speed of electromagnetic waves in a vacuum and compare it to the speed of electromagnetic waves in air and water.

- Vacuum $\sim 299,792,458$ m/s
- Air (0 degrees Celsius) $\sim 299,704,644$ m/s
- Water (20 degrees Celsius) $\sim 224,900,568$ m/s

-- What information can we gather from this? Is there such thing as a true vacuum? When light slows down what happens? Can we ever get a precise measurement of the speed of light?—

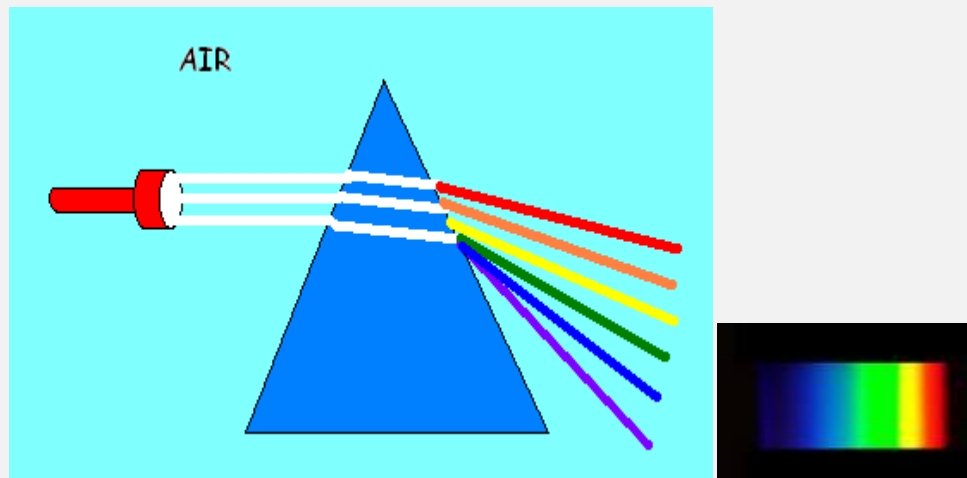
Review what happens to a wave like light when it travels between two different mediums.

- Straight on... no bending



2. Prisms can create spectrum

- At an angle... we get bending
- Once white light is bent because different colors bend different amount it creates what we call a spectrum.



Ask students what the notice about the colors being bent. Do they think that any other wave length in electromagnetic spectrum can be bent as well, including radio, gamma, UV, and Infrared?

Have student explore this site: <http://phet.colorado.edu/en/simulation/bending-light>

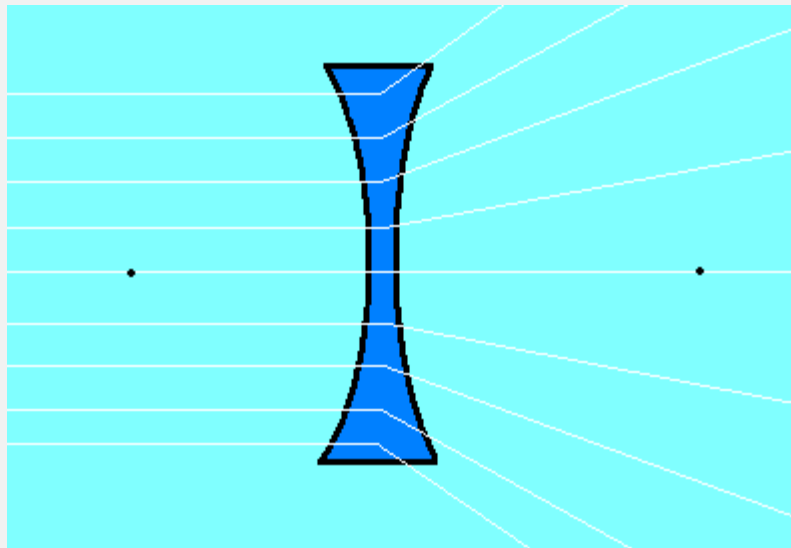
Questions for Website:

- a. Move around the laser then describe two things you notice as you move the laser around.
- b. Adjust index of refraction of both materials. What do you notice about the laser beam when you adjust it?
- c. Click on the tab at the top that says prism break. Then click on “white light” and “multiple rays” in the box to the right. Next move around as many prisms from the bottom and see what happens when you place the prism in the beam. Describe what you notice.
- d. What do you notice about the relationship between shape and bending of light?

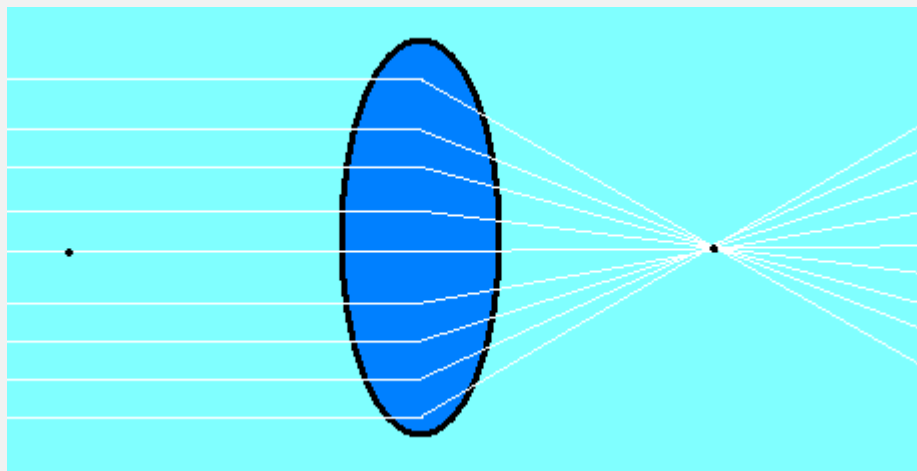
Adjustment 1) Add light hitting different mirror types here if needed and develop and understanding of the law of reflection (snell's law).

3. Lenses can focus light to create an image

- Using lens to focus light
 - Review the importance of the shape of the medium. Each shape helps contribute a special focus point.
- Parabolic shaped lenses act as a prism can also create a spectrum
 - Concave



- Convex



○

- Focal point is a very important part of parabola. Lens designed to take light in and send through focus

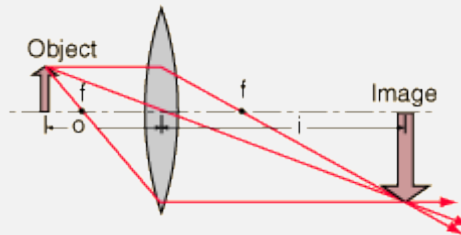
Drawing Ray Diagrams Instruction:

Ray 1: *The ray leaving the tip of the object traveling parallel to the optical axis will pass through the focal point f after passing through the lens.*

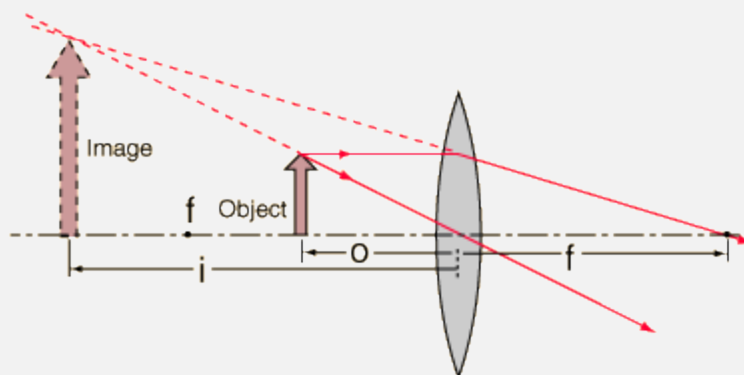
Ray 2: *The ray leaving the tip of the object and passing through the focal point f will emerge from the lens traveling parallel to the optical axis.*

Ray 3: *The ray leaving the tip of the object and passing through the center of the lens will emerge from the lens undeflected.*

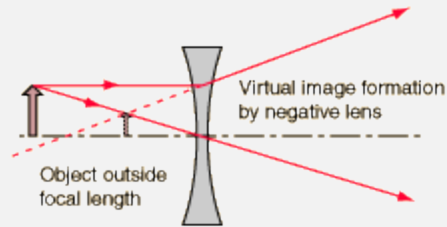
Have students ray diagram for a convex lens with the located somewhere behind the focus. Let them choose the object. Here the object is an arrow. Let them be creative. Note the inverted image, and magnification. Ex...



Have students draw a ray diagram for a convex lens with the object located somewhere in front of the focus. Skip step 2 when object is closer that focal length. Let them choose the object. Note the virtual image and magnification. Ex...



Have students ray diagram for a concave lens with the object located somewhere behind the focus. Let them choose the object. Note the virtual image and magnification. Ex...



Adjustment 2) Have the students do a ray diagram for a concave lens with the object in front of the focal length.

Adjustment 3) Mirrors used in same manner. Draw concave mirror object behind focus. Draw concave mirror object in front of focus. Then have the students draw a convex mirror ray diagram with the image of object in front of and behind focal point.

Playing with Phet: http://phet.colorado.edu/sims/geometric-optics/geometric-optics_en.html

Questions on Simulation:

- Click and choose between the different types of rays. Describe what you notice. Which one follows the rules written above?
- Change curvature length. What happens to focal length and image? Why?
- Change refractive index. What happens to focal length and image? Why?
- Change diameter. What happens to image? Why?
- Click on virtual image on right of screen. Move the object around. When do you notice the virtual image?
- Place the object directly on focal point. What do you notice?

Assessment

- Review answers to questions as a class

Focus

- How light is bent, how different colors bend different amounts. How we can use the bending to enlarge, shrink, invert images. How refraction came first caused color separation then reflection (Newton) solved problem. How we can use ray diagrams to figure out what image will look like. Looking at shape of lens or mirror, understanding math behind parabola and foci, by sending in parallel lines into lens or mirror we can get an image and determine if it will be shrunk, enlarged, inverted or right-side-up. Have them draw a ray diagram for concave lens, concave mirror, convex lens, and convex mirror.

Lesson II Inquiry Laboratory for thin lens equation (90-120 minutes)

Main Topics

- Lens equation

Instruction

- Review graphs
 - Hyperbolic graph
 - Linear graph equation
 - Using program to graph, finding y-intercept and slope
- Pass out lab manuals
- Allow students to figure out as much on their own as possible

Materials Needed

- Copy of lab manual (included)
- Light bench
- Convex lens
- Light source with an image in front of it
- Measuring stick

Assessment

- Assess the students as the progress
- Assess their graphs at the end

Teacher Guide to Lab

- Groups of 2-4
- One lens per group, each group can have lenses with different focal length. This is good for comparison reasons. However the lens needs to be convex.
- They need to get the focal length by an object fairly far away before starting the lab.
- They shouldn't find an image at $1f$ and $0.5f$. Due to the image being virtual it won't be seen.
- The first graph should be a hyperbolic curve, with the asymptotes at the focal length. The piece of the graph not seen would be located in the third quadrant and would be the virtual image.
- The second graph should be a linear graph.
 - $x = (1/d_o)$
 - $y = (1/d_i)$
 - $m = -1$

Lesson II

Thin lens
Equation
Lab

- $b=(1/f)$, because $y=b$, x is zero, if x is zero then d_o must be equal to infinity. When the object is infinitely far away ($x=0$) then $y=b$ since we know that all the rays of the image will pass through the focal length then $d_i=f$ then we conclude that $(1/d_i)=(1/f)$ as a consequence $b=(1/f)$.
- $y=mx+b$ then becomes $(1/d_i)=(-1)(1/d_o)+(1/f)$
 - Rearranging the equation gives us $(1/f)=(1/d_o)+(1/d_i)$
 - This is called the Thin Lens Equation

Focus

- The lab is on finding focal length of convex lens; however the hidden agenda is to derive lens equation by graphing. Background information needed is the understanding of different types of graphs and how to extract information from graph. Topics to cover in graph: hyperbolic graph, real and imaginary images, linear graph equation, y-intercept. Object distance at infinity and object distance not at infinity; what does it mean? Group discussion once lab is ended.

LAB: Lens Properties

1. Both distances are measured to the lens.
2. Measure the distance from the lens to image, when the object is infinitely far (like a building or tree out of the window, where the rays are almost parallel). Call that the **focal distance** (or focal length), **f**, for *your particular lens* and record it in the space provided below.

f= _____

3. Call the distance from the lens to the object, **d_o**, and the distance from the lens to the image **d_i**.
(NOTE: some high school and/or colleges use **s_i** and **s_o**)

Data Collection:

So that we can compare the results with different lenses, place your object at **4f**, **3.5f**, **3f**, **2.5f**, **2f**, **1.75f**, **1.5f**, **1.25f**, **1f**, **0.5f**. If you cannot get an image at **1f** or **0.5f** get a hint from your teacher.

Case	Object Distance d_o	Image Distance d_i	Real/Virtual image	Upright/inverted (compared to object)	Larger/Smaller (compared to object)	Closer/Further (compared to object)
4f						
3.5f						
3f						
2.5f						
2f						
1.75f						
1.5f						
1.25f						
1f						
0.5f						

Analysis:

1. Plot **d_i** vs. **d_o**.
 - a. Is this graph linear? If not what shape does it appear to be?
 - b. What value does **d_i** approach as **d_o** becomes very large? Hint: does the graph appear to have a horizontal asymptote?
 - c. What value does **d_o** approach as **d_i** becomes very large? Hint: does the graph appear to have a vertical asymptote?
2. Plot **(1/d_i)** vs. **(1/d_o)**.
 - a. Does your graph appear to be linear?
 - b. Using spreadsheet program determine the slope of the line?
 - c. What is the physical significance of the **y**-intercept?
3. Write the mathematical equation of the linear graph using the form **y=mx+b**, substituting the appropriate values for **y**, **m**, **x**, and **b**. Then solve for **(1/f)**.

Lesson III Spectroscopy (90-120 minutes)

Main Topics

- 1. Science behind spectroscopy
- 2. Hertzsprung-Russell Diagram

Materials Needed

- Computers with internet access for each student
- Blank copy of the HR diagram

Instruction

- Have students log onto computer and copy and paste the following url address
 - <http://scope.pari.edu>
- Have students click on the “science” tab at the top of the page, and have them read through the section.
- Have the students click on the “classroom” tab at the top of the page, and have them read and complete the lab on HR diagram
- Have students figure out as much as they can on their own

Assessment

- Review lab with them when finished

Focus

- Each star has its own unique spectrum. The star’s spectrum act likes it finger print. Scientist and students can look at the spectrum of a star and place it in its particular place on the HR diagram. By looking at the HR diagram you can figure out a lot about that particular star.

Lesson IV Astronomy Connections (90-120 minutes)

Main Topics

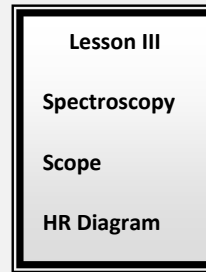
- 1. Optical Telescopes
- 2. Spectroscopy

Materials Needed

- Computer for each student

Instruction

1. Telescopes:



Telescope webquest: <http://telescope-web-quest.wikispaces.com/>

- a. How can we use optics to better understand object in sky? Discuss.
- b. Is optics limited to visible light only? Discuss.
- c. What is the importance of a smooth surface to lens or mirror? Discuss.
- d. What is the importance of size to a mirror or lens? Discuss.
- e. Properties of glass. Any limiting factors because of the properties? Discuss.
- f. Are there other ways to study the sky without optics? Discuss.

2. Spectroscopy:

Spectroscopy webquest: <https://sites.google.com/site/spectroscopywebquest/>

- a. How do scientists use the spectral line to indentify stars? Discuss
- b. Describe how a spectrum is formed.
- c. Are spectral lines limited to visible light?

Assessment

- Review the questions
- Go over the answers as a class

Focus

- How can we use lenses to better understand the universe
- How can we use spectrums to better understand the universe

Sources

"AP Central - Advanced Placement Scores, Courses & Exam Center | AP Central - APC Members Home." *HTML REDIRECT*. Web. 14 July 2011. <<http://apcentral.collegeboard.com/apc/Controller.jpf>>.

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PhET: Free Online Physics, Chemistry, Biology, Earth Science and Math Simulations. University of Colorado. Web. 14 July 2011. <<http://phet.colorado.edu/>>.

"Library." *ThinkQuest*. Web. 14 July 2011. <<http://thinkquest.org/pls/html/think.library>>.

Adjustments

- 1) Adding mirrors

- 2) Ray diagram for concave lens with object in front of focal length
- 3) Ray diagrams for mirrors