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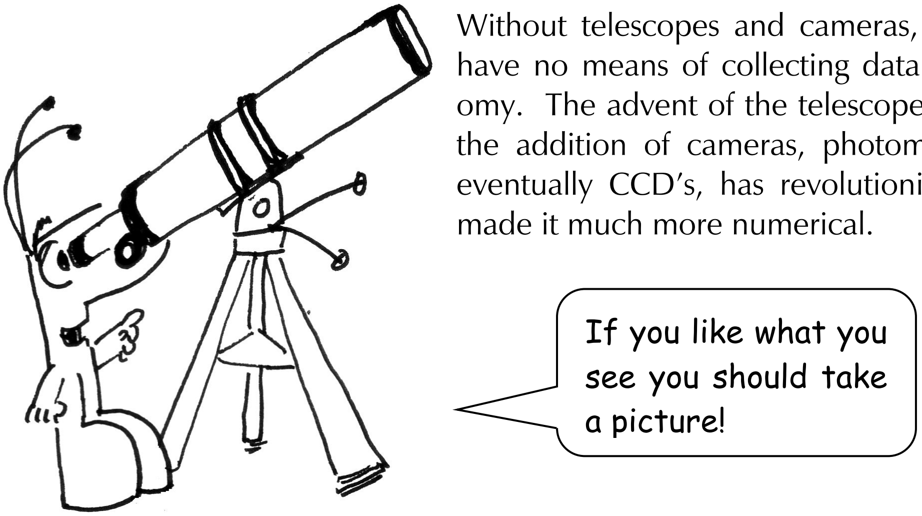
Conceptual Astronomy 2 Unit 1: Instrumentation



Without telescopes and cameras, astronomers would have no means of collecting data for modern astronomy. The advent of the telescope 400 years ago, and the addition of cameras, photomultiplier tubes, and eventually CCD's, has revolutionized astronomy and made it much more numerical.

Prior to these advances, much of extra-solar astronomy was **qualitative** (using comparisons and ratios). With the ability to measure brightness, color and position accurately and with consistency, the **quantitative** (based on measurement) story of stellar evolution and our place in the universe can begin to be understood. This unit is about the equipment astronomers use to collect light and measure it, known as **instrumentation.**

In this section we begin by studying reflection and refraction, and move on to telescopes and cameras. Reflection and Refraction are the basic principles of telescope functionality and are required to understand these important tools. Then basic telescope technology is shown, and the unit ends with an examination of what actually happens in a CCD camera.

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CA2 1.0: Instrumentation Objectives

By the end of this unit, students will be able to:

1. State the law of reflection and use it to predict the path of light rays that strike mirrors.
2. Use ray tracing techniques to find images in flat mirrors and concave mirrors.
3. State the law of refraction conceptually and use it to predict the path of light entering and leaving glass.
4. Understand how refraction is used to make convex lenses that can focus.
5. Find real images formed by convex lenses using ray tracing or the thin lens equation.
6. Describe images formed by concave mirrors and convex lenses in terms of their location, size, orientation, and nature.
7. Explain how to build a simple refracting telescope.
8. Discuss the most important characteristics of telescopes.
9. Compute the magnification of a telescope.
10. Compare and contrast several kinds of telescope designs.
11. Select telescopes based on the objective of the observer.
12. Understand what a CCD camera measures.
13. Define necessary vocabulary terms presented in this unit including:
    Aperture
    CCD
    Center of curvature
    Concave/Convex
    Eyepiece
    Focal length
    Focus
    Incident angle
    Law of Reflection
    Magnification
    Normal line
    Objective
    Pixel
    Real Image
    Reflected angle
    Refracted angle
    Resolution

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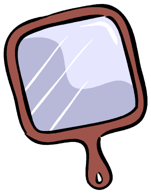
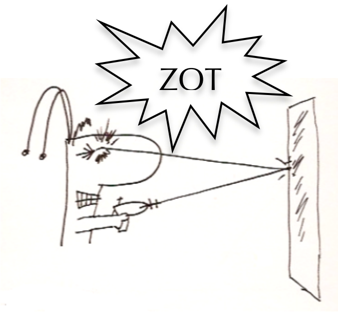
CA2 1.1: The Law of Reflection: Lab



Purpose: To observe the law of reflection in a plane mirror and in a curved mirror.

Materials needed: small low power laser, chalk erasers and chalk dust, flat mirror, concave mirror (such as a makeup mirror)

SAFETY PRECAUTION: Only use a small, low power, red laser pointer for these demonstrations. Do not point the laser at people's faces, or allow reflected laser light to hit faces. **Repeated or long-term exposure to laser pointer light is not good for your eyes.**



Procedure:
1. Set up the plane mirror flat on a tabletop, shiny side up. Using the chalk erasers, create a small amount of dust in the air. Shine the laser through the dust at the mirror. Observe the beam as it strikes the mirror and reflects. Sketch what you saw in the space to the right.

2. Is the angle the beam strikes the mirror equal to the angle it makes when it reflects?
____YES ____NO (check one)

3. This is called **The Law of Reflection**. Write the law of reflection here.

____

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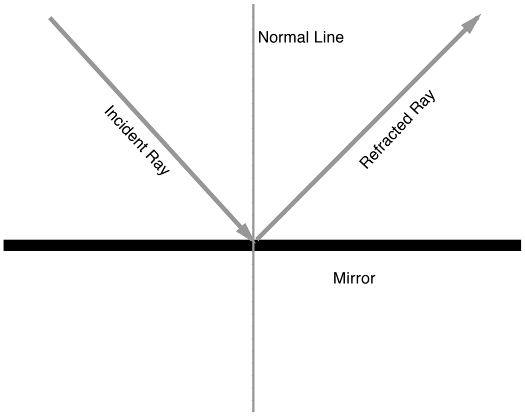
____

4. The diagram at right shows a technical version of what this looks like. The horizontal line represents them mirror. Notice the vertical line. The definition of the **normal** line is a line that is perpendicular to the surface of the mirror. Label it. The **angle of incidence** is the angle between the incoming beam and the normal. In the diagram, label this θ_i. (θ is a Greek letter called theta and is commonly used to represent angles.) The angle between the reflected ray and the normal line is known as the **angle of reflection.** Label this θ_r.



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CA2 1.1: The Law of Reflection: Lab

5. Write the formal law of reflection using math symbols and words.

Flat mirrors cannot **focus** light, or cause it to gather together in a single place. To focus light, needed to make a telescope function, we need to use a curved mirror. The best shape for a curved mirror is parabolic, because it has the property that all light approaching the parabolic mirror parallel to the axis of the parabola will, when the law of reflection is applied, converge on a single point called the focus.

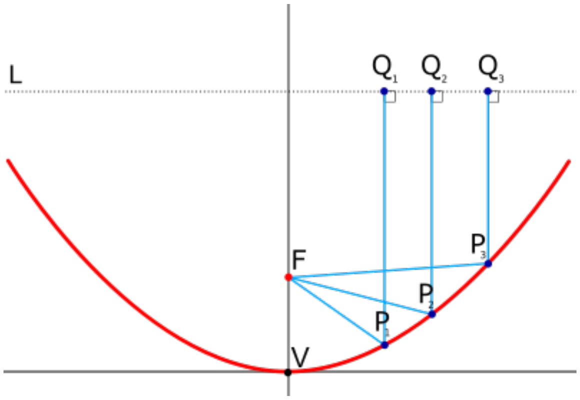

Figure 1. Image source: Wikipedia

In this diagram line segments QP represent light from a distant object, the parabola is shiny like a mirror, and F is the focus point where all the light meets. It turns out that each reflection point obeys the law of reflection for flat mirrors. In some telescope designs, the camera is located at point F.

6. Using the makeup mirror or concave mirror and some chalk dust, shine the laser at the mirror. Make sure the mirror is vertical on the desk. Aim the laser across the table at the mirror and move it back and forth to observe the light heading toward the focus. Sketch what you see here. Describe what you see. Are there any patterns?

7. What is the distance from this focal point to the surface of the mirror? This is called the **focal length** of the mirror.

Creating parabolic mirrors is difficult and expensive. It is somewhat easier to make a spherical mirror. If the radius of curvature is not too great, a spherical mirror behaves almost exactly like a parabolic mirror. In the next activity, we will investigate images formed by spherical mirrors.

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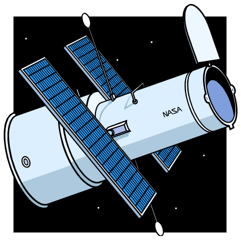
CA2 1.2: Ray Tracing and Image Formation in Concave Mirrors: Activity

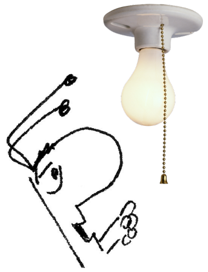


Purpose: To learn how concave mirrors can form images of extended objects.

Equipment needed: A ruler and pencil.

Background:
In this activity, we will use the rules we learned in the previous activity about the law of reflection and the rules for curved mirrors. The effects you observed in the previous activity can used to determine where images formed by the mirror will lie. These observations and exercises will show you how this works.

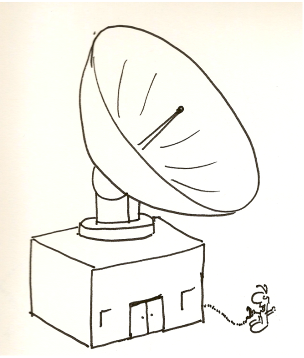
An object such the light as shown below emits light in every direction. Sketch rays coming off of this light bulb.



A mirror placed nearby can intercept *some* of the light. But which way will the light go after it hits the mirror? Predicting every path of every ray is difficult. However, there are two paths the light can take that are easy to predict.

To understand how a concave mirror can focus images of extended objects like planets or the moon, we will construct what is known as a **ray trace diagram.** A ray trace diagram follows the light in an optical system to show where images form.

The **principal axis** of the mirror is a line of symmetry starting from the center of the mirror, perpendicular to its surface. It is the line essentially along the direction you are "aiming" the mirror. Sketch the principal axis for this radio telescope (satellite dish) mirror.



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CA2 1.2: Ray Tracing and Image Formation in Concave Mirrors: Activity

In the previous activity we observed a curve mirror redirect a laser beam so it kept passing through a focus point. We're going to exploit that property and suggest the following rules:

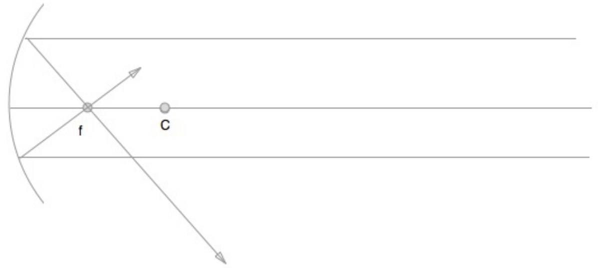
Rule 1: Rays approaching a parabolic mirror from a great distance, aligned with the axis of the mirror, will pass through the focus point.

Rule 2: Rays passing through the focus point of a curved mirror will reflect and follow a path parallel to the axis of the mirror.

We're going to use these rules to learn how to predict where the image of an object in front of the mirror will be.

1. A typical situation is shown at right. The **focal point**, or location where parallel rays converge after reflecting, is needed to solve these problems so that is shown. Point C refers to the **center of curvature** of the mirror that is exactly twice as far from the mirror as the focus point. Label the sketch to the right with these terms: mirror, principal axis, focus, center of curvature.

2. To see how the mirror works, we draw rays from a distant object approaching the mirror. The object is so far away; the incoming rays hardly diverge and appear parallel, heading in to the mirror and parallel to the principal axis. According to Rule 1, these rays will bounce off the mirror and pass through the focus point. Sketch this.



The intersection will show where the focus point is. Mark the focus point with an f.

The center of curvature of the lens is twice as far from the mirror as the focal point. Mark this spot with a C. Sometimes we call this point 2f.

3. This spot is where light from a distant source is concentrated. Such an arrangement might be used in a satellite dish or a solar water pre-heater assembly on a roof. If, on the other hand, we put a light bulb at the focus point, a beam is produced. What sort of technology is this arrangement used for?

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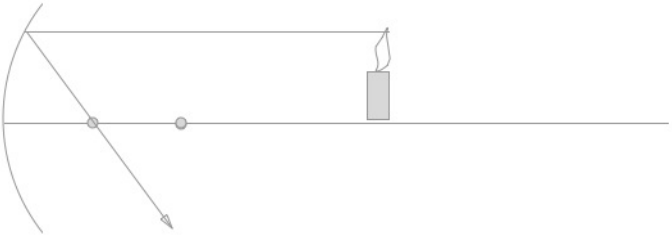
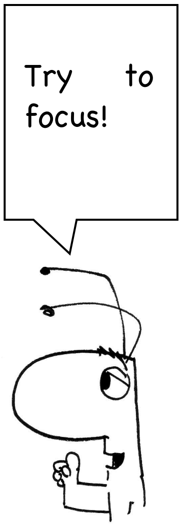
CA2 1.2: Ray Tracing and Image Formation

4. Now we turn to the situation where there is a relatively nearby object such as a candle. Light emanates from all directions from the candle, but some of it strikes the mirror. Some of it even approaches parallel, as before, and thus will pass through the focal point.

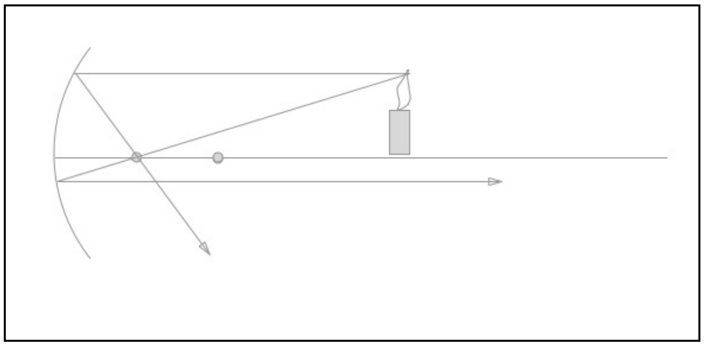
Sketch this. Place the candle (or object) to the right of the center of curvature.





5. According to Rule 2, light leaving the top of the candle will sometimes pass through the focus *before* hitting the mirror, and will therefore bounce back parallel to the principal axis. Sketch this in the box above, and include Rule 1 as well.

6. Since the light came from the top of the candle, the intersection shows where the image will be. The candle's image appears between the intersection and the principal axis. Because the mirror bounces the light downward, the image will appear upside down— between the principal axis and the intersection. In the diagram below, add the image of the candle.



In this particular example, the image appears to be smaller than the original object. That is not always the case. Depending on where you put the object, several different outcomes are possible. These will be investigated in the next activity.

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CA2 1.2: Ray Tracing and Image Formation in Concave Mirrors: Activity

Use this page to practice drawing ray trace diagrams.

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CA2 1.2.1: Curved Mirror Ray Tracing: Worksheet

Using ray tracing, find the images for these three situations. Describe each image in terms of its **size** (larger or smaller than the original object), its **orientation** (upright or inverted) and its position (called the **image distance**, measured from the mirror.) For each of the following draw a candle sitting on the principal axis (at positions >C, = C, and >f but at the same time <C). Then use ray tracing to find the image, and describe it.

1. Object > C.

2. Object = C.

3. Object <C, >f.

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CA2 1.2.1: Curved Mirror Ray Tracing: Worksheet

Questions:

4. Will a mirror with a long focal length appear to be deeply curved or nearly flat?

5. What other applications are there for curved mirrors besides telescopes?

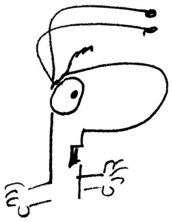
6. If the object is extremely far away, approximately where will the image form?

7. Will a mirror that is larger in diameter make a brighter or dimmer image?

8. Suppose a mirror with a focal length of 4 m is used to image the moon. Approximately where will it form an image?

9. Astronomers sometimes refer to mirrored telescopes as "light buckets." What do they mean by this?

10. Why is it dangerous to carry a large concave mirror around outside?



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CA2 1.3: Refraction: Activity

Materials needed: People, pencil, cup of water. Prisms and rectangles of glass and a laser (optional)

Purpose: To see the effect of refraction in glass and water and understand how a lens works.

Procedure:
1. Have you ever seen light make a thing appear to be bent? Try this. Put a pencil inside a glass of water. As seen from some angles, the pencil will appear to be crooked. Sketch what you see here.

This effect is known as **refraction**, or the bending of light. In this activity we will do various demonstrations to explain why light bends as it enters a transparent material.

The main reason the effect of refraction occurs is because *light slows down in a transparent material***.** This occurs because transparent materials consist of atoms that intercept the rays of light and make them stop temporarily, held in place by the atoms until they are released. Between the atoms, light travels at the speed of light—but its overall average speed is reduced because of the interruptions. This is just like a car that travels at 65 mph between gas stations on the freeway, but stopping for gas lowers the average speed.

The average speed of a car is less because it stops for gas once in a while.

To demonstrate this effect, try this. Form a group of 4 students and stand together shoulder to shoulder in a row, linking arms together. Lay a stick on the floor a few feet in front of you, representing a wall of glass. The students represent a **wave front** and the direction they are walking represents the direction a **ray** of light would move. As the students approach the air glass **interface** or junction between two transparent materials, they move at the speed of light. After they cross the line, they slow down.

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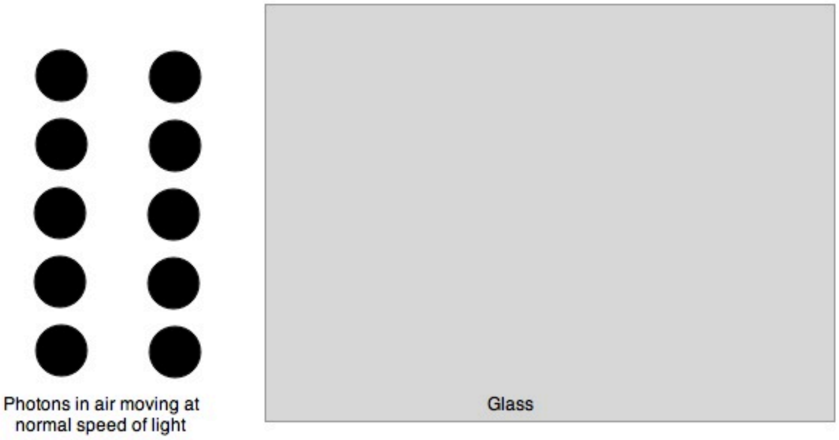
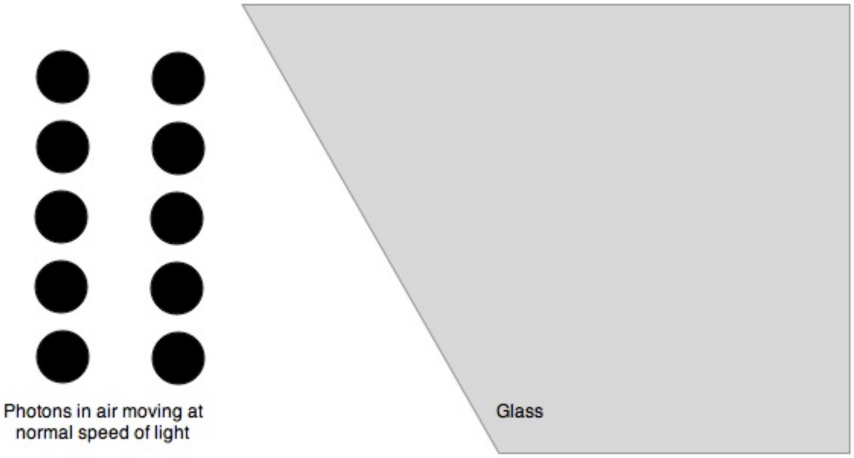
CA2 1.3: Refraction: Activity

2. In the illustration below, the circles represent people or photons of light. The second column represents the particles of light one nanosecond later as they approach the interface. Draw what happens to the photon-people after they cross the line into the "glass" and slow down.



3. Now try the demonstration again, this time with the interface at an angle as shown here.



If the students lined up in a row, representing photons, keep their arms linked, they will wind up changing direction. The same effect might occur if a marching band encounters a mud patch on one side. The band will slowly veer towards the mud because those marchers cannot maintain the same speed as the rest of the band.

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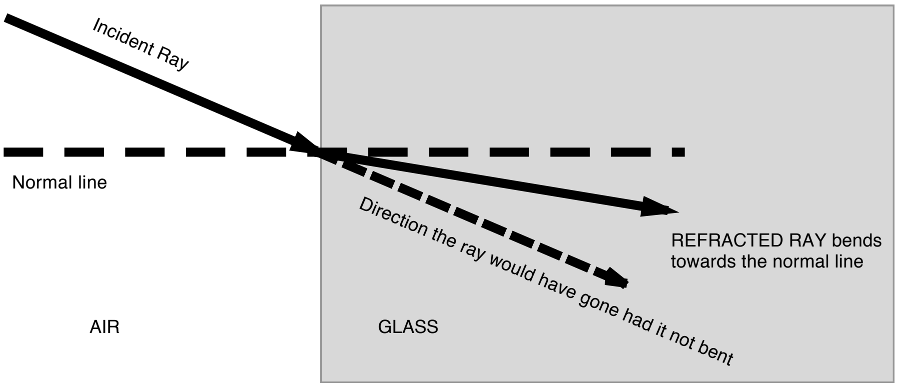
CA2 1.3: Refraction: Activity

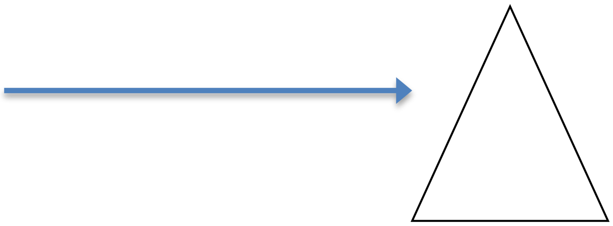
As the light ray approaches the interface, it will bend in a predictable way. As shown in the illustration below, *a ray at an angle, approaching a material with a higher optical density (which means it is thinner, with fewer atoms per cubic centimeter) will bend towards the normal line.*



4. The opposite effect is also true. If a ray at an angle approaches a material with a smaller optical density, what will happen?

Of course, a ray that approaches an interface at a right angle will not bend, because neither side is slowed down preferentially.

5. Now let us consider a triangle of glass, as shown. Using the refraction rules above, predict where the laser beam might go.



6. What would happen if the triangle were upside down?

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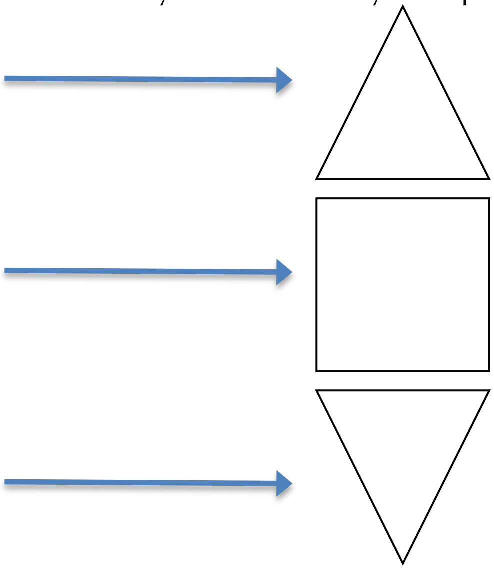
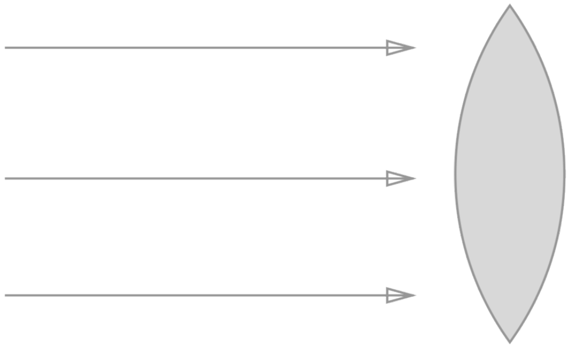
CA2 1.3: Refraction: Activity

7. Sketch where you think the rays will pass in the combined system below.



8. You may notice a resemblance to the shape of a magnifying glass, send from the side. This is known as a **double-convex or biconvex lens.** Such lenses can be used to construct telescopes and microscopes. If a continuously curving shape is used instead of triangles and rectangles, the focus will be more precise. In the sketch below, every ray approaching the lens parallel to its principal axis will wind up passing through the focus. Complete the sketch below to show this.



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CA2 1.4: Double-Convex Lens Ray Tracing: Activity

You may have noticed that the way light passes through a double-convex lens is exactly like the rules we discovered for concave mirrors. Because both devices converge light to a focus, they are equivalent optically. Everything a concave mirror can do, a double convex lens can do as well. The rules for mirrors are shown below. Rewrite them to apply to lenses. Note: light goes *through* a lens, and doesn't bounce back like it does for convex lenses.

Concave Mirror Rules

Rule 1: Rays approaching a parabolic mirror from a great distance, aligned with the principal axis of the mirror, will pass through the focus point.

Rule 2: Rays passing through the focus point of a curved mirror will reflect and follow a path parallel to the principal axis of the mirror.

1. Convex Lens Rules

2. What does it look like? Sketch rays following these rules below.

Questions:

3. Will a lens with a longer focal length than another be thicker or thinner in the center?

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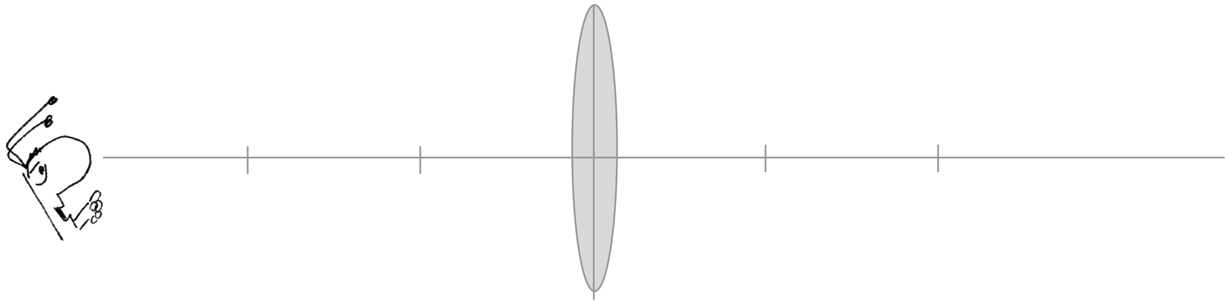
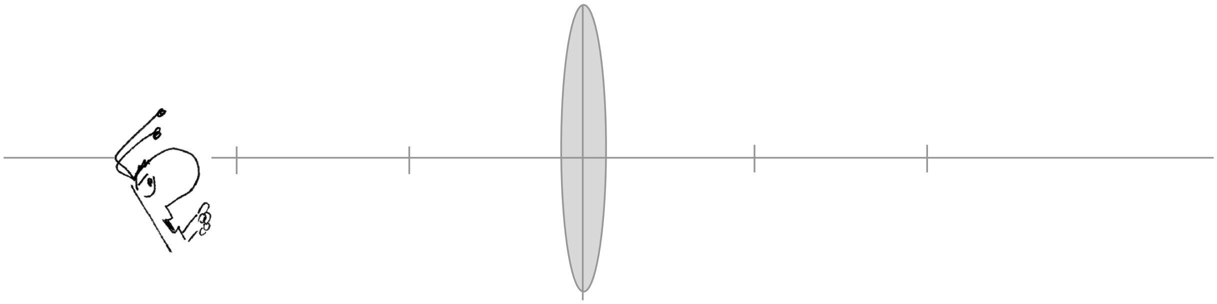
CA2 1.4: Double-Convex Lens Ray Tracing: Activity

4. What is the main difference in the rules for ray tracing for concave mirrors as opposed to convex lenses?

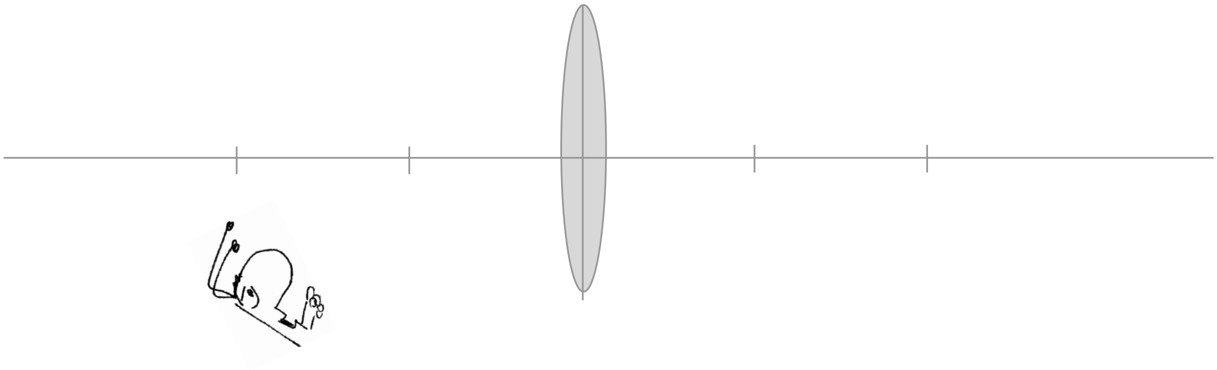
5. Recreate the three situations set up in the curved mirror worksheet. Draw the ray traces for each situation as shown below. For this one, place the object (candle) at >2f or >C. Cosmo is pointing to where you should draw your object (usually a candle.)



6. Place this object at C.



7. Place this object between f and 2f (C).



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CA2 1.5: Thin-Lens Optical Bench: Lab

Purpose: To show how double-convex lenses can make predictable images when the object is far away.

Equipment needed: Optical bench (meterstick, lens holder, small lamp or candle, candle holder, blank paper, double convex lens such as a magnifying glass)

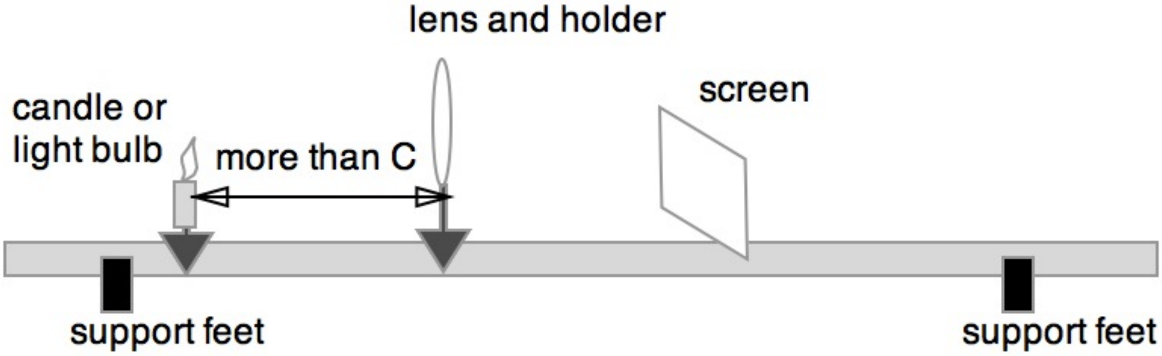
Precautions: If candles are used, students should remove baggy jackets, and tie back long hair. Open flames should be used with supervision and due caution.

Procedure

1. Measure the focal length of the lens you are using by using it to project a focused image of a distant light source (such as a window from across the room) onto the blank paper. When the image is sharp, the distance between the lens and the paper is the focal length. Record the focal length of your lens here. Use centimeters for this lab.

F =

2. Set up the optical bench as shown. Arrange the light source so it is somewhat farther than two times the focal length of your lens. Focus the light onto some blank paper on the other side of the lens. Move the paper until the image is sharp.



Measure the **image distance** (between the focused image on paper and lens):

Measure the **object distance** (between the lens and light source):

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CA2 1.5: Thin-Lens Optical Bench: Lab

3. While you have the equipment set up, try this mini-experiment. What do you think will happen if you cover half of the light source with your hand? Try it and see.

4. Use the **thin lens equation** to solve for f. Do not use the value of f from #1. We are attempting to see if we can get the answer two different ways, which is an important strategy in science. The thin lens equation is $\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$, where d_o is the object distance and d_i is the image distance, and f is the focal length.

5. Now draw a ray trace diagram *to scale* using the measured focal length and object distance, and see if the image distance produced is the same as what you measured in #2.

6. Your teacher may ask you to repeat the lab with different object distances. Record these measurements on your own paper.

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CA2 1.5: Thin-Lens Optical Bench: Lab

Questions

7. Why is the image always inverted?

8. In what everyday technology are lenses used to make small images of distant objects besides telescopes?

9. The light through the lens is reversible. That is, you can place an object where the image was and it will create a larger image far away from the lens. What commonplace piece of technology uses this arrangement?

10. What effect do you think that diameter of a lens would have on the brightness of an image?

11. Suppose you put a light source at the focus point. What kind of image or pattern is formed?

12. One main purpose for convex lenses is for magnifying glasses. Use yours to look at something in the traditional way and answer this question: Where is the object in terms of the focal length? Describe the image you see compared to the object.

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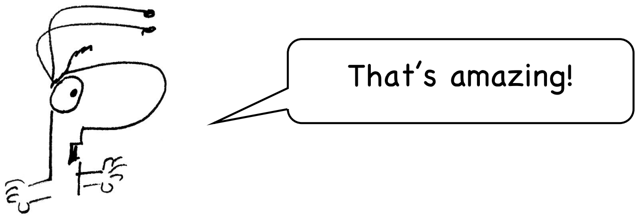
CA2 1.5: Thin-Lens Optical Bench: Lab

Going Further

13. Try designing a homemade camera or projector with a magnifying glass. If you draw a small picture on a piece of transparency, then light it from behind, the magnifying glass can be used to project the image onto a wall in a darkened room.

14. To make a primitive camera, put the lens at the end of a box and put a sheet of thin white paper at the other end. Adjust the distance from the lens to the paper until an image of a distant bright object is focused. Then you can trace the image on the thin paper. This was how portraits were sometimes painted before the invention of photographic film.



15. Try using the magnifying glass from a distance closer than f, as it was intended. You will not be able to focus the light on a screen. Additionally, when you look through the lens, the image will not be inverted. It will be larger and **virtual**. Try to learn to draw virtual image ray traces. (*Hint: you already did one, with the flat mirror activity.)

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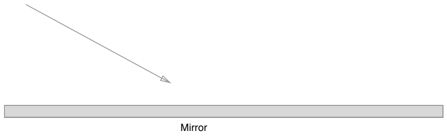
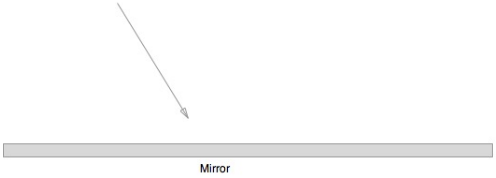
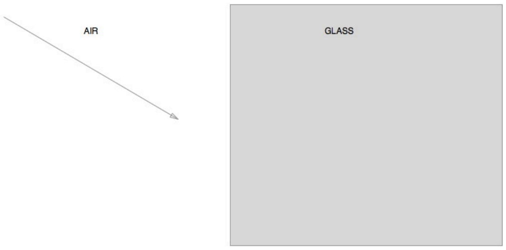
CA2 1.6: Reflection and Refraction: Activity

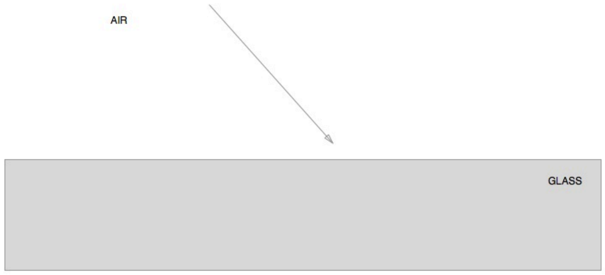
1. Predict (by sketching) which way you think these rays will go when they hit the mirror shown. Label the normal line, incident and reflected rays.





2. Predict (by sketching) which way you think these rays will go when they pass through the transparent interface. Show the normal line, the incident angle and refracted angle.





3. Ray tracing for curved mirrors.

Draw the ray trace diagram, finding the image, for the situations shown on the next page. Describe the image in words: Larger/smaller than the original object, upright/inverted, and image distance compared to object distance.

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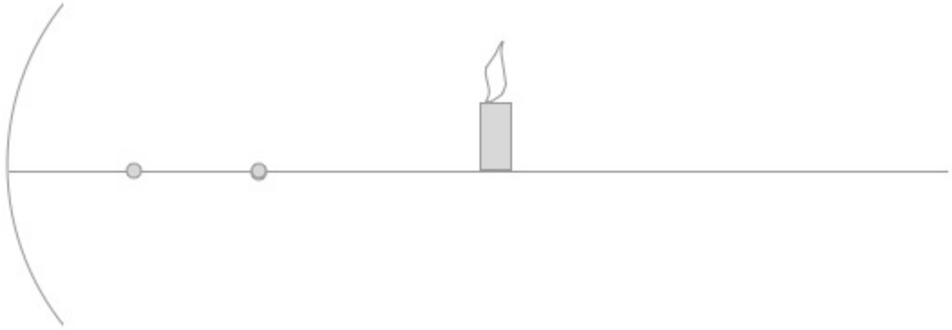
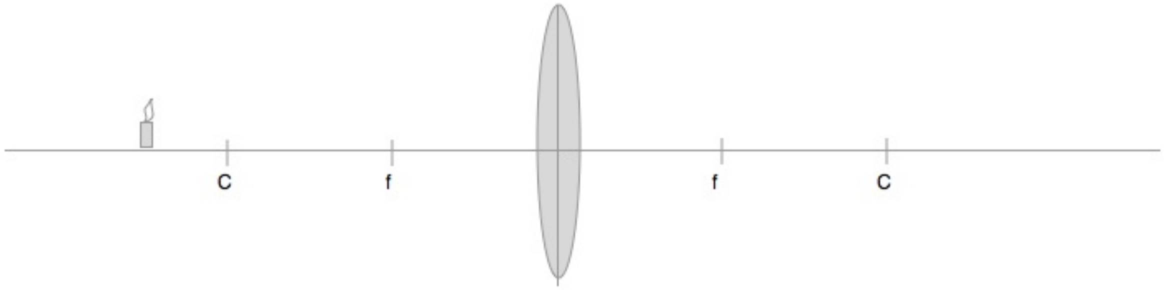
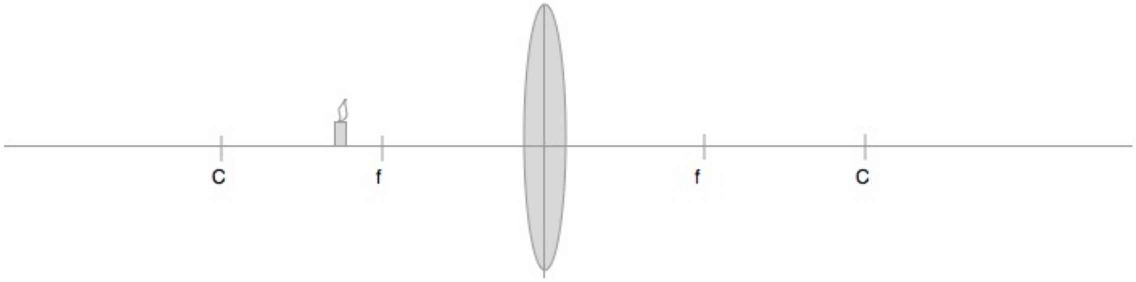
CA2 1.6: Reflection and Refraction: Activity



4. Ray tracing for convex lenses.
Draw the ray trace diagram, finding the image, for the situations shown. Describe the image in words: Larger/smaller than the original object, upright/inverted, and image distance compared to object distance.





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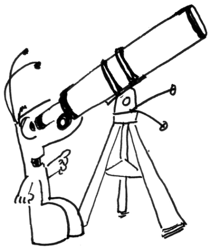
CA2 1.7: A Small Optical Bench Telescope: Lab

Purpose: To build a simple telescope with lenses and investigate its properties.

Materials needed: Two convex lenses of different focal length, resolution target, and magnification target.

Procedure:
1. Find the focal length of the two lenses and determine which one is longer. Record the method, and the values you obtained, in the space below.



2. Hold the lens with the longer focal length in one hand, extended away from your face. This one is closer to the object you are observing, so it is called the **objective.** Hold the lens with the shorter focal length near your face, as shown in the illustration. This one is closer to your eye so it is called the **eyepiece.** Look through both lenses at once, and adjust the distance between them until the view is clear and sharp. (Hint: the distance between the lenses will be approximately the sum of the focal lengths when the image is focused.)

This is a simple telescope. Describe the image below, as compared to what you see without the telescope.

3. The **magnification** of a telescope is how many times larger the image appears than what your eye can see. To *calculate* the magnification, use the formula

$$M = \frac{-f_o}{f_i}$$

Where f_o is the focal length of the objective and f_e is the focal length of the eyepiece.

Calculate the magnification of your primitive telescope and write it in the space above.

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CA2 1.7: A Small Optical Bench Telescope: Lab

4. To *observe* the magnification of your telescope, look at the magnification target printed in your workbook. The idea is to look at the grid with the telescope and compare it to the grid you see without the telescope. With practice, you can use double vision to do the comparison. Use one eye to look at the grid with the telescope, while *leaving the other eye open* to see the grid without the telescope. If you keep both eyes open, you can see both grids at once, and compare how many of the small boxes (seen with the unaided eye) fit in one of the large boxes (seen with the telescope-eye). The ratio should be approximately equal to the magnification you observed already.

Observe the magnification grid on the last page of this activity, and describe whether or not the magnification you see is similar to what the formula predicts.

5. Telescopes also make images brighter. Larger lenses can concentrate more light, and therefore yield brighter images. To show this effect, look at something bright inside a darkened room with your handheld telescope. (Recall in the optical bench lab, the projected image got dimmer when we covered half of the lens. It didn't cut the image in half.) While looking through your telescope have a partner cover half of the objective lens with their hand or a piece of paper. You should be able to see a complete picture, but dimmer than before. What this tells us is that brightness depends on surface area of the lens, and the surface area depends on the diameter, so the wider the telescope lens, the brighter the image.

Suppose a telescope has twice the diameter of its objective than another. How many times brighter will the image be?

6. Telescopes also enable us to see more detail than the eye can see alone. To see this effect, hang up the resolution target across the room and ask yourself: at what numbered level do the lines appear to merge together, showing no space between them?

Now observe the target with your homemade telescope and answer the question again. Telescopes allow you to see more detail than the human eye can perceive alone.

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CA2 1.7: A Small Optical Bench Telescope: Lab

7. If a commercially available telescope is available, or a pair of binoculars, use those and compare the results to what your homemade telescope saw. Describe the differences below.

8. f/ratio. The f/ratio of a telescope is determined as follows.

$$f\,/\,ratio = \frac{f_o}{aperture}$$

Equation for finding f/ratio

The *aperture* is the diameter of the objective lens. What is the aperture of your bench telescope?

9. What is the f/ratio of your bench telescope? (show your work below)

10. If a telescope or camera lens has a small f/ratio (e.g. 3, 4, 5, 6) it is called a *fast* lens. It creates small, bright images that require short exposures to complete images. Telescopes and cameras with a large f/ratio (e.g. 9, 10, 11) make larger images, but take more time to expose the images because they are dimmer. Thus they are sometimes called *slow* lenses. Is the optical bench telescope you constructed *fast* or *slow?*

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CA2 1.7: A Small Optical Bench Telescope: Lab

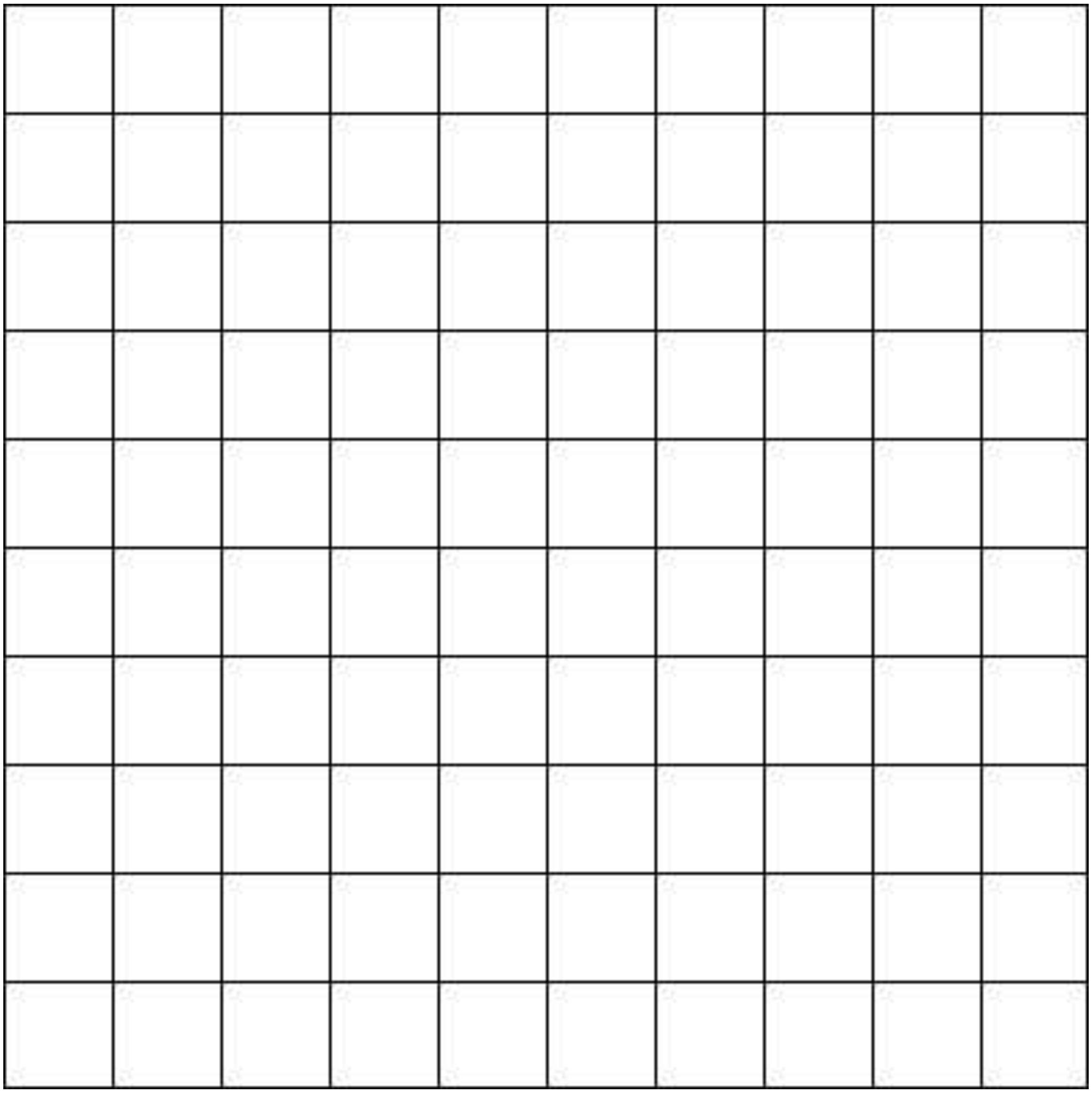

Figure 1. Magnification Grid.

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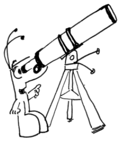
CA2 1.8: Telescope Types: Activity



Purpose: To investigate the different types of telescopes and
learn which are best for a specific purpose.

Materials needed: Various types of telescopes, if available. Computer with internet access.

Background:
For each type of telescope mentioned, use the internet or the example telescopes provided to describe it and tell about its advantages and disadvantages.

1. **Refractors.** Galileo first built his refracting telescope in the early 1600's. Refracting telescopes use only lenses. The telescope you constructed for the optical bench telescope is a refractor. In a refractor, the tube is about as long as the focal length of the objective, which is typically much longer than the focal length of the eyepiece. Draw a picture of a refracting telescope that shows how the light passes through it.

What are the advantages and disadvantages of this design?

____

____

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2. **Newtonian Reflectors.** Isaac Newton designed a reflecting telescope to overcome some of the problems with refracting telescopes. Instead of using lenses, Newton's design used a curved piece of metal (today, we use glass) to reflect the light to secondary mirror. The secondary mirror reflects the light sideways, out the side of the tube, near the large opening at the top. Thus the tube is approximately as long as the focal length of the mirror.

On the next page, sketch a picture of how the light goes through a Newtonian. Label the **primary mirror** and the **secondary mirror** as well as the location of the eyepiece.

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CA2 1.8: Telescope Types: Activity

What are the advantages and disadvantages of this design?

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3. **Cassegrain.** Cassegrain developed a telescope that took advantage of the fact that the secondary mirror in a Newtonian telescope blocks the light. Therefore the center part of the reflecting mirror is not used. To make the telescope easier to use, Cassegrain drilled a hole in the primary mirror and made the light bounce from the secondary through the hole, putting the observer (and cameras) at the bottom of the telescope rather than the top. This essentially folds the telescope in half, making the tube much shorter than the Newtonian design. Sketch a picture of how the light goes through a Cassegrain telescope below. Label the **primary mirror** and the **secondary mirror** as well as the location of the eyepiece. In some Cassegrain designs a corrector plate adjusts for some aberration caused by using a spherical mirror instead of a parabolic one. That particular design is called a **Schmidt-Cassegrain.**

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CA2 1.8: Telescope Types: Activity

What are the advantages and disadvantages of this design?

4. **Prime Focus.** A **prime focus** telescope has no secondary mirror but places the observer (and/or the camera) at the focal point. Satellite dishes and radio telescopes often use this design. Extremely large telescopes may use this design, such as the 200-inch telescope at Mt. Palomar. The more reflecting surfaces a telescope has, the more light is focused by the mirrors. Having only one primary mirror reduces the amount of signal lost. Sketch how such a telescope focuses light or radio waves.

What are the advantages and disadvantages of this design?

5. **Coude'.** A **Coude'** telescope focuses light off-axis so the secondary mirror does not block the light striking the primary. In other words, it is tilted with respect to the principal axis, and you do not point the mirror directly at the target like you would with an ordinary telescope. Otherwise, it is similar to a Cassegrain design. Some satellite dishes use this design for the same reason. On the next page sketch a pictures of a Coude' telescope's light path. Again, label the primary mirror.

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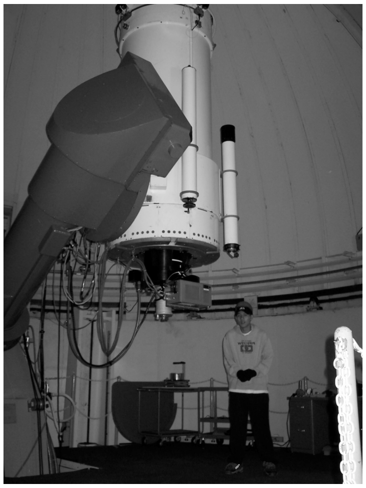
CA2 1.8: Telescope Types: Activity

What are the advantages and disadvantages of this design?

6. Which type of design do you think is illustrated in each picture below? How can you tell? (All photos by the author.)



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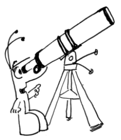
CA2 1.9: Comparing Telescopes: Activity



Purpose: To compare several telescopes and judge which is best for each purpose.

Materials needed: Several telescopes of differing design *or* several copies of advertising for telescopes in magazines such as *Astronomy* or *Sky and Telescope*. Online advertisements can be used from such sites as *telescope.com* (Orion Telescopes) or *telescopes.com* (a different vendor).

Procedure: Compare several telescopes either in person at a star party, in the classroom, or by reading advertising in an astronomy-related magazine or online. Telescope specifications can be found at Celestron.com, Meade.com, and other places. Complete the table below, using the instructions.

Type: Respond with **Galilean** (refractor), **Newtonian**, Dobsonian (essentially an inexpensive or homemade Newtonian), **Cassegrain** or **Schmidt-Cassegrain**, **Coude′**, or **Prime Focus**. (The last two would be unusual in backyard or school telescopes.) Other types exist, and if you cite them you should describe them.

Aperture: This is the diameter of the primary lens or mirror. This will usually be the first thing an ad says about a telescope. It if is not printed on the ad or real telescope you are using, you can measure it with a ruler. Often astronomers refer to different telescopes only by their aperture as in "tonight I will be using the 100-inch telescope to photograph asteroids."

A Newtonian Telescope with a German equatorial mount.

Focal length: In a refractor or Newtonian telescope, this is about as long as the tube. If it is not given in a telescope, you can compute it from the aperture and the f/ratio.

F/ratio: Usually given in an ad, but can be calculated from focal length and aperture.

Magnification with a 25 mm eyepiece: Since eyepieces can be changed easily, the best way to compare telescopes is to use the same eyepiece. Compute the magnification using the focal length of the objective and a 25 mm eyepiece.

Mount: The mount of a telescope is very important. A telescope which is not steady cannot be used no matter how good the optics.

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CA2 1.9: Comparing Telescopes: Activity

- Mounts can be motorized, computerized, or manual. A computerized mount can be directed with a telescope or control pad. In addition the structure of the mount can be one of the following:
- **Alt-az**: The telescope only can turn left and right, up and down, and without a computer, cannot easily follow the stars.
- **Equatorial**: This telescope is designed to follow the sky and has a tilted axis that can point to the North Star.
- **Fork**: Fork mounts hold the telescope on both sides. They are very stable and are often used in reflecting telescopes.
- **German Equatorial**: This design has an axis that points to the North Star and another that is perpendicular to that. These axes are mounted without a fork.

Special features: Special features include unusual finder scope technology such as lasers or reflex sights, computer control, cameras, moon filters, and so on.

Limiting resolution: **Resolution** can be theoretically computed using the equation $R=144/D$, where D is the aperture size in millimeters and R is the resolution or the smallest separation that can be seen as separate objects, measured in arcseconds. Earthbound telescopes cannot usually exceed a resolution of 0.1 arcsecond due to the Earth's atmosphere. Any answer smaller than 0.1 should be rounded up to 0.1. Smaller values are sharper images.

Describe Telescope				
Type				
Aperture				
f/ratio				
Focal length				
M with 25 mm eyepice				
Mount				
Resolution				
Special features				

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CA2 1.9: Comparing Telescopes: Activity

1. In your opinion, which is the best telescope for viewing planets, and why?

2. Which telescope would be best for viewing large, dim galaxies?

3. Which telescope is easiest to carry around in your car for observing in a dark sky location?

4. Which telescope yields the brightest images?

5. Which telescope yields the sharpest images?

6. Which telescope will take images in the least amount of time?

7. Which telescope will yield the largest images with a 25 mm eyepiece?

8. Which telescopes are computerized, if any?

9. Suppose you had $2000 to buy any telescope you wanted (and nothing else more important that the $2000 would be spent on instead). What kind would you spend it on and why?

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CA2 1.9: Comparing Telescopes: Activity

10. On this page consider analyzing an advertisement for 3 different telescopes. List the features of each telescope, and decide which one is the best one for a particular purpose. (Pick one: observing planets and moon, deep sky visual observing, or astrophotography.) Advertisements can be found online or in issues of *Sky and Telescope* or *Astronomy* magazines as well as photography magazines in some cases.

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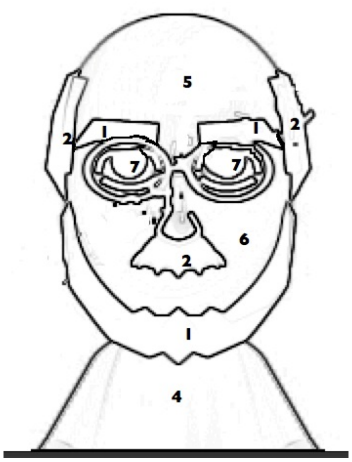
CA2 1.10: Digital Camera Images Color by Number: Activity

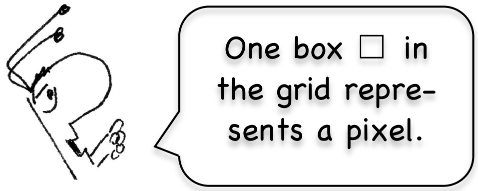


Purpose: To investigate how CCD cameras convert light into digital images.

Equipment needed: 5 colored pencils

Background and Procedure: Did you color-by-number when you were young? No? (Ask your parents.) Before computer-based art programs, children would sometimes paint pictures using a black-and-white drawing of an image labeled with numbers as shown here. Using colored pencils or crayons, children would fill each number with a corresponding paint color from a set of paints accompanying the drawing; 1 = black, 2 = grey, etc.

Today's digital cameras use **charge-coupled devices** (CCDs) which consist of millions of individual light sensors that essentially count the photons of light that hit them. Once collected, the computer converts these numbers into a picture. But how are the numbers converted? To find out, you will be doing something you haven't done in a long time. You will be coloring!



Look at the image on the next page. Each box contains a number that tells how many photons fell on that particular digital sensor. We call these individual brightness measurements **pixels** (picture elements). Your task is to color them in. But…there's a catch. (Isn't there always?) The catch is you will not have enough colored pencils to color all the numbers differently. So you will have to pick *ranges* that will be represented by different colors.

1. Look over the table carefully and find the largest number in the table. Write it here. ___

2. Look over the table carefully and find the smallest number in the table. Write it here. ___

3. In the table that follows, designate ranges of numbers to be represented by colors. For example, you could simply divide the range of numbers evenly by 5 and assign 1/5 of the range to each color. Or you could decide to make 1-500 one color, and divide the remaining colors unequally. It's up to you. Propose a coloring scheme in the table on the next page.

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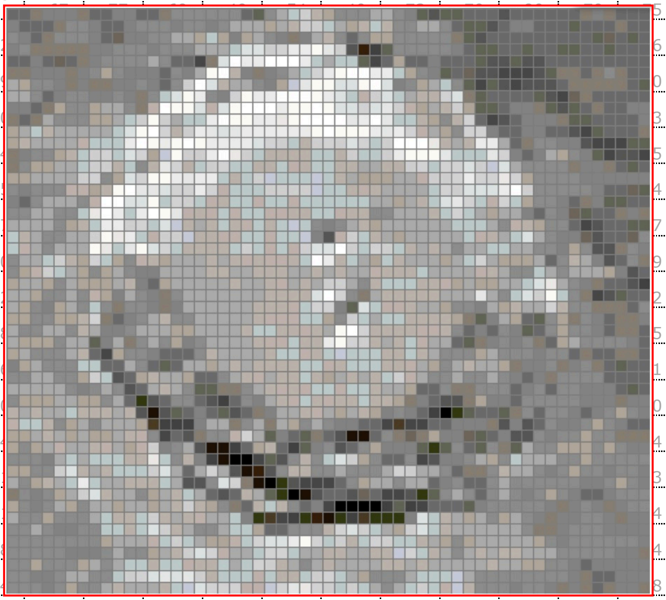
CA2 1.10: Digital Camera Images Color by Number: Activity

]Color					
Range					

\4. Now color your picture according to the scale.

5. What do you think the picture represents?
Choose one: Planetary nebula, crater, Saturn, space probe, edge-on spiral galaxy.



146	161	147	144	137	137	126	137	109	68	78	115	99	114	139	150	172	174	166	161	166
141	152	139	137	118	94	104	70	97	83	55	136	163	135	135	135	156	177	167	169	169
140	125	139	136	153	111	31	82	70	52	65	41	100	92	140	157	166	185	191	190	162
140	140	139	131	60	51	95	66	64	26	10	52	36	77	102	79	123	179	180	180	185
114	100	101	35	48	56	13	10	17	4	2	29	31	52	84	103	72	179	166	141	161
91	86	17	21	36	22	30	29	40	53	30	28	39	28	34	75	93	61	150	139	153
68	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	91	61	30	42	65	59	86	145	116
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	88	99	95	61	44	48	26	105	135
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100	108	96	71	55	89	84	135	139
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	83	99	101	100	85	85	98	80	137
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	83	73	96	94	104	84	92	109	144
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	99	80	81	90	98	88	110	84	30
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	90	80	86	94	118	94	98	75	14
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	79	80	81	81	134	157	118	172	67
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	75	86	81	110	153	119	137	138	75
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	85	74	88	125	105	109	128	148	68
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	84	96	137	164	151	127	153	136	75
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	127	170	178	198	170	154	162	164	67
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	157	139	156	159	152	164	161	139	69
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	125	122	123	141	146	118	100	109	61
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	132	159	152	155	134	151	118	137	57
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	232	205	147	124	135	128	116	137	70
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	69	84	64	89	108	101	102	116	67
120	118	108	89	73	66	90	78	62	103	91	95	96	77	80	96	109	91	92	98	58

6. Compare your picture to your classmates. Can you see details in yours not in theirs, or vice versa? Describe them.

____

____

7. How could we improve the detail in the image without using more pixels?
____

____

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CA2 1.10: Digital Camera Images Color by Number: Activity

8. How many “pixels” are in this image?

9. How many pixels would be in an image 1000 pixels wide and 1000 pixels tall?

Going Further

Consider purchasing a paint-by-number kit and

- Using a different color palette than the one in the instructions
- Leaving parts of the painting unfinished to show others how it works
- Creating a paint by number for astronomical objects
- Using a photo of an object and converting it to a paint by number as in this activity to share

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CA2 1.11: Using Image J in Astronomy: Activity

Purpose: To learn how to use basic image processing software for later use in labs and activities

Equipment needed: Working copy of Image J software; astronomy plug-in; computer

Background:

Image J is a free program available for multiple platforms and used for measuring and manipulating digital images. It was originally developed as a program for doing brain scans at the National Institutes of Health, but is now used for a variety of purposes including astronomy. It is available from http://rsb.info.nih.gov/ij/, and includes documentation and a variety of plugins including the Astronomy plugin package located here: http://www.astro.physik.uni-goettingen.de/~hessman/ImageJ/. The software installers and plugins should also be available on your teacher's resource disk that came with this book.

A complete tutorial on how to use Image J for astronomy is located at this web site: http://www.astro.physik.uni-goettingen.de/~hessman/ImageJ/Book/index.html

The activity in this workbook is just an introduction to a few specific skills you will need for this course.

Purpose: To learn how to open and measure basic quantities in digital imaging software such as Image J.

Procedure:

1. Open Image J. You should see a button bar that looks like this:

Paintbrush Tool

2. Use the File menu to open the sample image sample.fits. Do not double click on the file in your operating system. What do you think the image is?

The most commonly used commands in this course are listed below. Try each one and tell the result after the item listed.

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CA2 1.11: Using Image J in Astronomy: Activity

Straight line selections (right click for other types)

3. Use the **straight line selections tool** to draw a line across the crater's diameter. The length will be displayed under the buttons as you go. Once you let go of the mouse, the measurement will disappear. What is the diameter of the crater in pixels?

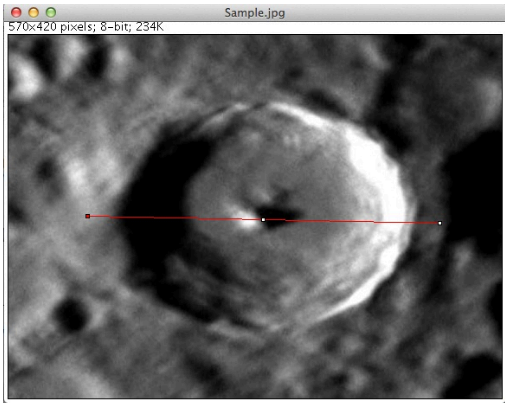

Figure 1. Picture courtesy of Jim Scala.

4. Perform a **plot profile** (Analyze>Plot Profile) across the crater, and sketch it here. Explain what you think the peaks and valleys represent?

5. Open the sample image sample2.fits. This image was used in an activity called Supplementary Activity 14 in the Hands-On Universe astronomy program (http://www.hou.lbl.gov) and is used with permission. What do you think this picture represents?

6. Use the astronomy plug-in "Aperture" under the Astronomy menu. (Information on how to install and access this plug-in is in Appendix CA2 A-7.) Click on one of the stars. A data table will appear where the total brightness enclosed by the innermost circle you see is displayed. Record the value you obtained here.

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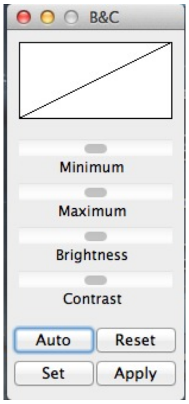
CA2 1.11: Using Image J in Astronomy: Activity



7. To make images easier to see, use the Image>Adjust>Brightness and Contrast command. Click "Auto" several times to see the effect on the image. You can also manipulate the settings manually. Describe the difference in the image.

8. You can zoom in and out to make the picture larger and smaller. Use the magnifying glass tool to zoom in. Click it, and then click on the area to zoom in. Press shift and click on an area to zoom back out.

Magnifying glass (or use "+" and "-" keys)

If you zoom in too much, what happens to the image?

9. If you point to a particular pixel on the screen, a number appears on the button bar. This tells you the pixel value underlying that particular pixel. It also tells you the x, y coordinates within the image. Go to 100, 74 and find out the pixel value there. Record it here:

10. Image J can do many other things such as measuring angles and areas, combine images to form color pictures, animate stacks of images to create videos, and more. Try to use the online tutorials mentioned at the beginning to learn at least one or two more interesting skills.

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CA2 1.12: Instrumentation: Application

1. The world's largest telescopes have approximately a 10-meter diameter. Calculate the surface area of the mirror.

2. Compare this to the area of a typical 10-inch mirror used in a backyard telescope. Convert the inches into meters, find the area, and compare to #1 by dividing and finding the ratio.

3. Suppose the large 10 meter telescope is an f/6 telescope. Compute the focal length.

4. Such telescopes do not usually use eyepieces because they are meant for use with cameras. But just for fun, what if a 50 mm focal length eyepiece were used with such a giant telescope…what would the magnification be?

5. If the mirror were used to focus light from a nearby lighthouse, located 400 meters from the telescope, where would the image of the lighthouse form?

6. What kind of telescope is this?

7. Suppose you take a picture with the backyard telescope that exposes the camera for 100 minutes. How long would it take to expose the same picture to get just as much light for the larger telescope? (Assume the same f/ratio.)

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CA2 1.12: Instrumentation: Worksheet

8. How big a building would be required to hold such a telescope? How many stories tall would it be? Assume a story is 3 meters tall, and the telescope design is Newtonian. Is this a good choice for the telescope design?

9. When observing the moon, astronomers using the telescope note the image is too bright; they cannot take pictures of it with the camera they have. So they cover the aperture with a **mask**, that covers most of the telescope's diameter except for a small circular hole. Describe what this does to the telescope's

a) focal length
b) f/ratio
c) image brightness
d) magnification

10. An astronomer often uses the technique of "mosaic" imaging, where several CCD chips are used to create a much larger imaging area. How many pixels are in an image from 4 CCD chips each with an area of 1000 x 1000 pixels?

11. Explain why all digital images are essentially color by number.

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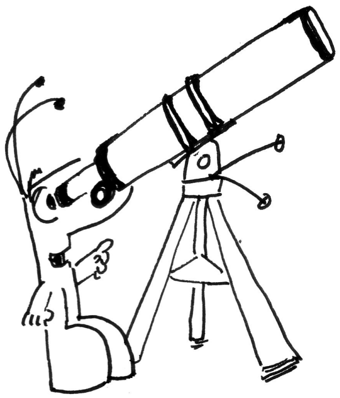
CA2 1.13: *Instrumentation: Puzzle*

Fill in the terms at the bottom of the puzzle. Then write the same letter in the box with the corresponding number. A quotation or phrase will be spelled out in the grid at top.

1	2	3		4	5	6	7	8	W		9	10	11	12		13	14	15	
16	17	18		19	20	21	22	23		24	H	25	26	D		H	27	28	
29		30	31	32	33	34	35	36	37	38		39	40	41		42	43	44	'
45		M	A	K	46		A	47	Y	48	49	D	Y		B	50	51	52	53
54	55		H	56		H	A	57		58	N	59	-	W	60	61	L		62
M	63	T	H																

1.	_ 1	_ 3	_ 6	_ 5	_ 16	_ 13	_ 8	_ 37	_ 17				MEANS "FAR-SEEING"; TUBE WITH 2 LENSES
2.	_ 36	_ 39	J	_ 18	_ 35	_ 9	_ 52	_ 54	_ 20				CLOSEST TO THE OBJECT
3.	_ 25	_ 19	_ 31	P	_ 60	_ 33	_ 42	_ 38					CLOSEST TO THE EYE
4.	_ 4	_ 49	C	_ 11	_ 7	_ 32	_ 46	_ 15	G	_ 12	_ 2		DISTANCE BETWEEN FOCUS POINT AND LENS
5.	_ 14	P	_ 50	_ 22	_ 30	_ 40	R	_ 53					DIAMETER OF OBJECTIVE
6.	R	_ 55	_ 23	_ 58	_ 51	U	_ 41	_ 63	O	_ 44			SHARPNESS OF IMAGE
7.	C	_ 21	_ 28	_ 34	_ 56	G	R	_ 24	I	_ 47			HAS A HOLE IN CENTER OF OBJECTIVE MIRROR
8.	P	_ 26	R	_ 27	_ 48	O	_ 61	I	C				SHAPE OF TELESCOPE MIRROR FOR BEST FOCUS
9.	C	_ 10	_ 29	R	G	_ 59							COUPLED DEVICE; USED IN CAMERAS
10.	_ 57	P	E	C	_ 45	R	_ 43	_ 62	C	O	P	E	USED TO SEE COLORS



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CA2 1.13: Instrumentation: Puzzle

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