   

Course Materials

PHYS/ASTR 1040: Elementary Astronomy
Instructor: John C. Armstrong
Course Web Page: weber.edu/jcarmstrong

   

Activities

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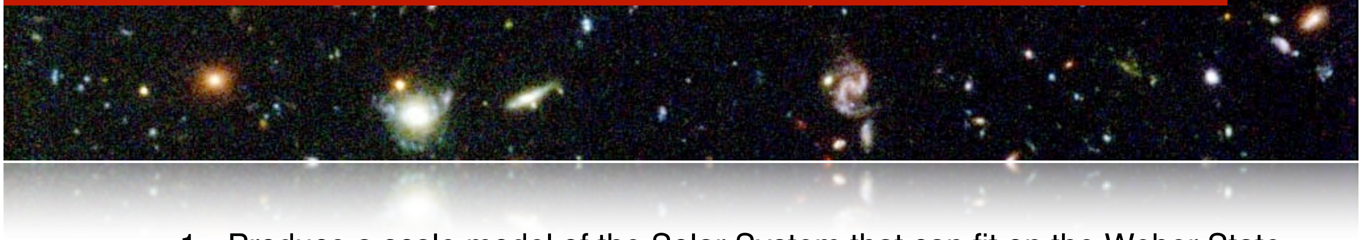
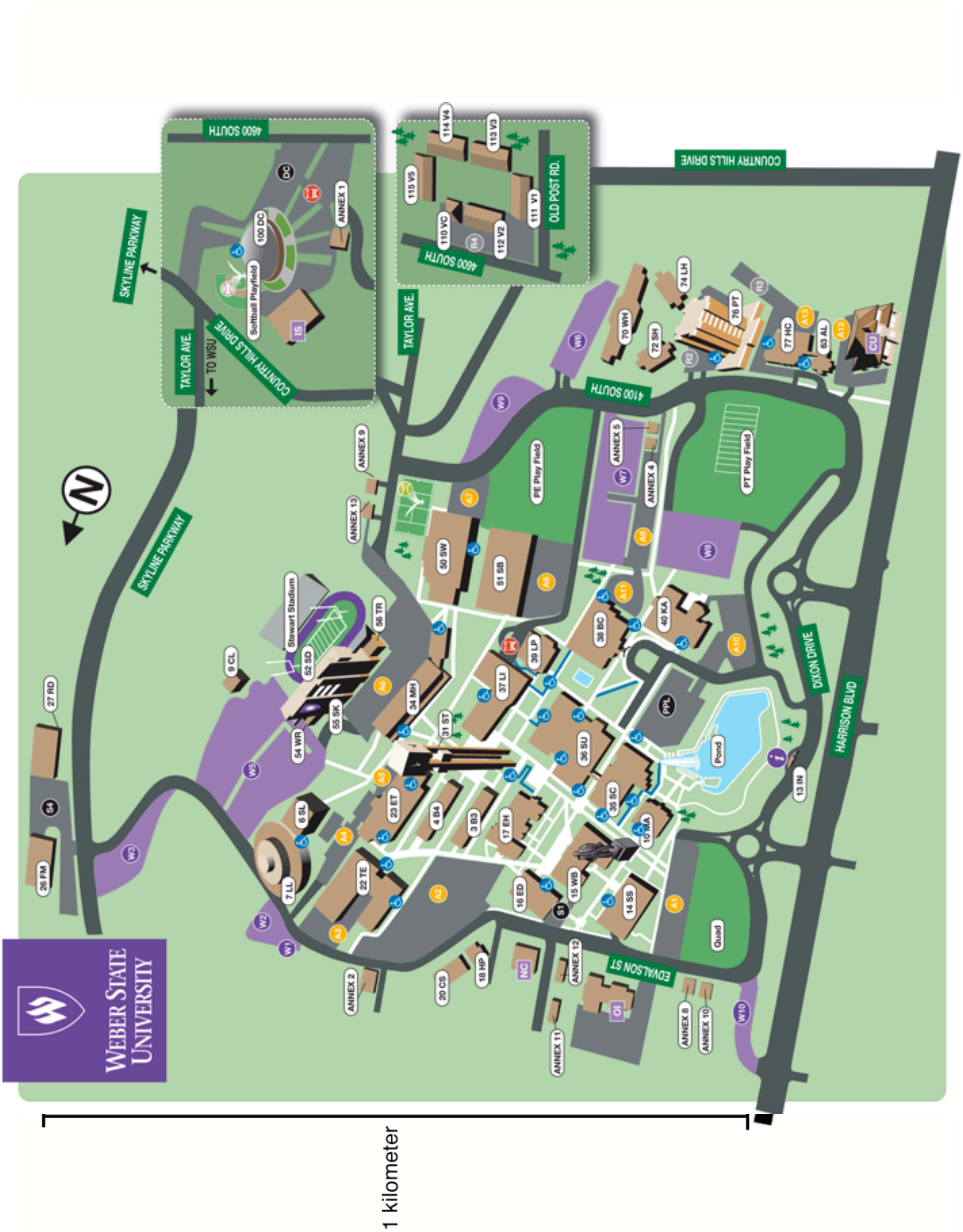
PHYS 1040: Elementary Astronomy



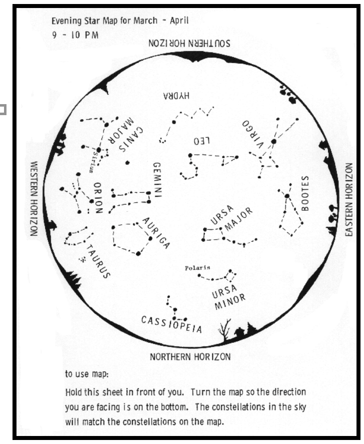
1. Produce a scale model of the Solar System that can fit on the Weber State Campus. With the Sun at the center, list the actual distance and scaled distance for Mercury, Venus, Earth, Mars, the Asteroid Belt, Jupiter, Saturn, Uranus, Neptune, and the Kuiper Belt (that is, Pluto) and draw this on the map provided.
    a. What is the scaled size of the Sun in your model (that is, what household object could represent it)?
    b. Where would the nearest star be relative to your scaled model?

Object	Size, km	Distance from Sun, millions of km	Your Scaled Distance (on the Map)
Sun	695,000	0	
Mercury	2,440	57.9	
Venus	6,051	108.2	
Earth	6,378	149.6	
Mars	3,397	227.9	
Jupiter	71,492	778.3	
Saturn	60,268	1,427	
Uranus	25,559	2,870	
Neptune	24,764	4,497	
Pluto	1,160	5,906	
Nearest Star (Alpha Centauri)		3.9×10^7 (4.2 lightyears)	
Nearest Large Galaxy (Andromeda)		2.3×10^{13} (2.5 million lightyears)	

2. Imagine yourself on a cosmic journey at the speed of light. How long would it take you to travel to the Sun? To Pluto? To the nearest star? To the nearest galaxy?
3. Visit http://space.weber.edu/planetcache/planetcache.html. Use this to explore other possible scale models! (Tested on Safari and Firefox)


WEBER STATE UNIVERSITY
SKYLINE PARKWAY
TAYLOR AVE.
TO WSU
COUNTRY HILLS DRIVE
4600 SOUTH
OLD POST RD.
4100 SOUTH
DIXON DRIVE
HARRISON BLVD
EDVALSON ST
Softball Playfield
Stewart Stadium
PE Play Field
PT Play Field
Pond
Quad
1 kilometer

Finding Things in the Sky



Purpose
The student will explore coordinate systems and ways to find things in the sky.

Materials
Paper and pencil
Planetarium

Background and Theory
The very first problem in astronomy is to get everyone talking about the same thing. This is much harder than in many other sciences. For example, in biology, you can say 'This big ugly frog here, the one with the blue and white speckles on its back, is poisonous.', and hand it to your colleague, whom you presumably hate. In astronomy, however, you can say 'That dot there. The reddish one. No. THAT one. What's the matter with you?! Come on, it's right there!' See? Much harder. Astronomers have invented all sorts of ways to make sure that our colleagues know what we are talking about. You will play with these methods in this lab.

Procedure
Print out the worksheet.

Part A: Building the Map:

1. This part of the lab will be done in groups of two. Get together with your neighbor. Introduce yourselves. Now, each of you pick a star in the planetarium sky. Any star will do, but they should not be the same star! Use the 'pointing and yelling' method of stellar identification to get your neighbor to look at the same star.
2. Now, on a separate sheet of paper, draw a 'constellation' with that star in it. Draw several (at least 10) stars around the star in question. Make these stars larger on your picture if they are brighter, and try to get the separations right. Draw an arrow that points to your chosen star.
3. Exchange maps with your partner. Examine their map carefully. Does it accurately represent the sky around their star? Can you find their star from their map? If not, help them make corrections to the map, and give them their paper back.

Part B: Finding the Coordinates: Altitude and Azimuth

1. Your fist at arm's length spans about 10 degrees on the sky. Your outstretched hand is about 20 degrees, and the tip of your index finger is about one degree on the sky. Using these crude measurements, you can find the altitude of your star (its height above the horizon). Do that now, and write it down on the worksheet.
2. Around the 'cove' of the planetarium, there are markers telling the direction: north, south, east and west, along with the azimuthal angle. These four basic points have been further subdivided. Estimate the azimuth of your star, and write it on the worksheet.

Part C: Finding the Coordinates: Right Ascension and Declination

1. Now your instructor will add the celestial coordinate system to the sky. Find the R.A. and Dec of your star, and write them on the worksheet.

Part D: Stump the Chumps

1. Get together with another pair of students. Get the altitude and azimuth coordinates of a star from another student (you will exchange coordinates three times---I don't care how you do it, but for each of these times, you should get a different star to look for).
2. Look at the altitude and azimuth coordinates of the star. Find the star in the sky, and draw a map of the location of that star in the sky. As in Part A, include at least 10 stars, and make them larger when they are brighter. Use an arrow to show which star you think was indicated by the altitude and azimuth given. Label the bottom of your chart with the words 'Alt/Az', and the altitude and azimuth of the star in question. Give this piece of paper to the student who gave you the coordinates.
3. Now get a Right Ascension and Declination from another student. Use the right ascension and declination to locate the star in the sky, and draw the star map, labeling it with 'RA and Dec', and the coordinates of the star in question. Give your map to the student who gave you the coordinates.
4. Finally, wait for your instructor to change the date or time of your observations. Now choose which coordinate system to use, and ask the third student to give you those coordinates for the star in the sky. Again, draw a star map indicating the location of the star in the sky. Write the name of the coordinate system you've used under the map you've drawn, and the coordinates you were given. Give this map to the student who gave you the coordinates.

Part E: Who's the Chump?

1. Now, you should have four star maps for the same star. Compare them. Are they similar? Did the other students in the class identify 'your' star correctly? How could you have helped them do better? (Include all four maps when you hand in your work.)
2. In general, what's the best method for getting people (who are just observing for fun) to find things in the sky (pointing, constellations (or star maps), horizon coordinates or celestial coordinates)?
3. Is this the best method for professional astronomers? Why or why not?

Revised: 24 April, 2003

Finding Things in the Sky Worksheet

Part A: Building the Map

On a separate sheet of paper.

Part B: Finding the Coordinates: Altitude and Azimuth

Altitude:____________________

Azimuth:_____________________

Part C: Finding the Coordinates: Right Ascension and Declination

Right Ascension:____________________

Declination:_____________________

Part D: Stump the Chumps

On three separate sheets of paper.

Part E: Who's the Chump?

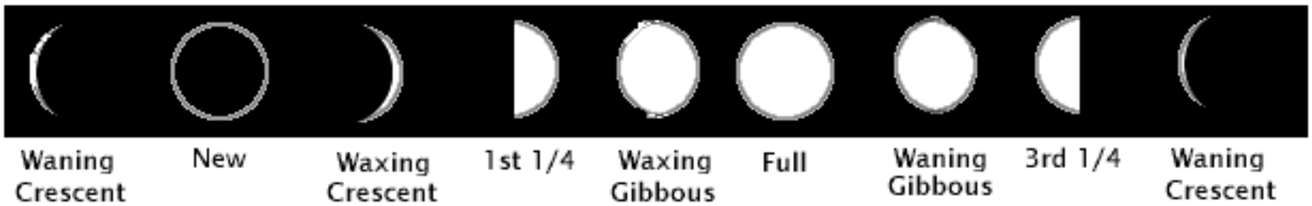
Answer these AFTER completing part D!

1. Are all the maps similar?
2. Did the other students find the right star?
3. How could you have improved your coordinates?

4. What's the best method to find things in the sky?
5. What's the best method for professional astronomers?

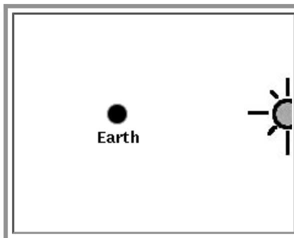
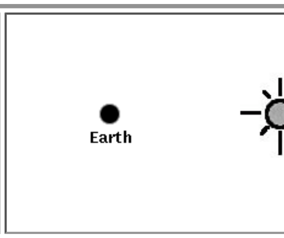
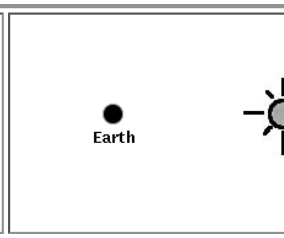
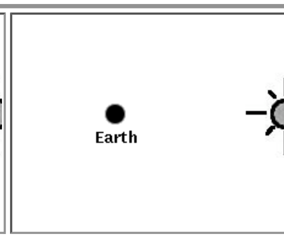
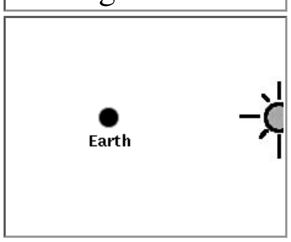
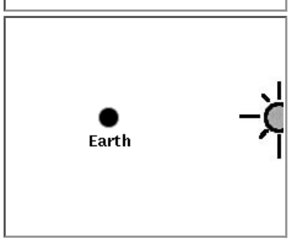
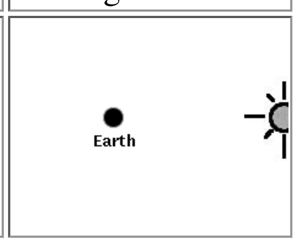
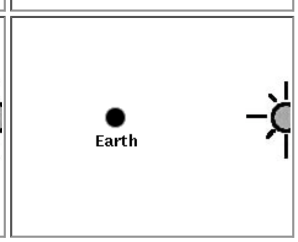
Phases of the Moon

Summary
This lab is designed to be an introduction to the scientific process. You will, using simple tools, deduce the motion of the Moon around the Earth. You will determine the direction of motion, and the reason for the phases.



Procedure

1. Form a group of three with your neighbors. Choose one person to be the Moon, one person to be the Earth and one person to be the Record-keeper.
2. Study the phases chart above, which shows the moon at different phases throughout the lunar cycle. Note carefully what changes about the moon from each image to the next.
3. The Moon should pick up a styrofoam ball from the front of the room, and then everyone heads out to the hallway.
4. Choose a location for the Sun. The Sun remains stationary for the entire lesson after that! (It's often easiest to say that the 'Sun' is located at one end of the hallway.)
5. The Earth stands in one spot for the entire lesson (but can turn around to see the Moon). The Moon stands relative to the Earth so that the styrofoam ball appears to the Earth in each phase. **The Moon must make sure that the white side of the styrofoam ball always faces towards the 'Sun'!** The Earth decides when the appropriate phase is shown.
6. The images below are all looking down on the Earth-Moon-Sun system from North. All should try to imagine what a spaceman, looking down from North, would see for each phase. The recorder marks the location of the Moon in the appropriate box in the table below.

			
Waning Crescent	New	Waxing Crescent	First 1/4
			
Waxing Gibbous	Full	Waning Gibbous	Third 1/4

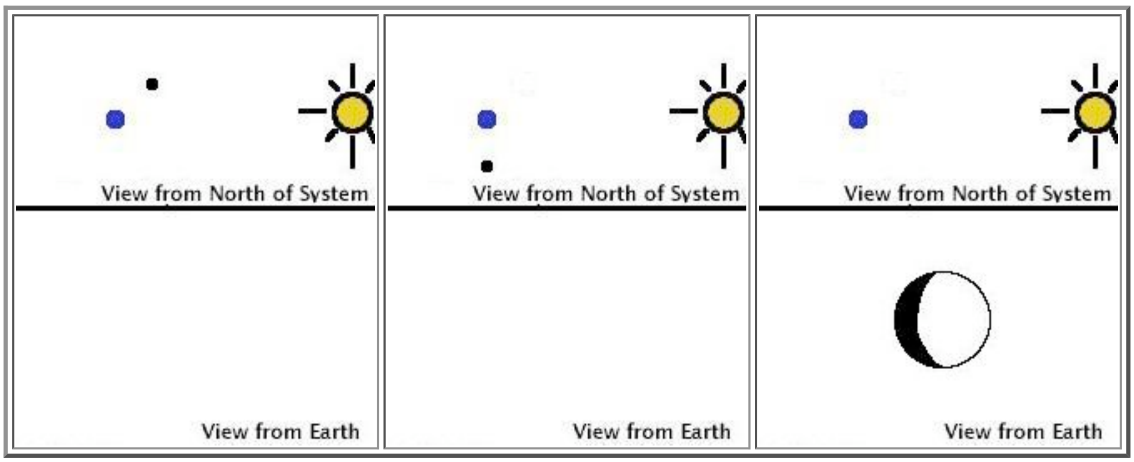
When you are finished, work together to answer the following questions: **1.** In which direction does the Moon orbit the Earth? CLOCKWISE or COUNTERCLOCKWISE

2. For observers from the Northern hemisphere, which side of the Moon is illuminated when the Moon is just past new phase? RIGHT or LEFT

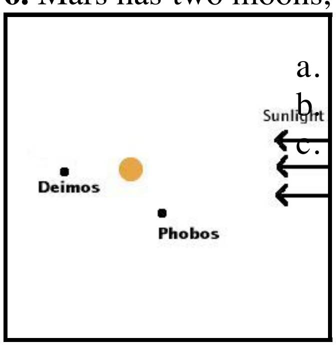
3. If you were to observe a crescent moon with the horns of the crescent pointing right, is the Moon WAXING or WANING? Hint: consider the previous question!

4. When an earth-bound person observes the Moon in its full phase, which phase of Earth is observed by a person on the Moon? NEW or FULL or SOME OTHER PHASE

5. In the following three pictures, fill in the missing piece (either in the top or the bottom panel).

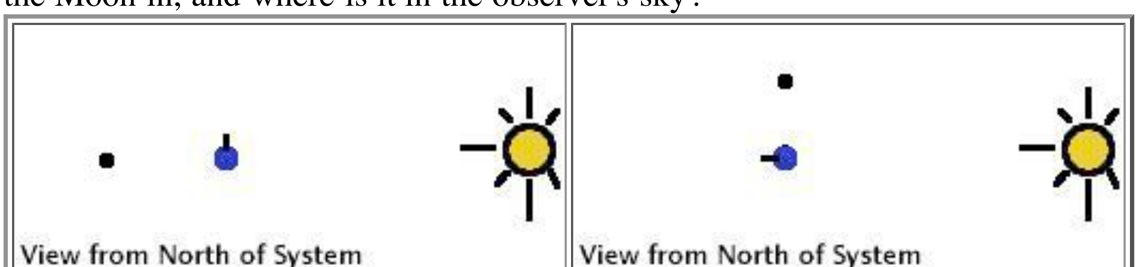


6. Mars has two moons, Phobos and Deimos. In the picture,



a. What is the phase of Phobos as seen from Mars?
b. What is the phase of Deimos as seen from Mars?
c. What is the phase of Deimos as seen from Phobos?

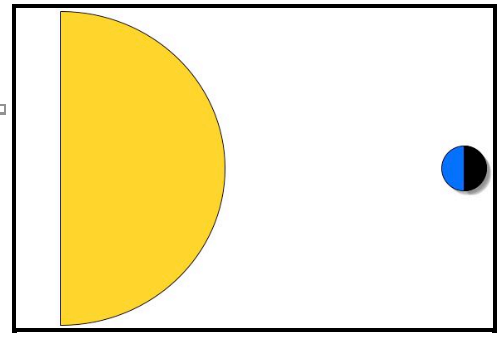
7. For each of the following pictures, what is the time for the observer (the solid black line), what phase is the Moon in, and where is it in the observer's sky?



Time:	Time:

Phase:	Phase:
Location:	Location:

The Seasons



Purpose
The student will explore various explanations for the causes of the seasons.

Materials
Directed light, cardboard with square hole.

Background and Theory
One of the simplest and yet most confusing astronomical issues is the 'reason for the seasons'. Years ago, a group of film-makers went to a graduation ceremony at Harvard University, and asked students **AND FACULTY!** what caused the seasons. Clearly, this would not be interesting if they all got it right. In fact, nearly everyone got it wrong. This has led to consternation and dismay in the scientific community. Myself, I wonder how much of that was just due to the fact that people hadn't thought about it for a while, and, most likely, had been partying a little too hard to have a good thought about it on the spur of the moment!

In any event, just so that you can all be better educated than your average Harvard grad, we are going to do some work on this problem right here today!

Procedure
Print out the worksheet.

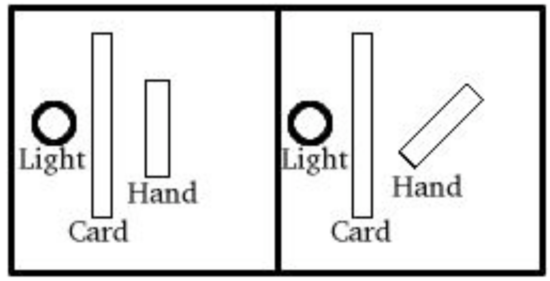
Part A: The Seasons Here on Earth:

1. Write down on your worksheet your prediction for the cause of the seasons. Do not worry if you are not sure---that's the point of this exercise! Just write something reasonable down. This is your working model of the 'reason for the seasons'.
2. Now, answer the following questions about YOUR model:
    1. Are the seasons experienced at the same time in the Northern and Southern Hemispheres?
    2. Does the length of the day change with season?
    3. Are there any special places that will have a unique experience at any time of year (i.e. the sun does not rise in a given 24 hour period?)
3. Now for some information about the Earth. You may know any number of the following facts:
    1. The seasons are reversed in the Northern and Southern Hemispheres, so that the Southern Hemisphere experiences summer in February.
    2. The number of daylight hours is greater in the summer than in the winter.
    3. In the summer months, at the poles of the Earth, the daytime lasts for 24 hours. (At the North Pole, the sun rises on March 21, and does not set again until Sept 21---the sun is above the horizon for six straight months!)
    4. The Earth's orbit is only very slightly elliptical, and the Earth is actually closest to the Sun in the northern wintertime.

    Are each of these observations of the Earth consistent with your model? Why or why not?
4. How would you like to change your model to be more consistent with the actual observations of the Earth?
5. In one sentence, give the reason for the seasons.

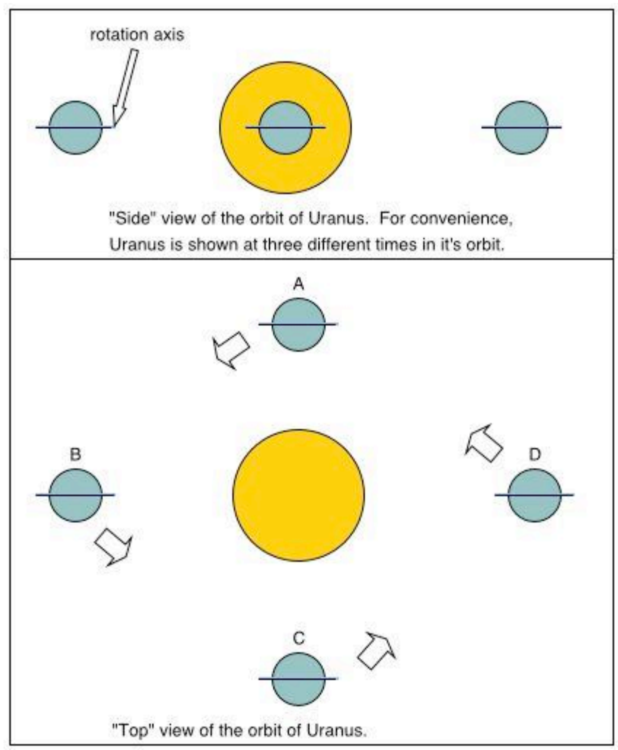
6. Write down one fact you learned in this Part. What is the difference between a fact and a model (aka theory)?

Part B: The Intensity of Sunlight:



1. Get a card, with a square cut out of it. Stand by the overhead projector. Hold the card up so that the light from the projector passes straight through it. Hold up your hand in the square of light, parallel to the card. Now move your hand so that the light strikes it at an angle, as shown in the two figures at right.
2. When you hold your card parallel to your hand, does the square of light cover more or less of your skin than when you hold it at a slant?
3. In which case does your hand feel warmer?
4. In January, which hemisphere (North or South) is most perpendicular to the Sun?
5. Explain how the tilt of the Earth's axis causes the seasons to vary over the course of the year.

Part C: The Seasons on Uranus:



1. Uranus is a unique planet, for many reasons. But probably the most interesting thing about it is that it has an extreme axial tilt. In fact, the rotation axis of Uranus is tilted by 98^o to the orbital plane. That is, Uranus' poles sometimes point nearly directly at the Sun! See the figure below if this is not clear (in this figure, Uranus rotates in and out of the page, around the rotation axis---moving your fingers around might help you figure out what's happening!). Uranus rotates once around its axis in 0.7 Earth days, and revolves once around the Sun in 84 Earth years.
2. In position A, above, how many daylight hours would a typical Uranian have each day? To what Earth season(s) might this position correspond (Winter, Spring, Summer, Fall)?
3. In position D, how many daylight hours would a Uranian on the 'left' half of the planet have each day?
4. In position B, how many daylight hours would a Uranian on the 'left' half of the planet have each day?
5. Where on Earth would you have to live to experience seasons like those of a typical Uranian?

Part D: The Seasons on Planet _______:

1. You discover a new extra-solar planet! This planet orbits its star at about 1AU (the distance from the Earth to the Sun), and is about the same mass and size as the Earth. It is a great candidate for looking for life! What do you name your new planet?
2. Through lots of very careful observations and clever deductions, you discover that ________ is tidally locked to its Sun, much like the Moon is tidally locked to the Earth. Describe the seasons on

___________. Use diagrams if necessary to aid your explanation.

3. How are ________'s seasons different from the Earth's seasons?
4. Where would you expect life to flourish on ________? Where would you expect it to fail miserably?
5. There is a way to make ______ somewhat more Earth-like in its seasons, without altering the fact that it is tidally locked. What property of ______ would make its seasons more Earth-like?

The Seasons Worksheet

Part A: The Seasons Here on Earth:

1. What do you predict is the cause of the seasons on Earth? (This is YOUR model.)

2.
    1. In your model, are the seasons experienced at the same time in the Northern and Southern Hemispheres?
    2. In your model, does the length of the day change with season?
    3. In your model, are there any special locations?

3. Is your model consistent with the facts listed about the Earth?

4. How would you like to change your model to be more consistent with the actual observations of the Earth?

5. In one sentence, state the cause of the seasons.

6. List one fact, and explain the difference between a fact and a model.

Part B: Intensity of Sunlight.

1. *No written answer required.*
2. When you hold your card parallel to your hand, does the square of light cover more or less of your skin than when you hold it at a slant?

3. In which case does your hand feel warmer?

4. In January, which hemisphere (North or South) is most perpendicular to the Sun?

5. Explain how the tilt of the Earth's axis causes the seasons to vary over the course of the year.

Part C: The Seasons on Uranus:

1. In position A, above, how many daylight hours would a typical Uranian have each day? To what Earth season(s) might this position correspond (Winter, Spring, Summer, Fall)?

2. In position D, how many daylight hours would a Uranian on the 'left' half of the planet have each day?

3. In position B, how many daylight hours would a Uranian on the 'left' half of the planet have each day?

4. Where on Earth would you have to live to experience seasons like those of a typical Uranian?

Part D: The Seasons on Planet _______:

1. What do you name your new planet?

2. Describe the seasons on your planet.

3. How are ________'s seasons different from the Earth's seasons?

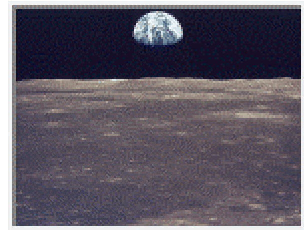
4. Where would you expect life to flourish on ________? Where would you expect it to fail miserably?

5. There is a way to make ______ somewhat more Earth-like in its seasons, without altering the fact that

it is tidally locked. What property of ______ would make its seasons more Earth-like?

Name ______________________________ Section _______

Date _________



Measuring the Mass of the Earth

Objective

To derive the mass of the Earth using direct measurement of the acceleration of an object at the Earth's surface.

Introduction

Sir Isaac Newton changed the way in which humankind viewed the world. His laws describing the fundamental properties of physical reality took scientists from empirical work to mathematical logic. In particular, his description of gravity gave us a means to understand how we are bound to the Earth, how the moon is bound to the Earth, how the Earth is bound to the Sun, and so on. We now understand how one planet can perturb another or how a distant cluster of galaxies can "pull" us across immense distances.

Using Newton's formulae and knowledge of the radius of the Earth and the universal constant of gravitation, we can determine the mass of the Earth. We will be using the following equations:

1. $F = \frac{Gm_1 m_2}{R^2}$	2. $F = m_2 a$	3. $a = -2\frac{x}{t^2}$

where F is force, G (also known as **big G**) is the universal constant of gravitation (6.67 x 10^{-11} $m^3/kg\ s^2$), m_1 is the mass of the Earth, m_2 is the mass of an object on the surface of the Earth, a is the acceleration of that object (negative because the direction of the acceleration is down), x is the distance the object falls, and t is the amount of time it takes that object to fall that distance.

We can manipulate equations 1 and 2 to get the mass of the Earth in terms of the acceleration, radius, and constant of gravitation (your instructor will show you how):

4. $m_1 = \frac{aR^2}{G}$

Since we "know" R to be 6,378 km (=6,378,000 m; let's say we measured it somehow by observing the length and angles of shadows at different places on the Earth's surface) and G was fortunately measured for us by a physicist, all we need is a, the acceleration of an object at the Earth's surface.

We don't need to know the mass of the object. (Why is this true?) Although any object can be dropped, use an object that will experience a minimum of air resistance. Drop the object from a height that is high enough to minimize the relative fraction of time it takes us to start and stop a stop watch, but not so high that air resistance starts to affect the results.

Procedure

Find a location suitable for dropping stones or marbles. Examples of locations include open stairwells, balconies, and rooftops. Measure the distance the objects will be falling. Use a stopwatch with a precision of 1/100 of a second, and time how long each object takes to fall this distance. Work in groups and determine who will be dropping, who will be timing, who will be recording, who will measure the height, who has the calculator, who will be quality control, etc.

Exercise

Record the times in the following chart:

Trial No.	Time (sec)	Trial No.	Time (sec)	Trial No.	Time (sec)	Trial No.	Time (sec)
1		6		11		16	
2		7		12		17	
3		8		13		18	
4		9		14		19	
5		10		15		20	

Distance the object(s) fell (x): ________ meters Uncertainty: ________ meters

Share this data with the other members of your team. For mathematical understanding, each team member should do the following calculations individually. Again, please show all calculations here.

1. Calculate the average time taken to fall the distance, x:

   Average time: ___________________ seconds

2. Calculate the uncertainty in this average (via an ***<u>approximate</u>*** method):
   - Toss out the longest and shortest times
   - Subtract the now-shortest time from the now-longest time and divide by 2

   Uncertainty: _________ seconds

3. Square the value of the average time of fall:

   t^2 = ______________ sec^2

4. Solve for the acceleration of the object:

   $a = -2x/t^2$ = __________ m/s^2

5. Since the negative sign for the acceleration refers to direction, we can disregard it when determining the mass of the Earth. Solve for the mass of the Earth:

$$m_1 = aR^2/G = \_\_\_\_\_\_\_\_\_\_\_\_ \ kg$$

Questions

1. Why is it a good idea to take many measurements and average the results?

2. Compare your value for the mass of the Earth to the true value of 6×10^{24} kg. That is, calculate the percentage difference:

3. How does your value for the acceleration compare to the actual value of 9.8 m/s^2? With this answer in mind, how does your measurement for the acceleration of an object affect your derived value for the mass of the Earth?

4. Given your estimates for the uncertainties in the distance and times, what is the range of values allowed for the acceleration due to gravity at the surface of the Earth? That is, what are the lowest and highest values you find given the uncertainties of your experiment?

    - Highest value comes from combining the highest possible height with the shortest possible time, given your uncertainties. Calculate the highest value for the acceleration:

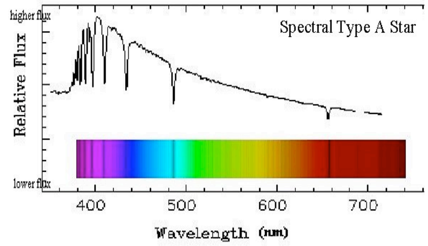
    - Lowest possible value comes from combining the shortest possible height with the longest possible time, given your uncertainties. Calculate the lowest value for the acceleration.

(continued on next page)

5. Does the real value for the mass of the Earth lie within your uncertainties? (You can figure this out without doing any additional calculations.) Explain.

Name ____ Section _____________

Application Exercise: Analyzing Spectra



Objective

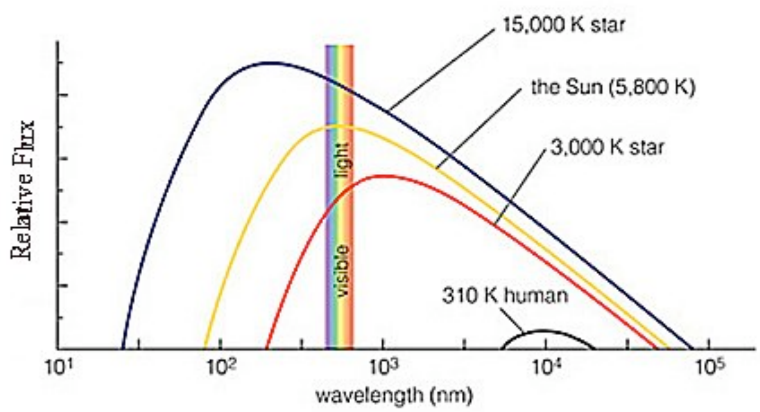
To observe and record the emission lines of various gases; to identify a particular gas based upon its emission spectrum; to identify the composition of a "star" based upon its absorption spectrum.

Materials

- ♦ Rainbow glasses or slide-mounted grating
- ♦ Colored pencils or crayons

Introduction

Astronomy is nearly entirely a study of light. From this single source of information, we find what is "going on" in distant objects, their physical conditions, compositions, and processes they are undergoing. To collect the light so critical to our science, we use telescopes to gather and focus the light on a spectrograph, and use charge-coupled devices (CCDs) to record the information. What we record is the amount of light the object is emitting at each wavelength, from the ultraviolet to the infrared (depending on the instruments we use). The pattern of light an object emits at each wavelength is called its spectrum. By spreading out light into different wavelengths, we attempt to figure out what is physically "controlling" how much light we see at each wavelength. We do this by examining three components of the spectrum: the continuum emission (or thermal or blackbody radiation), emission lines, and absorption lines.

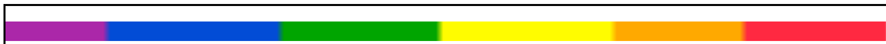


A continuous spectrum is generated by a thermal radiator—a furnace, a planet, a star, an animal, humans—that is considered *opaque* to radiation. Anything having a temperature above absolute zero radiates. These thermal objects trap heat, so to speak, and the photons bounce around among the atoms or molecules, randomizing the energies of the photons (smearing the light out) and keeping the object basically in thermal equilibrium. The amount of "bouncing around" depends only on the temperature of the object. Hotter objects emit more energy per unit surface area than cooler objects, and the photons emitted from a hotter object have a higher average energy than those from cooler objects. In other words, the hotter the object, the brighter and "bluer" it looks.

The important thing to remember about absorption and emission lines is that every atom of a particular element will always have the same pattern of lines all of the time. The spacing of the lines in the spectrum of a given element is exactly the same in both absorption and emission. Emission lines are *added* to the continuum, while absorption lines are *subtracted* (taken out). In contrast, the continuum emission always has a smooth profile, with emission at a given wavelength (note that we do not mean *line* emission here) being only a bit stronger or weaker than that of its neighboring wavelengths.

In many respects, light exhibits a wave-like behavior. As with waves in water, this means light waves have a *velocity* (*c* in a vacuum; 300,000 km/s), a *wavelength* (lambda, λ), and a *frequency* (nu, ν). The distance a light wave travels in one second is its velocity, expressed in meters per second (*m/s*); the distance between two wave crests (or troughs) is the wavelength; the number of waves that pass per second is the frequency (number/second).

Wavelengths shorter than those corresponding to infrared light are usually measured in nanometers•. One nanometer is one-billions of a meter (1 nm = 10^{-9} m). The wavelength of the light determines the color. A wavelength of around 650 nm corresponds to red light; 500 nm, to green light; 450 nm, to blue light. The human eye responds to the wavelength range of around 400 - 700 nm.



300 nm	400 nm	500 nm	550 nm	575 nm	600 nm	625 nm	650 nm

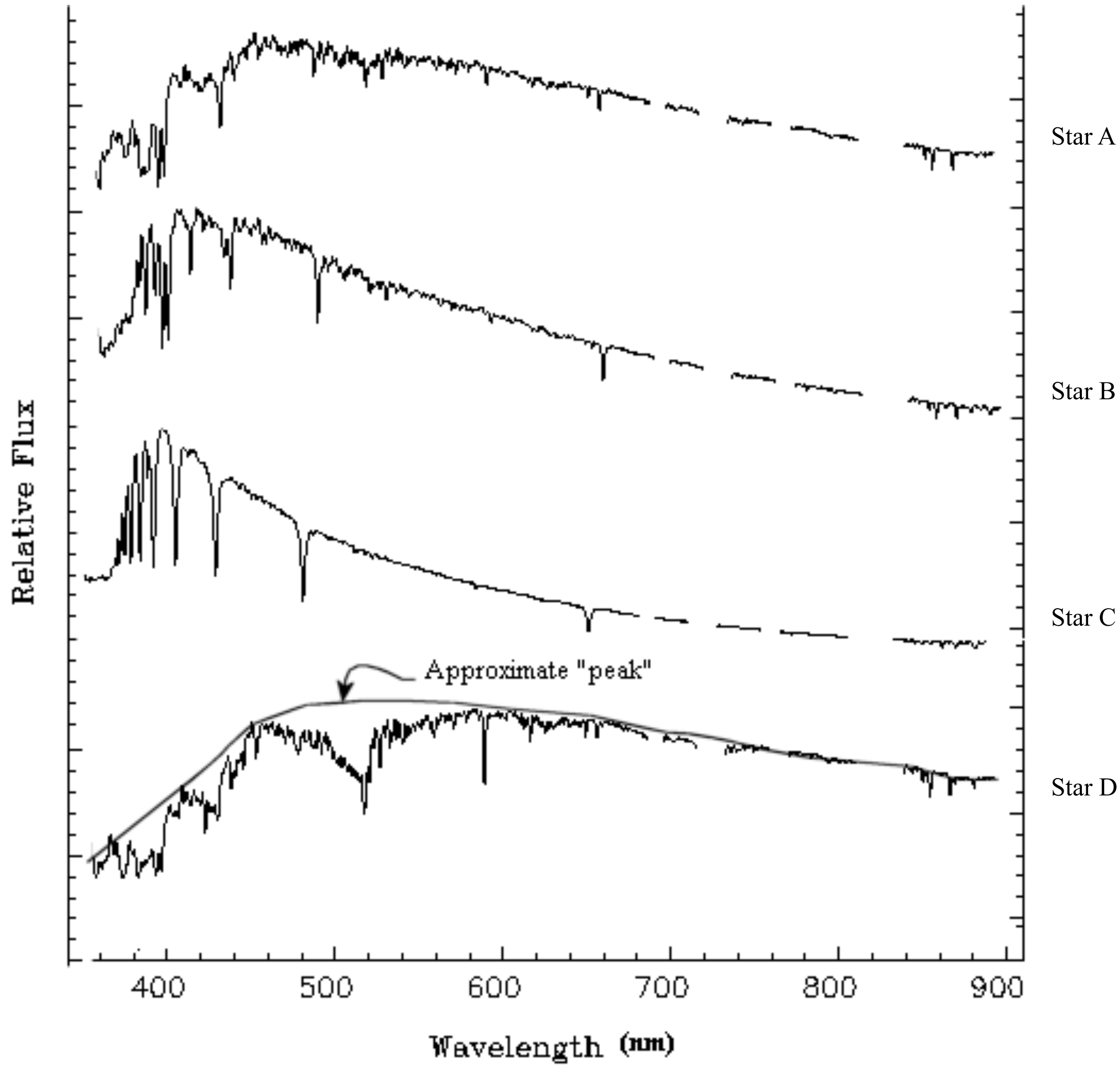
To spread the light into its component wavelengths or colors, we will be using a transmission grating. A *transmission grating* is a piece of transparent glass or plastic ruled with many finely spaced lines. The slides we use have around 600 lines per mm! A grating will break up light into a spectrum just like a prism, but will form multiple spectra. The image of the object will go straight through the grating, forming what is known as the "zeroth" image. The spectrum formed beside the zeroth image (either to the right or to the left) is called the "first-order". The next one out is called the "second-order", etc. As one looks toward the higher-order spectra, the spectra become fainter and more dispersed (spread out).

We will be viewing emission tubes, each containing a different gas. When we plug the power boxes containing the tubes into the wall, we send electricity through the tubes and add energy to the gas. This causes the electrons in the atoms to become excited—they “jump” to higher energy levels. After a short amount of time, the electrons drop back to lower energy states, releasing a photon of a specific frequency, one that corresponds exactly to the energy difference between the levels. Depending on the number of possible transitions available to the electrons in each atom (basically the number of energy levels available to them; you’ll soon note not due strictly to the number of electrons each atom has), photons of different wavelengths and thus different colors are released from each gas. The unique patterns formed by the different gases are their *fingerprints*, their *DNA*, and the main topic of this lab.

• Many, many astronomers still adhere to the now defunct (in most scientific circles) unit of wavelength measure called the Ångstrom (Å). One nanometer = 10 Ångstroms, making an Ångstrom 10^{-10} meters.

Exercise

Continuous spectra



Shown here are actual spectra from four different stars. Before you do ANY calculations, write down the above star "names" in order of temperature (as you predict they will be once you do the calculations) from the star with the highest surface temperature to the star with the lowest surface temperature. Give the reasons why you ordered the stars the way you did; that is, on what criteria did you base your decision?

Wien's Law: $\lambda_{peak} = \frac{2.9 \times 10^6}{T}$ (Eqn. 1), or the peak wavelength of a blackbody curve, measured in nanometers, is equal to 2.9 x 10^6 (K nm) divided by the surface temperature in Kelvin. In terms of the surface temperature, this equation is: $T = \frac{2.9 \times 10^6}{\lambda_{peak}}$ (Eqn. 2).

Fit a blackbody curve to the spectra shown above of the stars A, B, and C, and calculate the corresponding temperatures. Star D has the curve already drawn for you. The shape of the curve for this star was difficult to trace because of the deep absorption lines around 520 nm, probably due to molecules in the star. The deep absorption around 380 – 400 nm is due to singly ionized calcium. [Isn't it amazing that we know this stuff?]

The peak wavelength, λ_{peak}, for star D was estimated to be about 500 nm. Putting this value into Eqn. 2 above, we calculate a temperature for this star of about 5800 K. Show the set-up of your equations for the other three stars here, and make sure your answers are clearly marked. Do your calculations agree with the predictions you made above? Comment briefly.

Absorption Spectra

Your instructor will place a container of antifreeze (or similarly dyed fluid) on the overhead projector that has been transformed into a spectrograph. Comment generally on what you observe. Include not only the affect on the projected spectrum, but also from the container itself. In your own words, explain why you are seeing an absorption spectrum.

Emission Spectra

Make a sketch of each spectrum from the gas discharge tubes. Be sure to reflect the correct intensity of each line, the correct spacing, the relative positions, etc.

Type of Gas	Sketch of the Spectrum			
Wavelength	400 nm	500 nm	600 nm	700 nm
Color	violet-blue	green-yellow	orange-red	deep red

Your instructor will insert an "unknown" gas emission tube into one of the power boxes. Examine the pattern and colors of the emission spectrum; mentally compare it to the gases you just observed. What is the "unknown" gas? __________

Comment generally in the similarity and differences of the spectra that you have observed. Include in your comments the colors you observed and how the spacing of these colors differed:

a. Are the lines closely packed together, or spread out over many different colors?
b. Are there many lines you can see, or only a few?
c. How do the colors of the lines from each tube relate to the color you see from each tube when *not* looking through the grating?

Questions

01. How does the light that astronomers see from distant stars and galaxies tell them that the same atoms with the same properties exist throughout the universe? Why are spectral lines often referred to as "atomic fingerprints"?

02. Distinguish among emission spectra, absorption spectra, and continuous spectra in how the spectra look.

03. Examine the following spectra (this is in color on-line).   Assuming that the artificial absorption spectrum shown of the Sun really represents what is observed, what is the evidence for the claim that iron exists in (the atmosphere of) the Sun?

Artificial Solar Spectrum (absorption)

Laboratory Spectrum of Iron (emission)

Star Abba

Star Babba

Star Cabba

Carbon (laboratory emission spectrum)

Nitrogen (laboratory emission spectrum)

Oxygen (laboratory emission spectrum)

Xenon (laboratory emission spectrum)

Hydrogen (laboratory emission spectrum)

Helium (laboratory emission spectrum)

All three stars—Abba, Babba, and Cabba—are made primarily of hydrogen and helium (just like all of the other stars in the sky). However, in this imaginary case, one star has a high percentage of carbon in its atmosphere, another has a high percentage of nitrogen, and the third has a high percentage of oxygen. [Note: in terms of actual abundances in stars, relative to hydrogen, stars may have 10,000 : 1 – 10,000 times more hydrogen atoms than, say, carbon.]

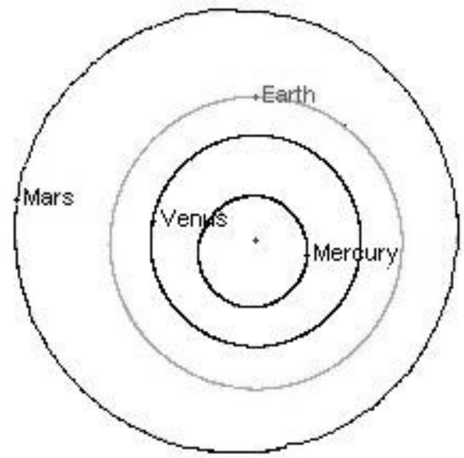
04. Which star has a high abundance of nitrogen in addition to hydrogen and helium? ______________________

05. Which star has a high abundance of oxygen in addition to hydrogen and helium? _______________________

06. That leaves, the third star that has a high abundance of carbon in addition to H and He: ________________

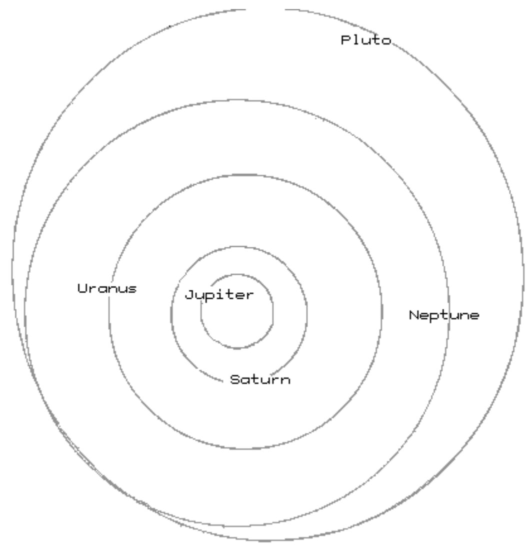
07. Do any of these three stars show evidence of having xenon in their atmospheres? Explain your answer to this question in light of your choice of stars for the previous three questions.

Formation of the Solar System



Summary
Any model of the formation of the solar system must account for the motions, compositions and locations of all the planets and their moons. In this lab, you will use the motions of objects in the solar system to concoct a model of the formation of the solar system.
Processes which were important to the formation of our solar system are also important in star formation, and galaxy evolution, so we will be visiting many of these concepts again.

Procedure
Part 1: Shapes of Planetary Orbits



1. Examine Figure 1, which shows the orbits of the inner planets. In general, what shape are the inner planet orbits?
2. Examine Figure 2, which shows the orbits of the outer planets. In general, what shape are the outer planet orbits?
3. Which of the planet orbits is different from the others? What are two ways in which the odd orbit is different from the others?

Part 2: Inclinations of Planetary Orbits

1. The inclination of an orbit is the angle between the orbit and the plane of the solar system. For example, the inclination of the Moon's orbit is 5^o, because the orbit of the Moon makes a 5^o angle to the orbit of the Earth around the Sun. Examine Table 1. Which planet has the largest inclination?

TABLE 1: Rotation and Revolution Data

Planet	Planet Revolution	Inclination of Orbit	Planet Rotation	Moon Revolution	Moon Rotation	Planet Density
Mercury	CCW	7	CCW	No moons	No moons	5.4
Venus	CCW	3.4	CW	No moons	No moons	5.2
Earth	CCW	0	CCW	CCW	CCW	5.5
Mars	CCW	1.9	CCW	CCW	N/A	3.9
Jupiter	CCW	1.3	CCW	CCW	CCW	1.3
Saturn	CCW	2.5	CCW	CCW	N/A	0.7
Uranus	CCW	0.77	CCW	CCW	N/A	1.3
Neptune	CCW	1.8	CCW	CCW	N/A	1.6

Pluto	CCW	17	CCW	CCW	N/A	2.1

2. Why is the Earth's inclination exactly 0?
3. How do the orbital inclinations of the inner planets compare with those of the outer ones?
4. In one sentence, describe the shape of the solar system, using your answers from Part 1 and Part 2.

Part 3: Rotations of the Planets

1. Examine Table 1. Answer the questions on the worksheet.

Part 4: The Composition of Planets

1. Different types of substances are solid, liquid or gas at different temperatures. For example, things like iron remain solid even at quite high temperatures (a few thousand degrees), whereas water becomes a liquid at 0^{o}C, and other molecules that form ices, such as ammonia and methane, don't become solid until extremely low temperatures, approximately -150^{o} C.
   Consider the temperatures of the early solar system. Was the outer solar system colder or hotter than the inner solar system?
2. Was iron a gas, liquid or solid in the inner solar system? In the outer solar system? How about water? Ammonia or methane? Fill in the table on the worksheet with this information.
3. Gases are easily blown around by the solar wind, which is strong near the Sun, but gets weaker and weaker the further away you are from the Sun. What happened to the ammonia and methane in the inner solar system? What happened to the ammonia and methane in the outer solar system?
4. In one sentence, describe the distributions of compositions in the solar system. This distribution must be accounted for in a model of the solar system, and of solar system formation.

Part 5: The Standard Model

The standard model of the formation of the solar system begins with an enormous cloud of gas and dust, which is slowly rotating counterclockwise. The cloud begins to collapse under gravity. This spinning cloud has angular momentum (like an ice skater), and so it collapses more easily along the axis than towards the axis.

During this time, the particles can slip past each other easily, since the cloud is not very dense. Later, when the solar wind begins to blow, the inner solar system loses much of its low-density (icy) material, which has remained in gaseous form. This material winds up in the outer solar system, on the moons and in the atmospheres of the gas giant planets.

As the cloud collapses, it becomes denser. Particles to begin to collide, and sometimes stick together, forming larger particles. These larger particles are orbiting the center of the cloud counterclockwise, because the smaller particles were traveling in that direction. The collisions with particles moving slightly outward in their orbits are as common as collisions with particles moving slightly inward in their orbits, causing the orbit of the growing body to become more and more circular, and less elliptical.

The cloud continues to collapse because of gravity, and to spin faster because of the conservation of angular momentum. Eventually, most of the large particles have been gathered up into a few large bodies, and continue adding mass by running into lots of smaller particles.

We have now accounted for the shape of the orbits, the shape of the solar system, the rotations of the planets, and the distribution of densities. All with a very simple model of a cloud which collapses under gravity, and conserves angular momentum. However, this is far from the whole story. It works pretty well for our solar system, but fails when applied to the dozens of planets around other stars which have been discovered in the last decade.

1. What would happen if the original cloud were too large and too low-density for gravity to be important?
2. What would happen if angular momentum was not conserved?
3. How might you explain Venus' counter-rotation? Feel free to engage in wild speculation. This is an unanswered question in astronomy!
4. How might you explain the oddities of Pluto's orbit? These irregularities are among the main reasons that many astronomers prefer not to consider Pluto a planet at all, but a captured comet instead.

The Formation of the Solar System

Name(s):____

Procedure
Part 1: Shapes of Planetary Orbits

1. What shape are the inner planet orbits?
2. What shape are the outer planet orbits?
3. Which of the planet orbits is different from the others? What are two ways in which the odd orbit is different from the others?

Part 2: Inclinations of Planetary Orbits

1. Examine Table 1. Which planet has the largest inclination?
2. Why is the Earth's inclination exactly 0?
3. How do the orbital inclinations of the inner planets compare with those of the outer ones?
4. In one sentence, describe the shape of the solar system, using your answers from Part 1 and Part 2.

Part 3: Rotations of the Planets

1. In which direction is our solar system rotating and revolving?

2. Which planet is not rotating the same direction?

3. Do the rotations of solar system bodies seem to indicate that most of them formed together at the same time in the same way, or separately under different conditions?

4. How could you tell if a moon or planet did not form with the rest? If a moon or planet did not form with all the others in its vicinity, how might it have gotten there?

5. In one sentence, describe the rotations and revolutions of the planets.

Part 4: The Composition of Planets

1. Which was hotter---inner or outer solar system?

2.

	Iron	**Water**	**Ammonia and Methane**
Inner Solar System			
Outer Solar System			

3. In one sentence, describe the distributions of densities in the solar system.

Part 5: The Standard Model

1. What would happen if the cloud were too thin for gravity to be important?

2. What would happen if angular momentum was not conserved?

3. How might you explain Venus' counter-rotation?

4. How might you explain the oddities of Pluto's orbit?

Viking Life Detection Experiments Results:

Earth Life (Pre-flight test)	Response of Sample	Response of sterile control
Gas Exchange (GEX)	O_2 or CO_2 emitted	none
Labeled Release (LR)	labeled gas emitted	none
Pyrolytic Release (PR)	carbon detected	none
No Life (Null Result)	**Response of Sample**	**Response of sterile control**
Gas Exchange (GEX)	none	none
Labeled Release (LR)	none	none
Pyrolytic Release (PR)	none	none
Mars - Actual	**Response of Sample**	**Response of sterile control**
Gas Exchange (GEX)	O_2 emitted	O_2 emitted
Labeled Release (LR)	labeled gas emitted	none
Pyrolytic Release (PR)	carbon detected	carbon detected

Life on Mars? Name___________________________

Goal
Explore the results of the Viking Life Detection experiments.

The Experiments

The Viking 1 & 2 landers (which arrived on Mars in 1976) each carried three experiments designed to detect the presence (or absence!) of life on Mars. These were:

1. **The Pyrolytic Release (PR) Experiment**, which tested for carbon fixation. In this experiment, a soil sample, extracted from the surface by the robotic arm, was exposed to a mixture of CO and CO_2 gas brought from Earth. The gas consisted of a known amount of a radioactive isotope of carbon, ^{14}C. The sample was exposed to this "atmosphere" for five days while a xeon lamp simulated the sun. Afterward, the sample was heated to 625 C to break down and outgas any organic material that might have been manufactured by organisms from the carbon in the atmosphere.

2. **The Gas Exchange (GEX) Experiment**, which tested for metabolic production of gaseous by-products in the presence of water and nutrients. A soil sample from the surface was partially submerged in water and nutrients and incubated for 12 days in a simulated Martian atmosphere. Gases that might be emitted from organisms could be detected.

3. **The Labeled Release (LR) Experiment**, which tested for metabolic activity. In this experiment, the sample was moistened with a nutrient solution labeled with radioactive ^{14}C. Afterward, it was allowed to incubate for 10 days. Any micro-organisms would consume the nutrient and give off gases enriched in ^{14}C.

Each of these experiments used a **sterile control** consisting of Martian soil taken from the surface and then heat-sterilized to 160 C.

Attached you will find the results from the viking lander experiments. The first experiment shows results in the laboratory for life on Earth. The second experiment shows results from a completely sterilized sample. The third set of results are the actual Viking experiments. Examine the results, discuss possible interpretations of these results with your partners, and answer these questions:

1. What is the purpose of the control?

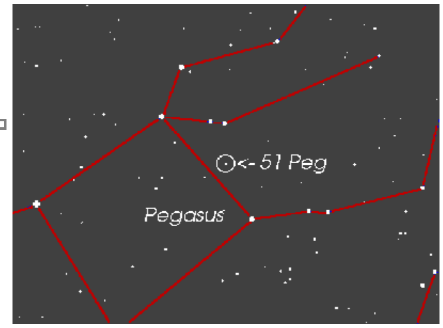
2. Examine the results of the Viking experiments for the **sample**. What conclusions can you draw from examining the sample alone?

3. Examine the results of the Viking experiments for the **control**. What conclusions can you draw in light of the results from the control?

4. Many scientists think these experiments failed to detect any positive indications of life. What arguments could be used against the notion that these experiments had rules out all possibilities of life?

5. Can you think of any methods to improve these experiments on future missions? Specifically, what techniques would you suggest?

51 Pegasi: The Discovery of a New Planet



Summary
The student discovers a planet orbiting another star and compares the results of the discovery with planets in our solar system.

Materials

- Graph Paper
- Scientific Calculator

Background and Theory
In just the past few years, astronomers have announced discoveries of at least 30 planets orbiting nearby stars. These discoveries seem to finally answer the question of whether or not our solar system is unique. We should note, however, that when astronomers state that they have discovered a new planet, what they are really saying is that their data can best be interpreted as a planet orbiting a star. One cannot "prove" that these other planets exist (short of actually going there to explore!); one can only state that, until the hypothesis is disproved, a planet orbiting the star best explains the observations. We cannot see these planets. We can only measure indirectly the influence each one has on its parent star as the star and planet orbit their common center of mass. The planet makes the star "wobble."

We enter this realm of discovery by working with actual data from observations of the star 51 Pegasi (51 Peg) made at the Lick Observatory in California. These data are the measurements of the Doppler shift of the wavelengths of the absorption lines seen in the spectra of 51 Peg. Table 1 lists the measured radial velocities (RV) as a function of time (recorded in days). As you can see, the radial velocities are sometimes positive and sometimes negative indicating that sometimes the star is receding from (the light is redshifted) and sometimes approaching (the light is blueshifted) our frame of reference. This wobble of the star was the first indication that the star 51 Peg had an invisible companion.

Observations

TABLE 1: 51 Pegasi Radial Velocity Data

Day	*v* (m/s)	Day	*v* (m/s)	Day	*v* (m/s)	Day	*v* (m/s)
0.6	-20.2	4.7	-27.5	7.8	-31.7	10.7	56.9
0.7	-8.1	4.8	-22.7	8.6	-44.1	10.8	51
0.8	5.6	5.6	45.3	8.7	-37.1	11.7	-2.5
1.6	56.4	5.7	47.6	8.8	-35.3	11.8	-4.6
1.7	66.8	5.8	56.2	9.6	25.1	12.6	-38.5
3.6	-35.1	6.6	65.3	9.7	35.7	12.7	-48.7
3.7	-42.6	6.7	62.5	9.8	41.2	13.6	2.7

4.6	-33.5	7.7	-22.6	10.6	61.3	13.7	17.6

Note: The days of the observations in this table are expressed in the number of days, or fraction thereof, from when the astronomer first started observing. That is, the dome of the telescope was first opened at Day = 0.

Table 1 lists the observed radial velocities. These were obtained by measuring the Doppler shift for the absorption lines using the formula:

$$\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$$

Solving for the radial velocity *v* of the star:

$$v = c\,\frac{\Delta\lambda}{\lambda}$$

Here, *c* is the speed of light, λ is the laboratory wavelength of the absorption line being measured, and $\Delta\lambda$ is the difference between the measured wavelength of the line and the laboratory value.

Procedure

Print out the worksheet.

1. Plot the 32 data points on graph paper, setting up your scale and labels. Use the observed radial velocities (in m/s) versus the day of the observation.

2. Draw a smooth curve (do not simply connect-the-dots) through the data. The curve is a *sine* curve (ask if you don't know) and thus will always reach the same maximum and minimum values and have the same "number of days" between each "peak" and "valley". You should interpolate between data where points are missing.

3. Thought question: Why are there data missing? Why are there sizable gaps in the data? (Hint, some gaps are a little over 1/2 day long and these are observations from the ground.)

UW Astro. Dept. | Main Page | Lab Listing

Planet Discovery Worksheet

1. A *period* is defined as one complete cycle; that is, where the radial velocities return to the same position on the curve (but at a later time).
   How many cycles did the star go through during the 14 days of observations?
   Number of cycles = ___________

2. What is the period, P, in days?
   Period = ___________ *days*

3. What is P in years?
   P = _____________ *years*

4. What is the uncertainty in your determination of the period? That is, by how many days or fractions of a day could your value be wrong?
   Uncertainty = ___________ *days*

5. What is the amplitude, *K*? (Take 1/2 of the value of the full range of the velocities.)
   K = ___________ *m/s*

6. How accurate is your determination of this value?
   Uncertainty = __________ *m/s*

7. We will make some simplifying assumptions for this new planetary system:

   a. the orbit of the planet is circular ($e = 0$)
   b. the mass of the star is 1 solar mass
   c. the mass of the planet is much, much less that of the star
   d. we are viewing the system nearly edge on
   e. we express everything in terms of the mass and period of Jupiter

   We make these assumptions to simplify the equations we have to use for determining the mass of the planet. The equation we must use is:

$$M_{planet} = \left(\frac{P}{12}\right)^{1/3} \frac{K}{13} M_{Jupiter}$$

   P should be expressed in years (or fraction of a year), and *K* in *m/s*. Twelve years is the approximate orbital period for Jupiter and 13 m/s is the magnitude of the "wobble" of the Sun due to Jupiter's gravitational pull. Not all calculators will take the cube root of a number. Get help if yours does not. Put in your values for *P* and *K* and calculate the mass of this new planet in terms of the mass of Jupiter. That is, your calculations will give the mass of the planet as some factor times the mass of Jupiter (for example: $M_{planet} = 4\ M_{Jupiter}$). Show all work.

8. Assume that the parent star is 1 solar mass, and that the planet is much less massive than the star. We can then calculate the distance this planet is away from its star, in astronomical units (AU's) by using Kepler's third law:

$$\frac{a^3}{P^2} = 1$$

Again, *P* is expressed in years (or fraction of a year), and *a* represents the semi-major axis in AU's. Solve for *a*:

$$a = (P^2)^{1/3}$$

a = ___________ *AU*

9. Compare this planet to those in our solar system. For example, Mercury is 0.4 AU from the Sun; Venus, 0.7 AU; Earth, 1.0 AU; Mars, 1.5 AU; Jupiter, 5.2 AU. Jupiter is more massive than all the rest of the matter in the solar system combined, excluding the Sun.

10. What is unusual about this new planet?

11. Science is based upon the ability to predict outcomes. However, nothing prepared astronomers for the characteristics of this "new" solar system. Why was it such a surprise?

12. If this actually is a planet, is it possibly hospitable to life? Explain.

13. Name your new planet -- a privilege you would have if you really did discover a new planet!

Back

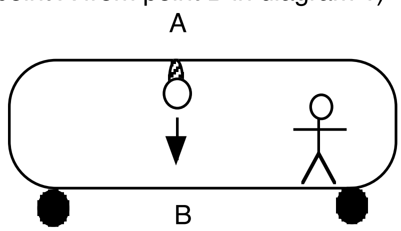
Dr. Armstrong
Elementary Astronomy

I. Special Relativity

One of Einstein's postulates of special relativity is: "The speed of light is the same for all observers no matter what their motion relative to the source of the light." One consequence of this postulate is that "the observed passage of time becomes slower for [a] fast moving object." In this exercise you will use some simple geometry to show this relationship.

Consider a passenger on a train moving very quickly. A passenger is going to measure how long it takes light from a light bulb on the ceiling of the car to reach the floor of the car after she turns on the light (how long it takes for the light to reach point A from point B in diagram 1).

Diagram 1.

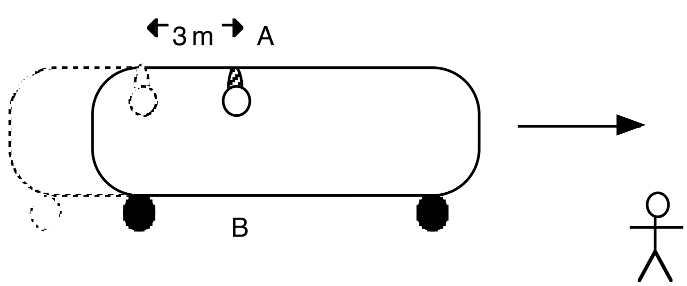


Note that since she is making all of her measurements inside the car, it doesn't matter how fast the train is going. The time it takes for the light to travel from the ceiling to the floor will of course be proportional to the height of the car (the time for a 20 foot ceiling would be twice the time for a 10 foot ceiling, etc...). A general rule applies for motion in a straight line: time of travel=distance traveled÷speed.

Question 1: Suppose that the car is 4 meters high and the speed on light is 3×10^8 meters per second. How long does the light take to reach the floor from the ceiling as measured by the passenger?

Now suppose there is another observer standing outside the train watching it go by. According to him, between the time the light was turned on and the time that the light hits the floor at point B, the train has changed position. Suppose that the train is moving so fast that it moves a distance of 3 meters in this time. In the diagram below, the dashed lines represent the train's position when the light bulb was turned on, while the solid lines represent the trains position when the light from the light bulb reaches point B.

Diagram 2.



Activity 1: Draw a line in diagram 2 to represent the path the light takes from the original position of the light bulb (point A) to point B according to the observer outside the train.

Question 2: How far does the light travel in going from A to B as measured by the observer outside the train? Is this distance more or less than the one observed by the (moving) passenger on the train?

Activity 2: Calculate the time the observer outside the train would figure the light took to travel from point A to point B. Use the distance you found in question 2 and the same speed of light you used in question 1.

Question 3: Compare the two times you found in question 1 and activity 2. Which is greater?

Question 4: Suppose at some later time the two observers compare their measurements for the time it took light to travel from A to B. Why would it appear to the observer outside the train that the person riding the train had a stopwatch that was running "slow"?

Question 5: Although the principle demonstrated by this exercise was correct, the situation described was somewhat unrealistic. Why are the effects described here difficult to observe with trains, lights, and stopwatches?

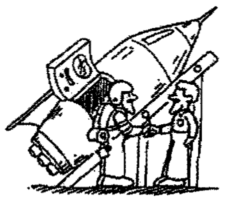
Name ______________________________ Date ____________

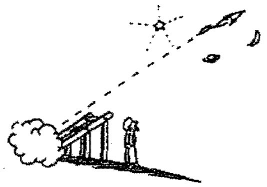
CONCEPTUAL Physics PRACTICE PAGE

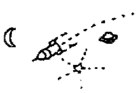
Chapter 35 Special Theory of Relativity

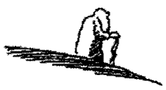
Time Dilation

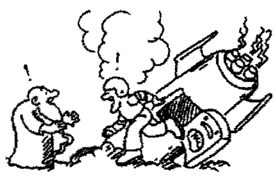
Chapter 35 in your textbook discusses *The Twin Trip*, in which a traveling twin takes a 2-hour journey while a stay-at-home brother records the passage of 2 1/2 hours. Quite remarkable! Times in both frames of reference are indicated by flashes of light, sent each 6 minutes from the spaceship, and received on Earth at 12-minute intervals for the spaceship leaving, and 3-minute intervals for the spaceship returning. Read this section in the book carefully, and fill in the clock readings aboard the spaceship when each flash is emitted, and on Earth when each flash is received.





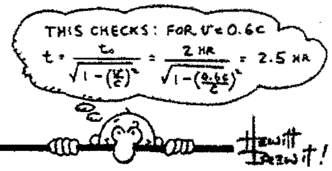




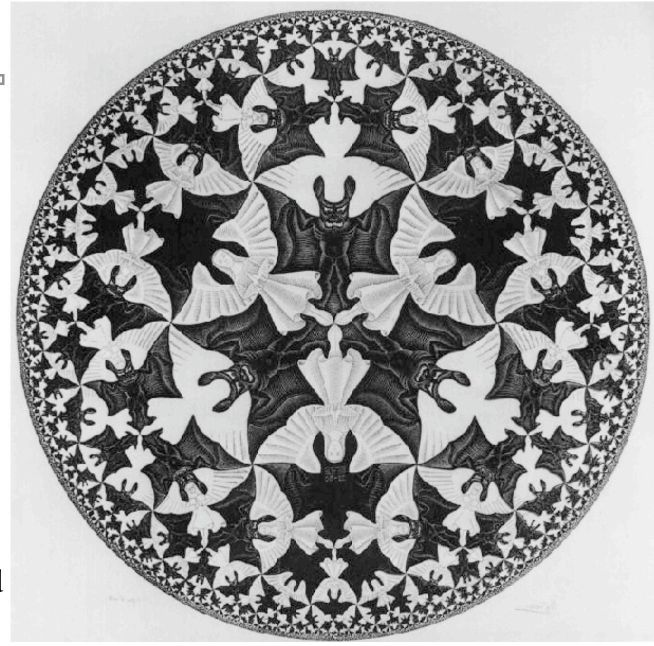


SHIP LEAVING EARTH		
FLASH	TIME ON SHIP WHEN FLASH SENT	TIME ON EARTH WHEN FLASH SEEN
0	12:00	12:00
1	12:06	
2		
3		
4		
5		
6		
7		
8		
9		
10		

SHIP APPROACHING EARTH		
FLASH	TIME ON SHIP WHEN FLASH SEEN	TIME ON EARTH WHEN FLASH SEEN
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		



The Curvature of Space



Purpose

In this lab we'll have a look at curvature and how we can think about the curvature of our own universe by looking at some examples from other "universes", first, and then how we might apply that knowledge to our own.

Procedure

Print the worksheet.

1. Imagine yourself in Flatland, a 2-dimensional flat space, like an infinite piece of paper. If a sphere passed down through the plane of Flatland, a Flatlander would first see a point, which would grow to a circle, reach a maximum size, shrink to a point again and disappear. What would a 4-dimensional sphere look like if it passed it through 3-dimensional space? Imagine you are a Flatlander, and a 3-dimensional cube is passed through Flatland. What possible shapes could you see as the cube passed through Flatland?

2. It's very hard to imagine a 3-dimensional space that's curved into a fourth dimension, so we have to refer to 2-dimensional spaces that are curved into a third dimension as an analogy. Imagine that you are a 2-dimensional creature living on the surface of a sphere. List three geometrical tests that would tell you if your universe is positively curved.

3. In many of his works, the Dutch graphic artist M.C. Escher explored two problems. The first was the regular division of a plane into tiles; the second was the representation of 3-dimensional objects and infinities in 2 dimensions. The two works in this assignment are projections of creatures "living" in 2-dimensional spaces, which may or may not be flat, onto the page, which is definitely flat. The creatures are **all the same size** in their own world - the apparent change in size of the angels and devils in Circle Limit V is an artifact of the projection onto the flat page, like the distortion of the size of Greenland on a Mercator map in an atlas. So how do you go about determining the curvature?

   Recall a few facts from geometry. First of all, on any surface, of any curvature, the sum of the angles at any point is equal to 360 degrees. Secondly, the sum of the interior angles of a triangle will be exactly 180 degrees for a flat surface, less than 180 degrees for a negatively curved surface, and more than 180 degrees for a positively curved one.

   In these works, the creatures are tiled, so that their bodies fit together in regular patterns. To find the curvature, find a repeating triangular shape and count how many triangles intersect at different points. From this you can determine the size of each of the angles of the triangle.

   Here is an example.

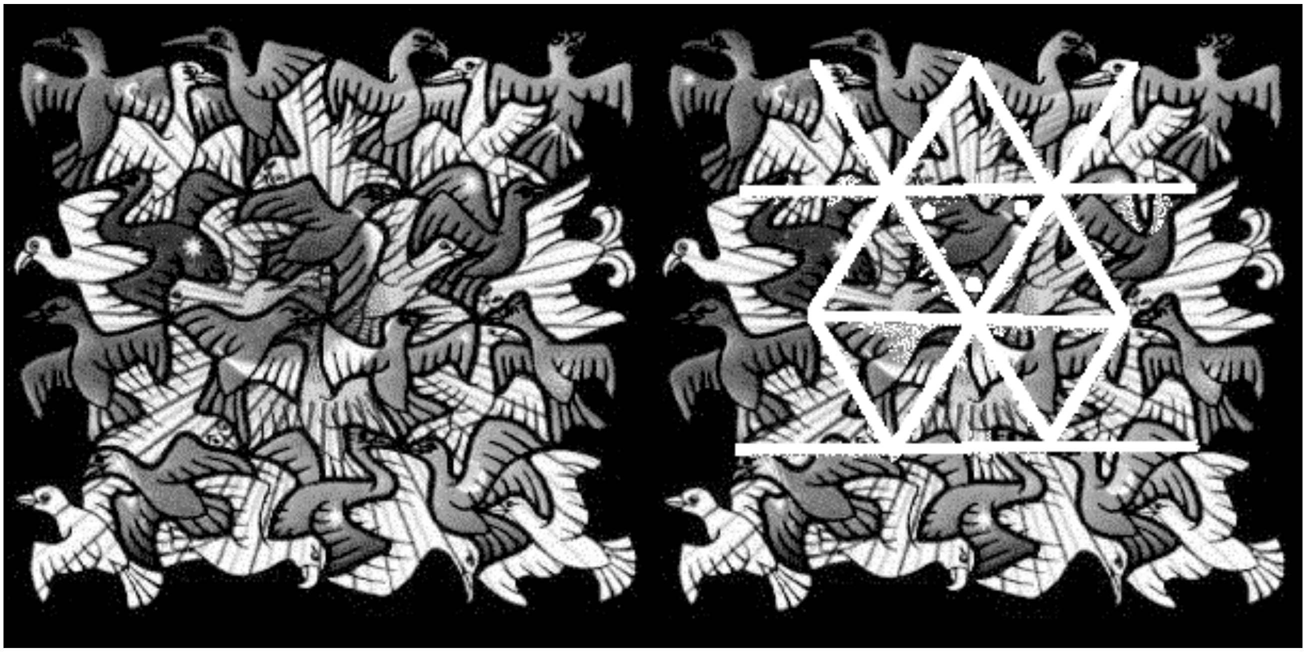


Figure 2: Sun and Moon by M.C.Escher (1948).

In Figure 2, there are two types of birds, which are all roughly triangular (their vertices being the points where 6 birds are touching: the wing-tips and the beaks). The birds are all the same size in their space, so that the 6 angles at a vertex are all the same. There are always **six** birds coming together at a vertex, so that each of the **interior angles** (the white dots on the image to the right) of each bird's triangle is:

360 degrees / 6 = 60 degrees.

The sum of the three angles of the triangle of each bird is therefore (60 + 60 + 60 =) 180 degrees, so that we now know that the curvature is flat.

First, guess what the curvature is in Figure 3. Then determine it using the method from the example.

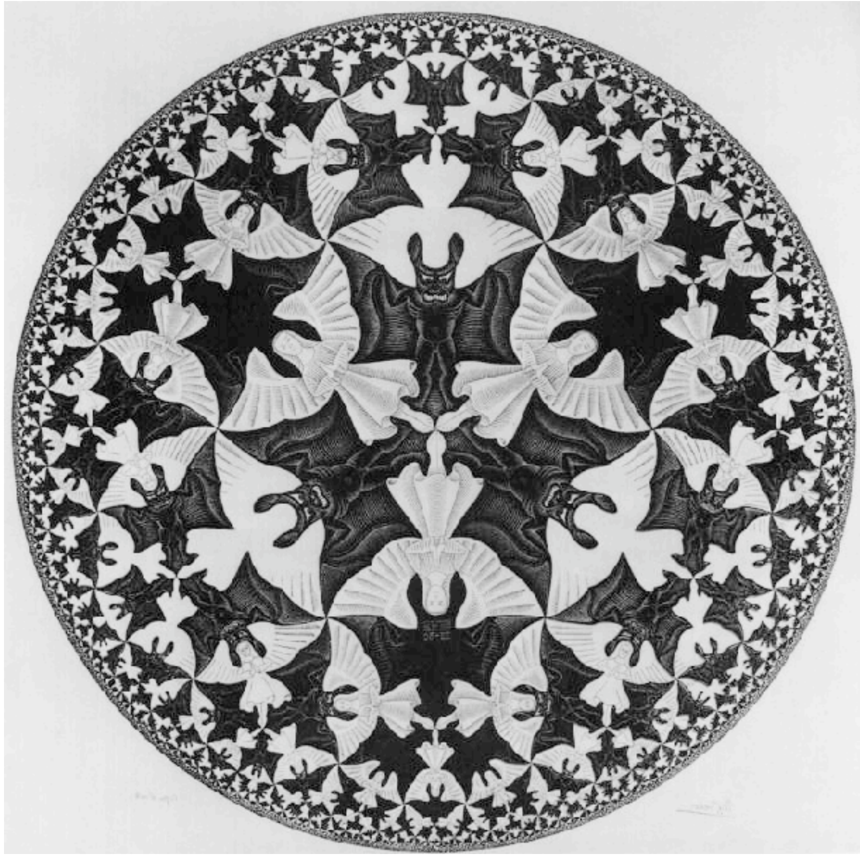


Figure 3: Circle Limit 4 -- (Heaven and Hell) by M.C.Escher (1960).

Again, the angels and devils occupy identical triangles in their own universe. Note that you are **not supposed to measure the angles**, but that you will have to use the method described in the example above, counting triangular tiles meeting at a vertex point. Also note that the triangles are **not** equilateral. That is, in this picture, all three angles are not the same! Show your work (it shouldn't take much space at all).

4. Enough with those 2-dimensional analogies. Let's move on to our real universe and see how geometry might tell us things interesting to astronomers and you. How might you use two beams of light to figure out what the curvature of our universe is? Of course, there's a big problem here: we can't follow the paths of the two light rays throughout the universe! On top of that, the local curvature of our universe isn't necessarily the same as the global curvature at all. What dominates the curvature in the inner solar system? Is it flat, positive or negative? How do we know?

The Curvature of Space: Worksheet

1. What would a 4-dimensional sphere look like if it passed it through our space? What possible shapes could you see as the cube passed through Flatland?

2. Name three geometrical tests to see if your universe is positively curved?

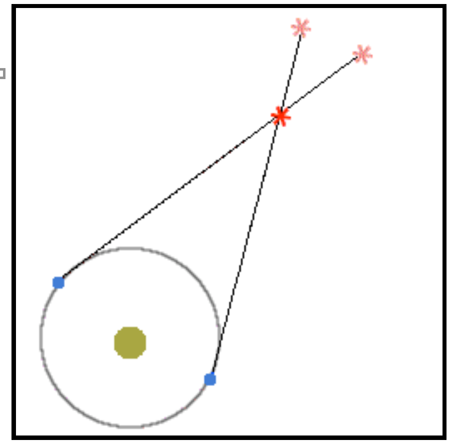
3. What do you guess is the curvature of the surface in Figure 3? What is the curvature of the surface in Figure 3? (Show your work!)

4. How might you use two beams of light to figure out what the curvature of our universe is?

5. What dominates the curvature in the inner solar system? Is it flat, positive or negative? How do we know?

Back

Parallax



Purpose
The student will explore parallax, a primary distance measuring technique.

Materials
Meterstick

Background and Theory
One of the most difficult problems in astronomy is determining the distances to objects in the sky. There are four basic methods of determining distances: radar, parallax, standard candles, and the Hubble Law. Each of these methods is most useful at certain distances, with radar being useful nearby (for example, the Moon), and the Hubble Law being useful at the most distant scales. In this exercise, we investigate the use of parallax to determine distances.

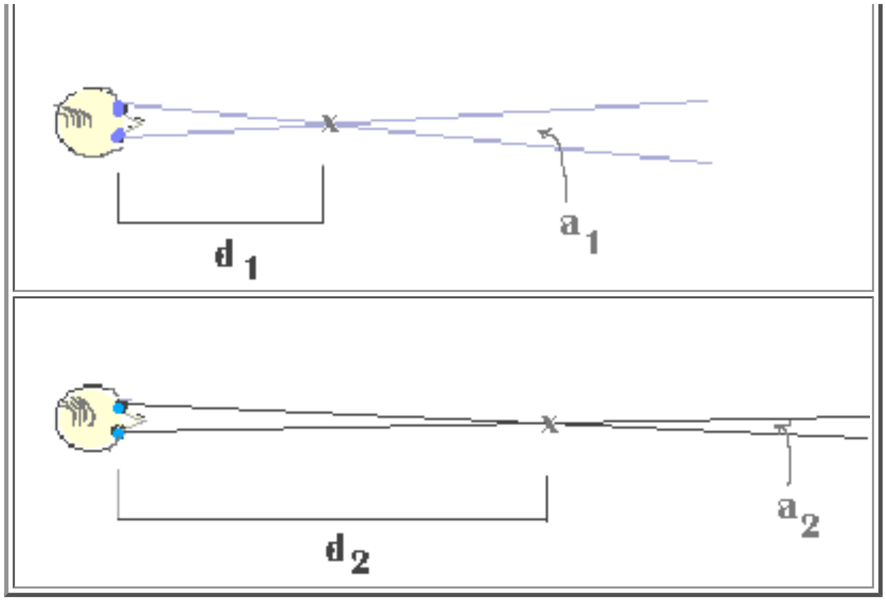
Even when observed with the largest telescopes, stars are still just points of light. Although we may be able to tell a lot about a star through its light, these observations do not give us a reference scale to use to measure their distances. We need to rely on a method with which you are actually already familiar: the parallax.

Procedure
Print out the worksheet.

1. Let's see how the parallax of an object varies with distance.

   a. One partner takes the meterstick and places the pencil vertically at the 50 cm mark. The other partner places the "zero" end of the meterstick against her/his chin, holding it out horizontally. This partner then alternates opening and closing each eye, noting how the pencil moves against specific background objects.
   b. Have your partner move the pen half of the original distance (to 25 cm). When you alternate opening and closing each eye does the pen appear to move more or less than before? Try to quantify how much more or less (twice as much? one-third as much? etc.).
   c. Now, have your lab partner move the pen twice the original distance to you, to approximately the end of the meterstick. When you alternate opening and closing each eye does the pen appear to move more or less than before? Try to quantify how much more or less (twice as much? one-third times as much? etc.).

2. Here is a look at the approximate relationship between distance and parallax from a different viewpoint, from above the observer.



- The distance $\mathbf{d_2}$ is twice the distance $\mathbf{d_1}$. Does it qualitatively appear that angle $\mathbf{a_2}$ is one-half of $\mathbf{a_1}$?
- When the distance is large enough that the parallax **angle** is very small, the parallax angle is proportional to the inverse of the distance (**1/d**). Conversely, if we can measure the parallax angle, we know that the distance to the object is proportional to the inverse of that angle.

3. There is a limit at which parallax becomes ineffective. This occurs when the parallax angle is so small that you can't see a change from one eye to the other. This distance is effectively infinity. You and your partner can find your personal infinity by taking the pencil farther and farther away from the observer until the parallax becomes undetectable.
   a. One of you should take the role of "observer" while the other walks straight away, holding the pencil out at arm's length, stopping every meter or so. The observer should alternate opening and closing each eye as the partner stops. How far away are you from each other when the pencil stops moving relative to even more distant objects?
   b. What can you determine about the usefulness of parallax at different distances?
4. To measure a parallax, you use a baseline: the distance between observation points. In the exercise above, the "baseline" is equal to the distance between the center of your eyes. Measure this distance for you and your partner. Compare these two numbers to the distances found in Step 3a. Is there a relationship between the two sets of numbers?
5. In astronomy, we use a "baseline" of the diameter of the Earth's orbit. The infinite background is made of stars much farther away than the star or object in question. We can measure accurate parallaxes of thousands of stars; unfortunately, most stars are simply *too far* to get an accurate parallax, and we must resort to other methods to determine their distances. Label the following on the image on the worksheet: Reference star(s), target star, Earth, Sun, dates of observation (choose one, then find the other consistent with that choice).

6. Technology improves all the time, and our options for choosing a baseline may be expected to expand. Which of the following scenarios would give the longest baseline for measuring parallax (and therefore would be most desirable)? Which is most feasible to do today? Why?
    a. A satellite orbiting high above the Earth.
    b. A telescope on the Moon.
    c. A satellite in Jupiter's orbit.
    d. A satellite in Pluto's orbit.

Parallax Worksheet

1.
   a. Describe how the pencil moved against background objects:

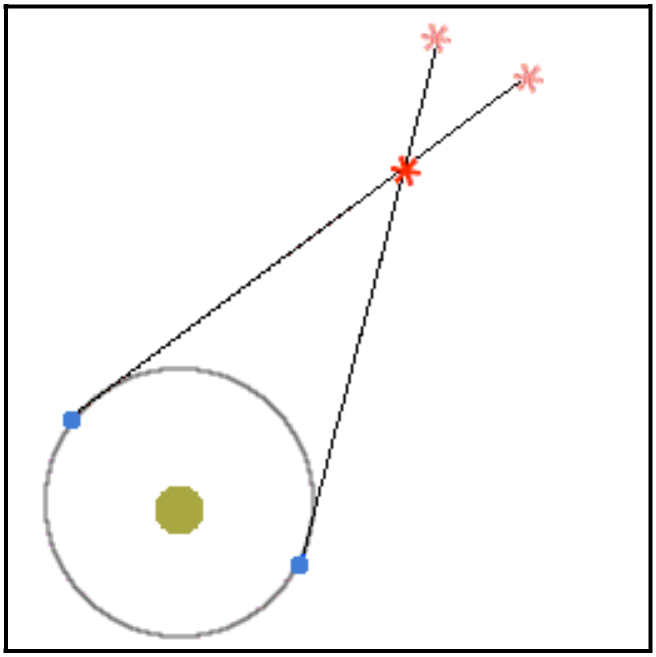
   b. Quantify the change in parallax when pencil was nearer: *(If you do not understand this question, read the instructions again before you ask for help.)*

   c. Quantify the change in parallax when pencil was farther:

2. (No written response needed)
3.
   a. Distance at which parallax became undetectable:

   b. Express your thoughts as to the usefulness of parallax at different distances. Is there a limit to measuring the parallax of an object?

4. Is the measurement of the baseline connected to the distance at which parallax becomes impossible to determine? Can you explain this?

5. 

6. Which scenario is most desirable: _________
Why?

Which scenario is most feasible: _________
Why?

Astronomy 1040 – Stars and Galaxies: The Ages of Star Clusters

NAME ___________________________

Goals:

- Understand how we can determine the distances of star clusters.
- Understand how we learn about stellar evolution from the properties of star clusters
- Understand how we can determine the ages of star clusters.

Cluster Hertzsprung-Russell Diagrams

Attached are Hertzsprung-Russell (HR) diagrams for six star clusters in the Milky Way. The clusters range in age from less than 20 million years (2×10^7 years) to 5 billion years (5×10^9 years). Today we will investigate the properties of star clusters, and determine their distances and ages.

The HR diagrams are plots of the brightness of stars (their apparent or absolute magnitude) on the y-axis versus (here we use apparent magnitude), the temperature (or color) of stars on the x-axis. In the attached diagrams, the color of the star is indicated by the "**B-V color**," which is the difference in brightness in Blue and yellow (Visual) filters.

- **Hotter stars** are brighter in blue light than in yellow light, have low values of B-V color, and are found on the **left side** of the diagram.
- **Cooler stars** are brighter in yellow light than in blue light, have larger values of B-V color, and are found on the **right side** of the diagram.

Since brighter stars are designated with a smaller number for apparent magnitude, magnitudes are plotted in reverse order to put the brighter stars at the top.

Investigating Stellar Evolution - For each cluster, identify the main sequence, and sketch in a line that follows the main sequence from its brightest point to the bottom of the diagram. For some clusters, you will need to extrapolate the main sequence to magnitudes fainter than have been plotted. Sometimes astronomical photographs don't reach faint enough stars to detect the bottom portion of the main sequence.

Using the HR diagrams, answer the following questions.

- Which cluster contains stars with the brightest **apparent** magnitudes?

- Which cluster contains the stars with the brightest absolute magnitudes?

- Which cluster contains the most red giants?

- In which cluster have white dwarf stars been detected?

- What is the difference in magnitude between white dwarfs and main sequence stars of the same temperature (color)?

Estimating Distances:

The Sun has a B-V color of about 0.6. For each cluster, estimate the **apparent** magnitude of stars like our Sun.

- Based on the apparent magnitudes of Sun-like stars, which cluster is the nearest?

- Based on the apparent magnitudes of Sun-like stars, which cluster is the farthest?

Sun-like stars have an absolute magnitude of about 5. The difference between the apparent magnitude and the absolute magnitude of a star is called the **distance modulus**.

From the chart below, estimate the distance to each cluster in light years.

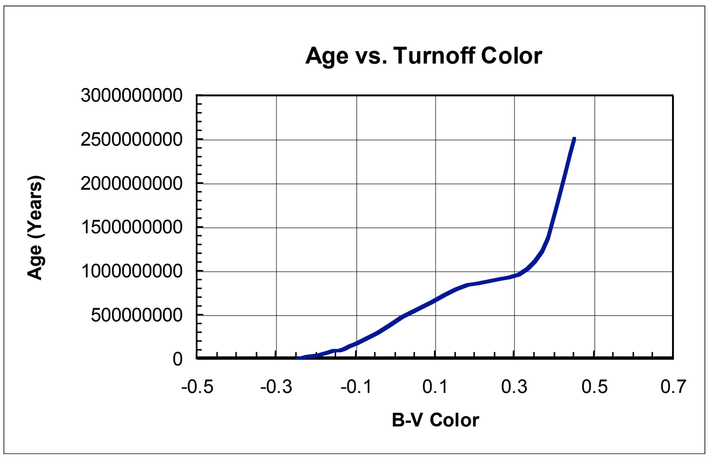
Distance Modulus	Distance in Light Years
0	30 ly
2.5	100 ly
5	300 ly
7.5	1,000 ly
10	3,000 ly
12.5	10,000 ly
15	30,000 ly
17.5	100,000 ly
20	300,000 ly

Cluster	Distance Modulus	Distance in Light Years
NGC 752		
M 67		
Hyades		
Pleiades		
M 34		
Jewelbox		

<u>Estimating the Ages of Star Clusters</u>

Massive stars burn their nuclear fuel faster than lower mass stars and leave the main sequence sooner. In a cluster in which all the stars formed at the same time, the stars "peel off" the main sequence from the top, leaving only progressively less and less massive stars remaining on the main sequence as time goes by. The **main sequence turnoff** is the point on the main sequence for which more massive stars have evolved away, but less massive stars still remain. Over time, the turnoff point moves down the main sequence to lower and lower mass stars. By measuring the turnoff point, astronomers can determine the age of a star cluster.

For each cluster, estimate the "color" of the main sequence turnoff in the HR diagram and determine the cluster's age from the chart below.

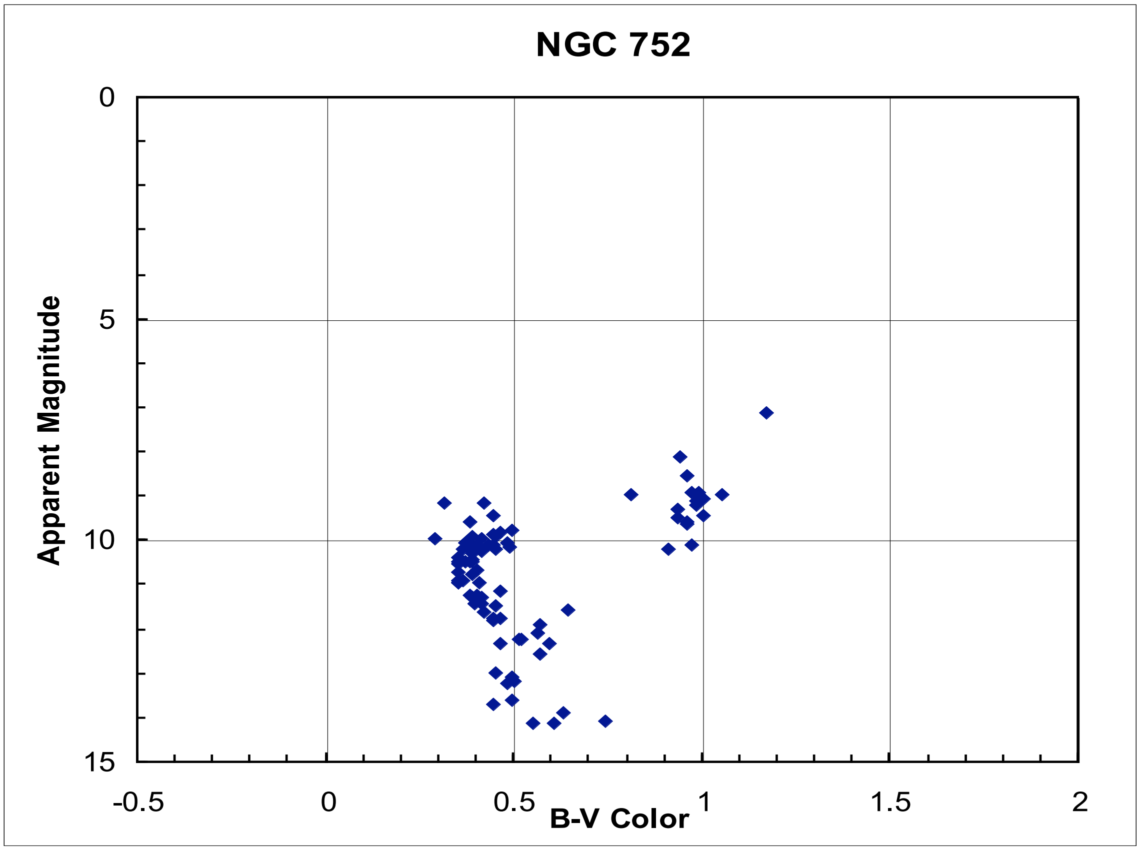


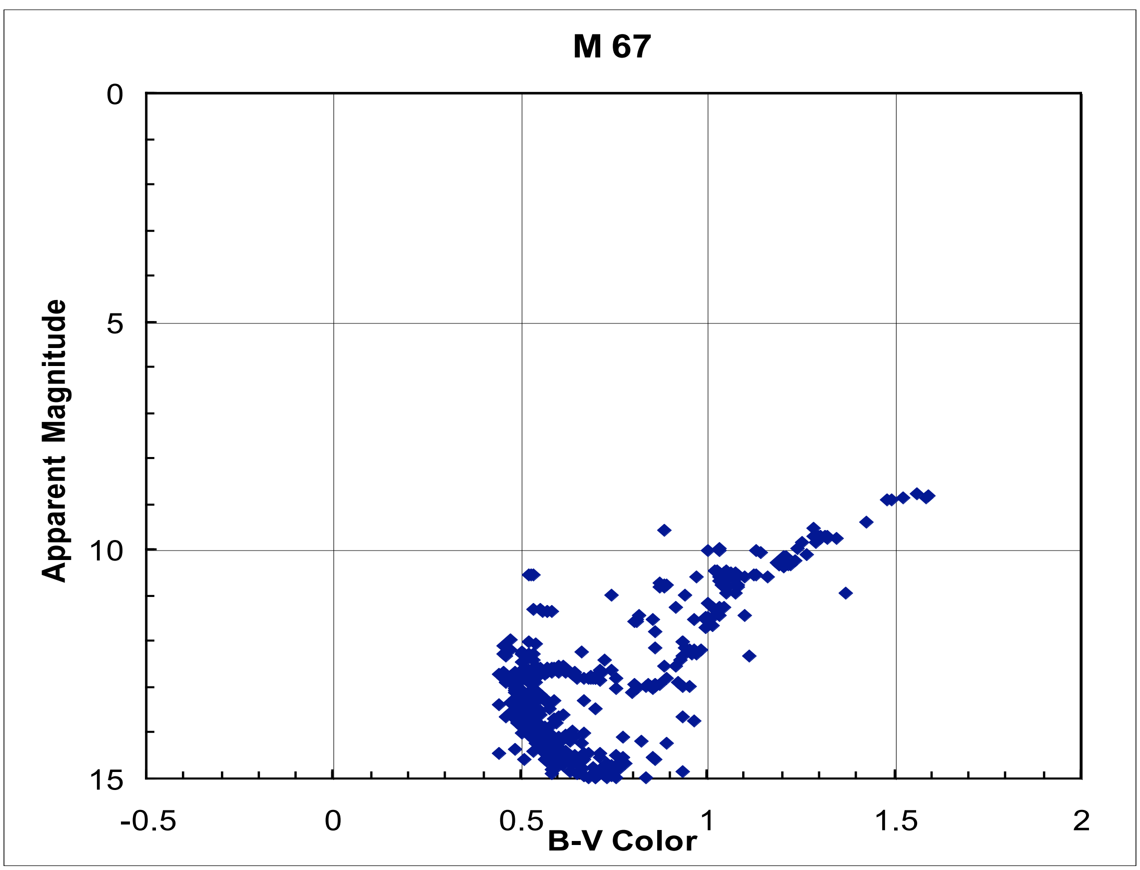
Cluster	Turnoff Color	Age
NGC 752		
M 67		
Hyades		
Pleiades		
M 34		
Jewelbox		

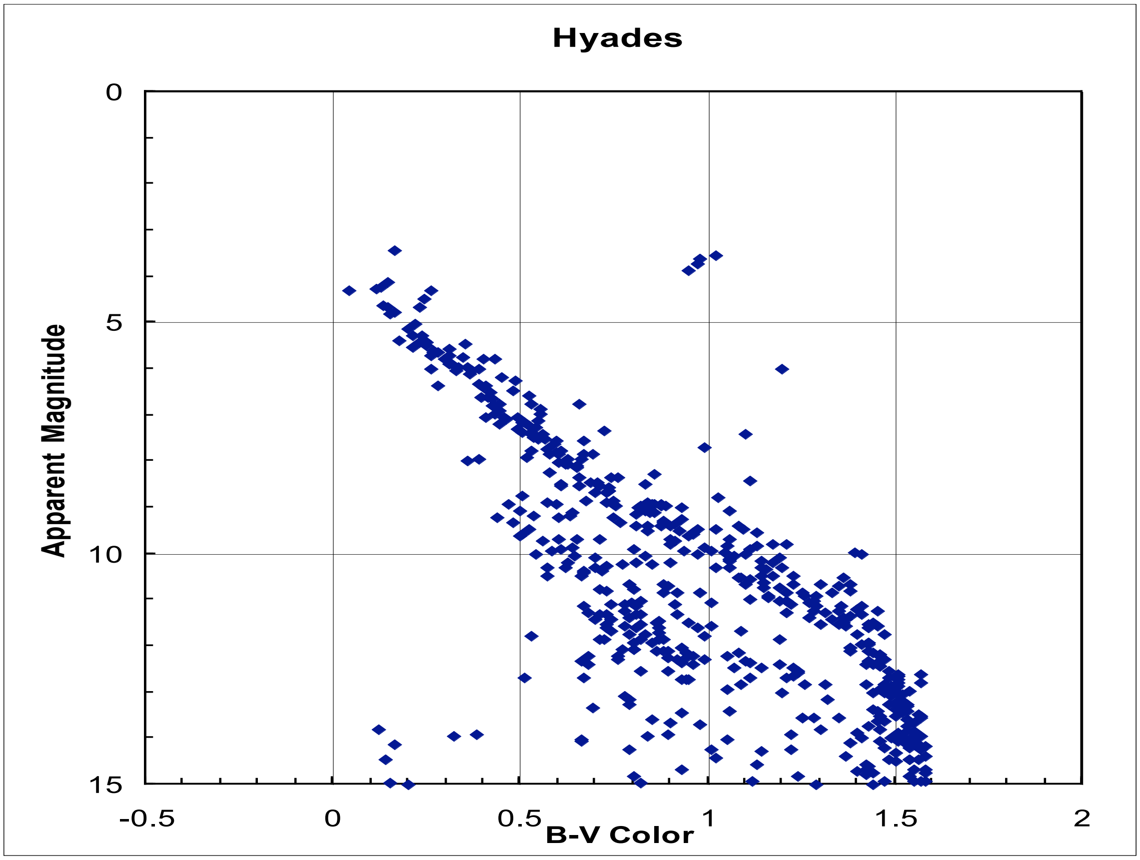
- Which cluster is the youngest?

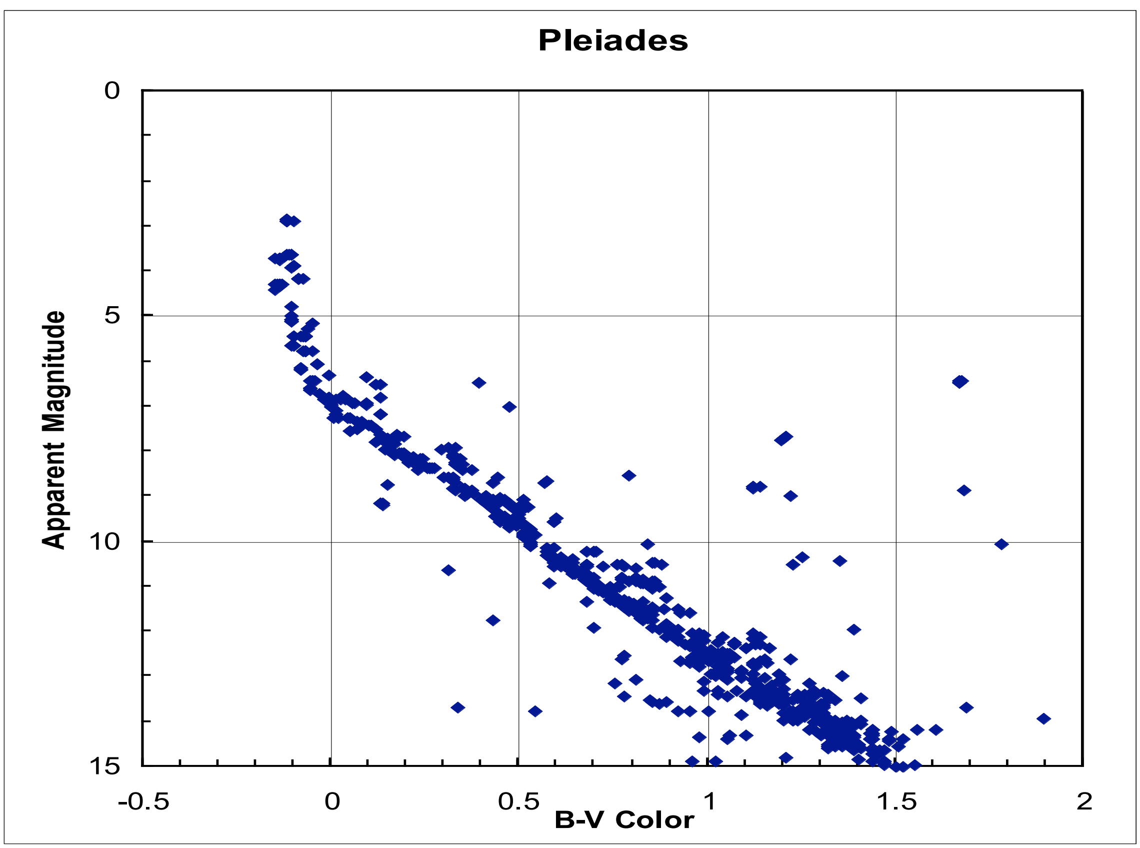
- Which cluster is the oldest?

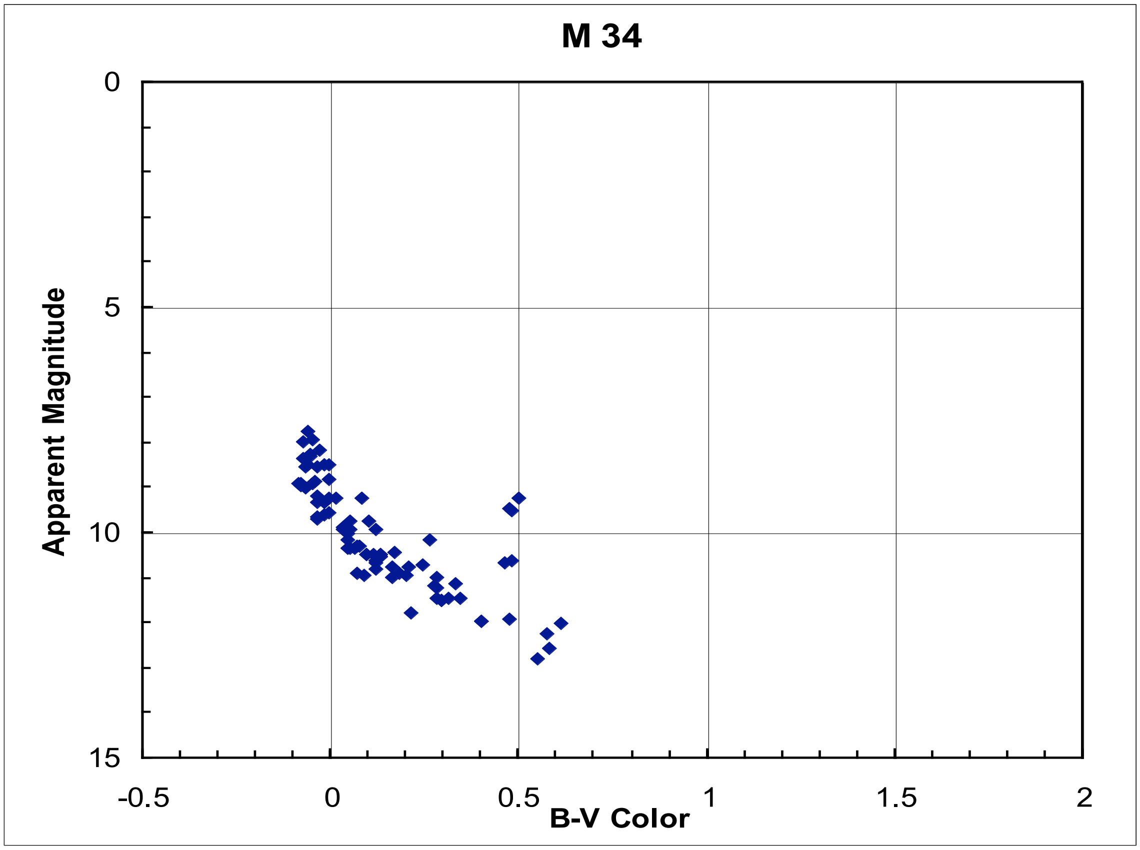
- **Critical Thinking:** Why has a cluster with a turnoff color of B-V=0.9 never been discovered?


NGC 752
Apparent Magnitude
B-V Color
0
5
10
15
-0.5
0
0.5
1
1.5
2


M 67
Apparent Magnitude
B-V Color
0
5
10
15
-0.5
0
0.5
1
1.5
2


Hyades
Apparent Magnitude
B-V Color
0
5
10
15
-0.5
0
0.5
1
1.5
2


Pleiades
Apparent Magnitude
B-V Color
0
5
10
15
-0.5
0
0.5
1
1.5
2


M 34
Apparent Magnitude
B-V Color
0
5
10
15
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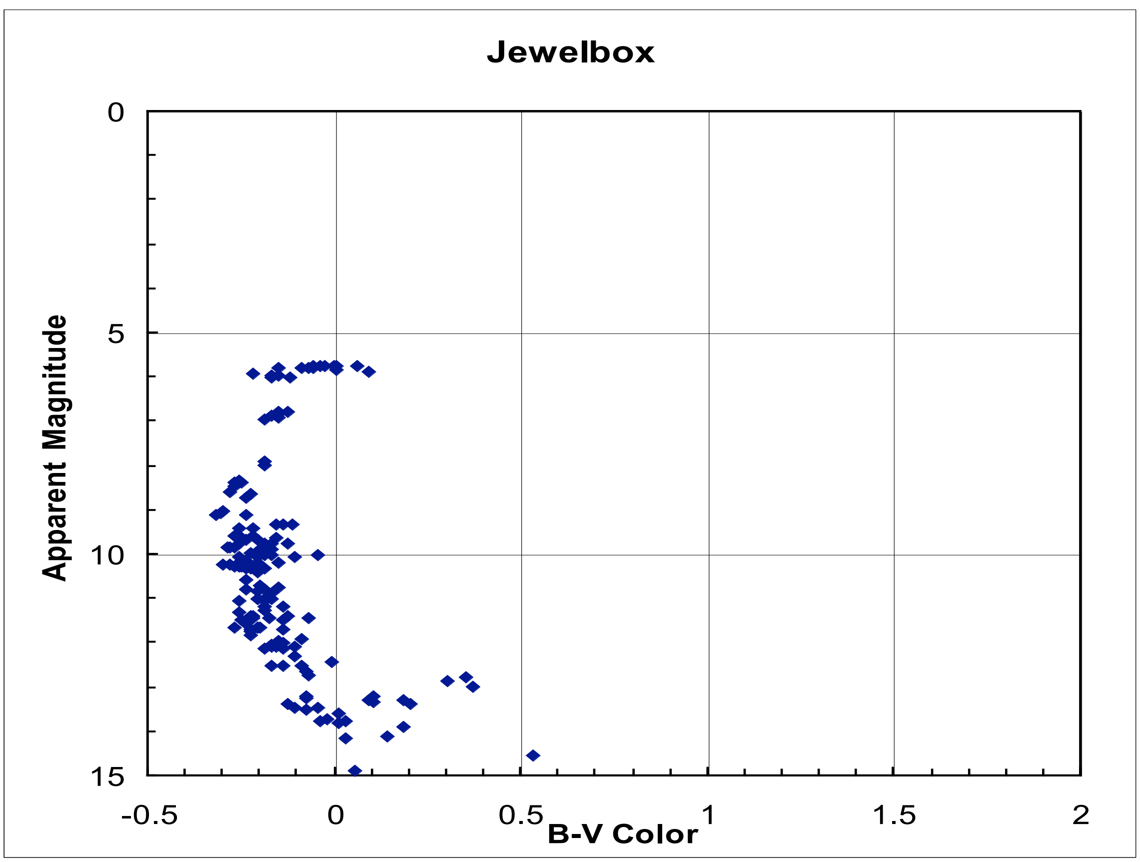
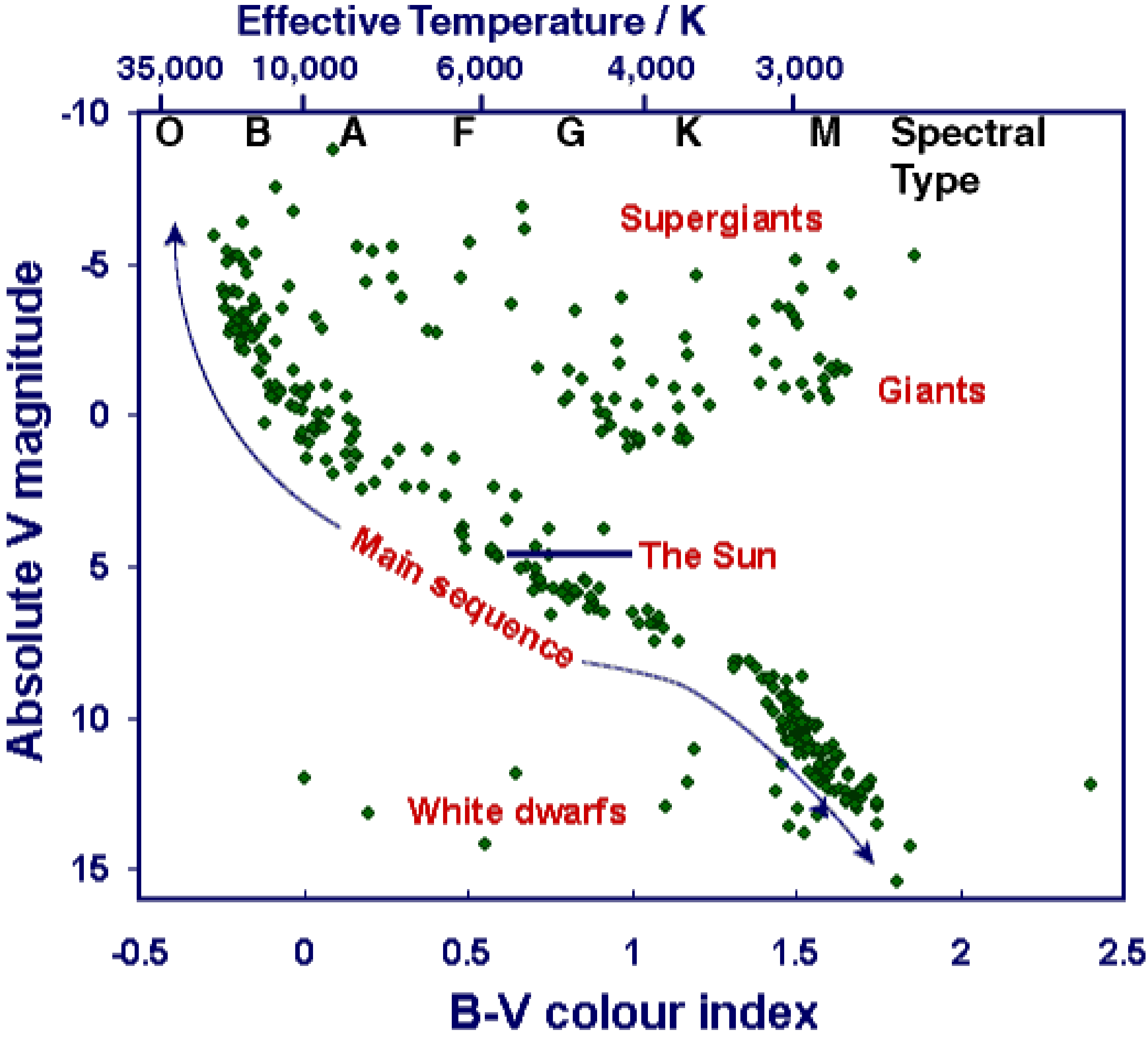
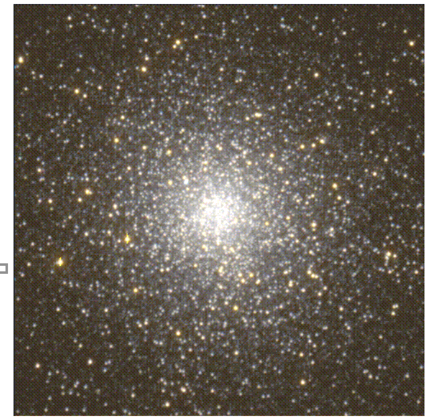
0
0.5
1
1.5
2


Jewelbox
Apparent Magnitude
B-V Color
0
5
10
15
-0.5
0
0.5
1
1.5
2



Effective Temperature / K
35,000
10,000
6,000
4,000
3,000
-10
-5
0
5
10
15
O
B
A
F
G
K
M
Spectral Type
Supergiants
Giants
Main sequence
The Sun
White dwarfs
Absolute V magnitude
-0.5
0
0.5
1
1.5
2
2.5
B-V colour index

Distance to the Center of the Milky Way



Adapted from *Learning Astronomy by Doing Astronomy* by Ana Larson

Summary

In this exercise, you will use the locations of globular clusters in the halo to estimate the distance of the Sun from the center of the Milky Way.

Background and Theory

In the not-too-distant past, astronomers though that the Sun was at the center of our galaxy, the Milky Way. Observations and determinations of distances were hampered by the lack of knowledge of interstellar dust, which blocks much of the starlight from distant parts of the galaxy (including the galactic center). It was not until the distances to globular clusters were determined using the RR Lyrae stars that a more accurate picture of the size and shape of our galaxy was constructed. By determining the distribution of the globular clusters, Harlow Shapley was able to determine the diameter of the galaxy, and the distanc to the galactic center.

Procedure

1. Using the polar graph in Figure 1, plot the galactic longitude versus distance for the globular clusters in Table 1. The Sun is at the center of this polar graph. Note that the distance given is not the actual distance, since we have projected a 3-dimensional space onto a 2-dimensional piece of paper. The actual distances are greater than those given here.

2. Estimate the center of the distribution of globular clusters, and mark it on the graph. Describe **how** you defined the center of the distribution.
3. Determine the distance from the Sun to the center of the distribution.
4. Determine the direction to the center of the distribution. This is the direction to the center of the galaxy.
5. In which constellation does the center of the galaxy lie?
6. At what time of year is this constellation most conspicuous? Hint: check a planisphere, or the textbook.
7. Why is the Milky Way Galaxy more spectacular in the summer than in the winter? (ignore weather conditions!)
8. Describe the two dimensional space distribution of the globular clusters.
9. How do we know the Sun is not at the center of this distribution?
10. During their long orbit around the center of the Milky Way Galaxy, each globular cluster will cross through the plane of the disk. Why do we find most globular clusters far out in the halo? (Hint: Do Kepler's laws apply to globular clusters?)

Figure 1: Polar Plot of the Distribution of Globular Clusters

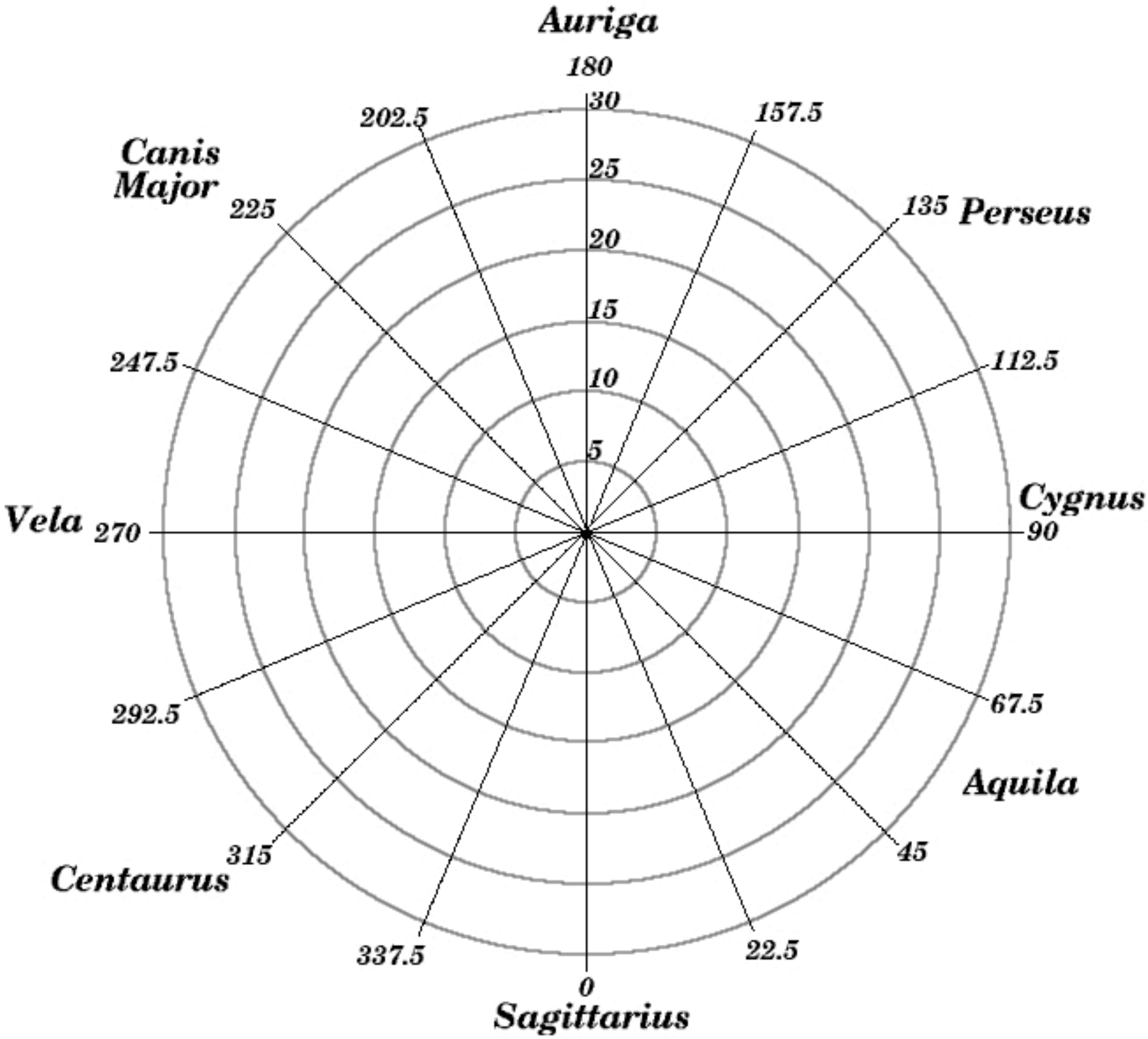
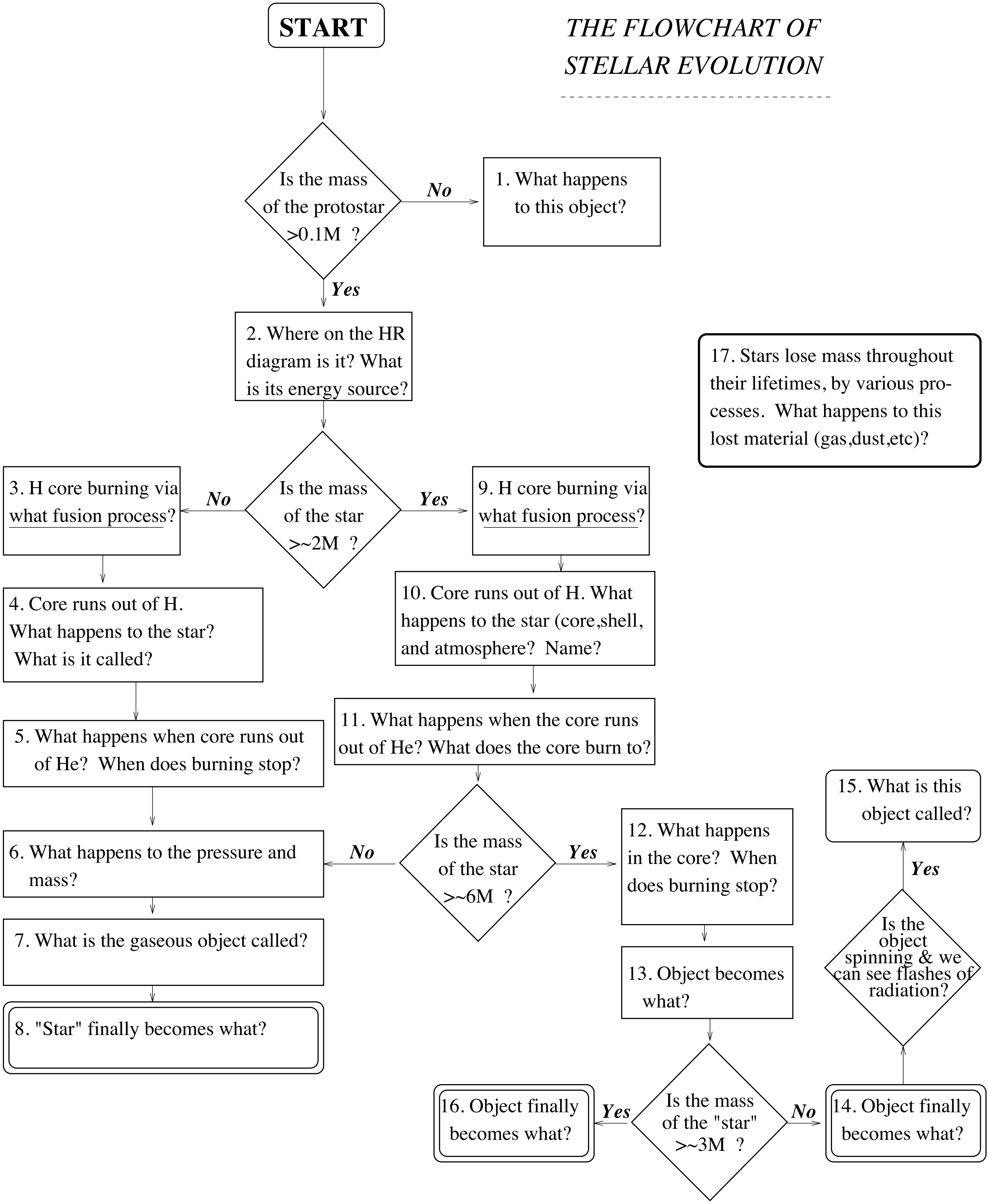


Table 1: Globular Cluster Data

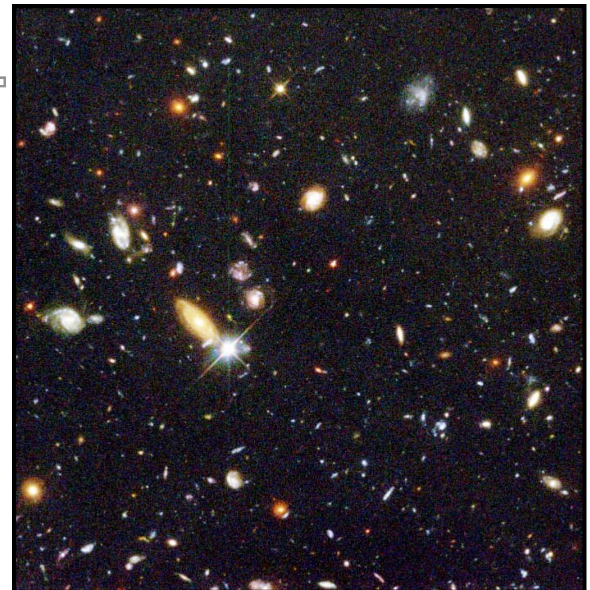
NGC #	Gal. Long.	Projected Distance (kpc)		NGC #	Gal. Long.	Projected Distance (kpc)		NGC #	Gal. Long.	Projected Distance (kpc)		NGC #	Gal. Long.	Projected Distance (kpc)
104	306	3.5		6273	357	7		288	147	0.3		6284	358	16.1
362	302	6.6		6287	0	16.6		1904	228	14.4		6293	357	9.7
2808	283	8.9		6333	5	12.6		Pal 4	202	30.9		6341	68	6.5

4147	251	4.2		6356	7	18.8		4590	299	11.2		6366	18	16.7
5024	333	3.4		6397	339	2.8		5053	335	3.1		6402	21	14.1
5139	309	5		6535	27	15.3		5272	42	2.2		6656	9	3
5634	342	17.6		6712	27	5.7		5694	331	27.4		6717	13	14.4
Pal 5	1	24.8		6723	0	7		5897	343	12.6		6752	337	4.8
5904	4	5.5		6760	36	8.4		6093	353	11.9		6779	62	10.4
6121	351	4.1		Pal 10	53	8.3		6541	349	3.9		6809	9	5.5
O 1276	22	25		Pal 11	32	27.2		6626	7	4.8		6838	56	2.6
6638	8	15.1		6864	20	31.5		6144	352	16.3		6934	52	17.3
6171	3	15.7		6981	35	17.7		6205	59	4.8		7078	65	9.4
6218	15	6.7		7089	54	9.9		6229	73	18.9		7099	27	9.1
6235	359	18.9		Pal 12	31	25.4		6254	15	5.7		7492	53	15.8
6266	353	11.6												

THE FLOWCHART OF STELLAR EVOLUTION



The Expanding Universe



Hubble Deep Field HST • WFPC2
PRC96-01a • ST ScI OPO • January 15, 1996 • R. Williams (ST ScI), NASA

Summary

In this exercise, you will use a two-dimensional analogy to explore the expansion of the Universe.

Background and Theory

The Hubble Law tells us that our Universe is expanding. We observe galaxies, find their distances and their velocities, and find that they are all moving away from us. The more distant the galaxy, the faster it is moving away. From this information, we can estimate the age of our Universe. We assume that the Universe has always been expanding at the same rate, then we know how long distant galaxies have been travelling in order to get where they are today!

Procedure

Print out the worksheet.

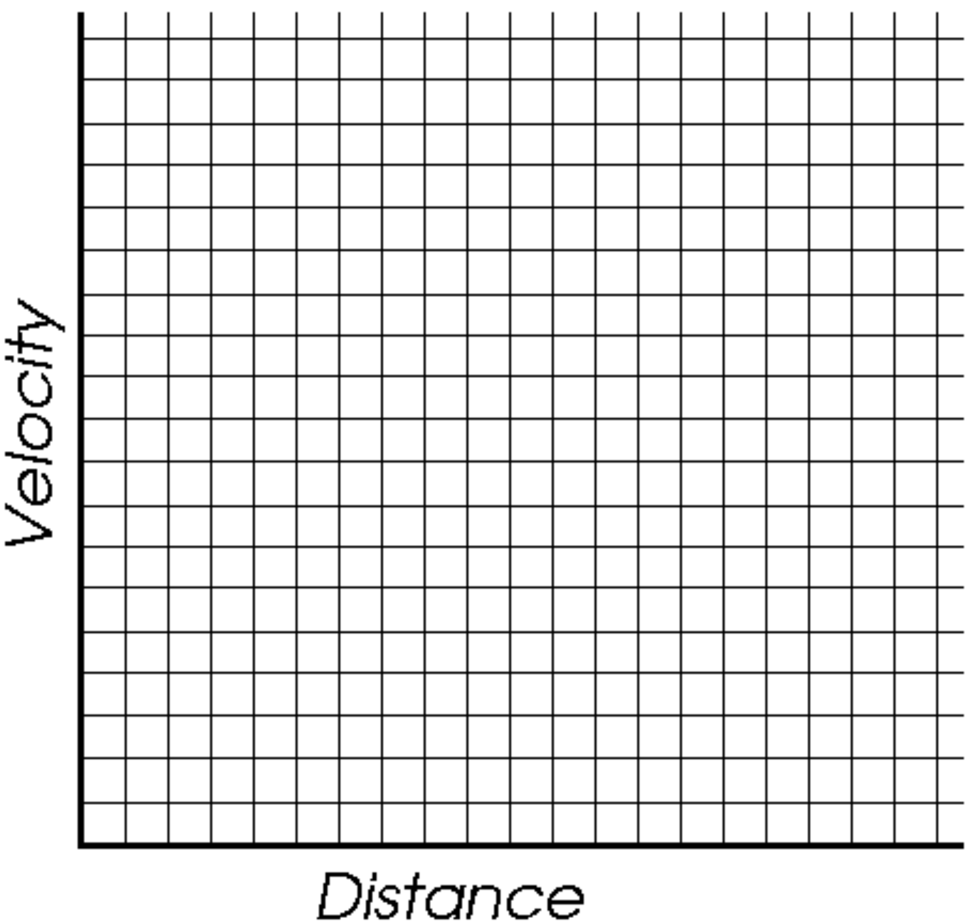
1. Blow up the balloon a little bit. DO NOT TIE IT SHUT!
2. Draw and number ten galaxies on the balloon. Mark one of these galaxies as the reference galaxy.
3. Measure the distance between the reference galaxy and each of the numbered galaxies. The easiest way to do this is to use a piece of string. Stretch it between the two points on the balloon, then measure the string. Record these data in the table. Be sure to indicate the units you are using.
4. Now blow up the balloon. You can tie it shut this time if you like.
5. Measure the distance between the reference galaxy and each of the numbered galaxies. Record these data in the table.
6. Subtract the first measurement from the second measurement, record the difference in the data table.
7. Estimate the amount of time it took you to blow up the balloon (in seconds). Divide the distance traveled (the difference) by this time to get a velocity.
8. Plot the velocity versus the second measurement to get the "Hubble Law for Balloons". Don't forget to label the units on your axes!
9. Fit a line to your data. "Eyeballing" it is close enough.
10. Find the slope. (Remember that the slope is "the change in y over the change in x".) This is exactly the way that we find the value of H from Hubble's Law.
11. Find the age of your balloon universe from this slope. How does it compare to the time it took you to blow the balloon up between measurements? What assumptions are you making by doing this? Are they sensible assumptions?
12. How would your results change if you used a different reference "galaxy" on the balloon? If you are not sure, try it!

UW Astro. Dept. Main Page Lab Listing

The Expanding Universe

Galaxy Number	first measurement	second measurement	difference	velocity

1. Plot the velocity versus the second measurement to get the "Hubble Law for Balloons". Label the units on your axes.



2. Draw a 'best-fit' straight line through your points. The line should go through (0,0) on your graph. Why?

3. Find the slope.

4. Find the age of your balloon universe from this slope.

5. How does this age compare to the time it took to blow up the balloon the second time?

6. What assumptions do you make about your balloon universe when you find it's age by this method? Are these sensible assumptions?

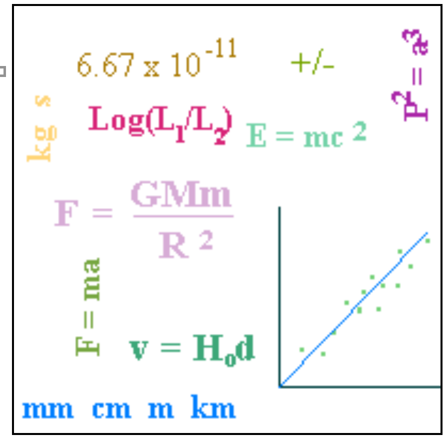
7. How would your results change if you used a different reference "galaxy" on the balloon? If you are not sure, try it!

Supporting Materials

PHYS/ASTR 1040:	Elementary Astronomy
Instructor:	John C. Armstrong
Course Web Page:	weber.edu/jcarmstrong

Scientific Methods



Summary
The student reviews five essentials of science: scientific notation, measurement errors and uncertainties, statistics, significant digits, and the scientific process.

Materials

- 15-cm Ruler (we measure using the metric system)
- Scientific Calculator (borrow one if necessary)
- Graph Paper

Background and Theory

Astronomy 101 covers the basic concepts in astronomy and astrophysics (really the same thing). There is some math involved -- algebra, scientific notation, arithmetic -- all grade school level mathematics.
If you happen to be a *mathophobe* (or *arithmetically challenged*), please do not worry about the level of math used in this course. First, the difficulty is at the 8th grade algebra level; second, remember that in class you always have your fellow students and your instructor to help.

Do you need to freshen up your algebra? Check out this review.

Procedure

Print out the answer sheet.

Read through the material presented here and follow the directions. Answer them as briefly as possible, yet make sure your answers are complete and understandable.

I. **Scientific Notation**
If necessary, review the section on scientific notation. Work the following problems first on paper, and then using a calculator. If you do not own a calculator that uses scientific notation, then **find someone who does** and borrow it.

   A. Multiply: 3.1×10^7 by 3×10^5

   B. Multiply: 1.496×10^{11} by 5.2

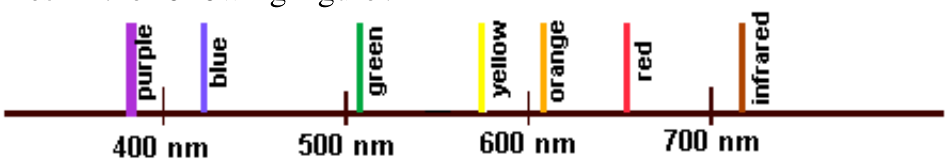
   C. Divide: $(6.4 \times 10^6)^2$ by 6.7×10^{-11}

II. **Measurement Errors and Uncertainties**

The term "error" signifies a deviation of the result from some "true" value. Often we cannot know what the true value is, and we can determine only estimates of the errors inherent in the experiment.

If we repeat the experiment, the results may differ from those of the first attempt. We can express this difference as a discrepancy between the two results. The fact that a discrepancy arises is due to the fact that we can determine our results only within a given ***uncertainty*** or error. The more precise our measuring tool, the more precise our answer; the more accurate our input data, the more accurate our results. But, *we will always have some uncertainty*.

A. As a simple example, find the wavelengths (in *nm* or 10^{-9} meters) of the blue, yellow, and red lines in the following figure?



1. Wavelengths:

2. What is the uncertainty in your answer? That is, how far off (in *nm*) could your determinations be?

3. How could you make your answer more precise?

4. Now, use a ruler to measure the distances between the blue and yellow lines, yellow and red lines, and blue and red lines. (You can do this directly from the screen; watch out for a parallax effect.) Write those measurements (in *cm* or *mm* here. Include your uncertainty for each measurement. For example, 4.5 cm +/- 0.05 cm:

5. Determine a rough "scale factor" or "plate scale" by dividing the difference in wavelengths between two colored lines by the distance in cm or mm (the units will be *nm/cm* or *nm/mm*. For example, if you estimated the yellow line wavelength at 510 nm and the blue line wavelength at 425 nm, the difference in wavelength is 85 nm. You measure a difference of 29 mm (+/- 1 mm). The scale factor would be 85nm/29mm, or 2.9 nm/mm. Do this for at least 3 different pairs of lines, average your results, and write your scale factor here:

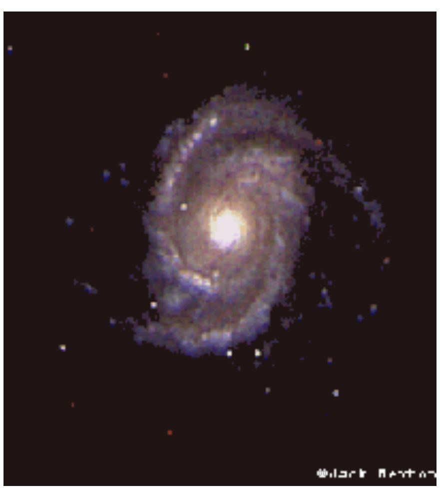
6. If you had a friend measure the distances, would her/his results differ from yours? Why or why not?

In science, we can never hope to have absolute precision, absolute accuracy. It is perfectly acceptable to have large uncertainties, ***as long as we let the reader know our estimate of those uncertainties so that an intelligent evaluation of the results can be made***. As scientists, we strive to perfect our experiments and observations in order to improve the precision and accuracy of our results.

B. I have used both terms "accuracy" and "precision." These two words do not mean the same thing. How does an "accurate" measurement differ from a "precise" measurement?

C. An astronomer has considerable leeway in setting the criteria for her/his observations and the interpretations of those observations. For example, astronomers may assume that if they see two morphologically similar galaxies, these galaxies are similar in actual size. Therefore, if one of the galaxies appears to be one-half the size of the other, then the "smaller" galaxy is twice as far from us.

Measure the diameters of the following three, similar (but not identical) galaxies (from "The Ultimate CCD Collection" by Don Parker and Jack Newton):



1. What criteria did you use when determining each diameter?

2. In determining the relative distances of these galaxies:
   a. Would it matter if you used a different criterion for measuring each galaxy? Why or why not?

   b. Would it matter if one of your class mates used different criteria than you did? Why or why not?

   If you were using these results in a report for this class, you would mention briefly your measuring criteria.

3. Distances
   a. Which galaxy is the nearest? Farthest?

   b. How much farther away from us is the farthest galaxy compared to the nearest?

   c. What assumption (stated above) is necessary for you to feel confident your answer is correct?

III. **Statistics**

We use an absolute minimum of statistics in this class. You are probably very familiar with the terms "mean" and "standard deviation" from your high school math as well as from large lecture classes here where the grades are based on a curve.

If we have enough data, we may wish to graph the observations and see if there is a relationship between the variables. For example, one can plot the magnitudes (brightness) of the stars on a planisphere against the sizes of the dots representing those stars. Here are measurements for five stars from the Edmund Scientific Star and Planet Locator:

Star Size vs. Magnitude

Star Name	Diameter (mm)	Magnitude
Sirius	2.7	-1.5

Arcturus	2.1	0.0
Procyon	2.0	0.4
Fomalhaut	1.8	1.2
Adhara	1.5	1.5

1. Using a piece of graph paper, plot the magnitude (brightness) of the star against its size.

2. Draw a straight, best-fit line through the data points. This means, draw a line that has approximately just as many data points above it as below it. Since these are real measurements, and each measurement has an error (I estimate +/- 0.2 mm), it would be a rare occasion indeed if the data formed a perfectly straight line.

3. Find the slope of this line. That is, find the change in ***y*** divided by the corresponding change in ***x***.

   a. What is the slope of the line?

   b. Does the equation, ***y = mx + b*** seem familiar?

   c. Do you see that for all future measurements, all we need to do is measure the size of the star and use our relationship to find the corresponding magnitude?

If this is child's play for you, then use your scientific calculator and a linear regression to find the slope and intercept, and the error in that slope and intercept, for these data.

If we have a large number of observations of the same thing,
- we expect the mean value to be at least near to the true value.
- we can find this mean value by totalling all values and dividing by the number of values.
- we can regard any deviation from the mean as an error.

We can use our calculators (or those of our classmates) to find the mean and standard deviation for our large number of observations.

IV. **Significant Digits**

The guidelines for significant digits are:

- Carry one or two non-significant digits through all calculations.
- Round the final answer to the required number of significant digits.
- The number of significant digits will be that of the value having the **smallest number** of significant digits.

A. How many significant digits are in the following numbers?
   1. 1.5
   2. 3.5689
   3. 4000
   4. 3.68

B. Multiply 1.5, 3.5689, 4000, and 3.68. Round your answer to the correct number of significant digits.

Did you get 80,000? If not, check out the math review on significant digits (which will also give you the answer to the "precise vs. accurate" question above).

Revised: 24 April, 2003

Scientific Methods: Algebra Review

The key to solving simple algebraic equations containing a single unknown (e.g. x + 6 = 10) is to realize that the equation is an equality. As long as you do the same mathematical operation (e.g. add a constant, subtract a constant, multiply by a constant, and divide by a constant) to both sides of the equation, the equality is still an equality. This includes squaring both sides of the equation or taking the square root of both sides of the equation.

Fundamental Laws:

- Distributive Law: 3(x + 2) = 3x + (3)(2) = 3x + 6
- Associative Law: 4x - 7x = x(4 - 7) = -3x

Example 1: $x + 6 = 10$	To solve for x, a. subtract 6 from both sides of the equation	$x + 6 = 10$ $(x + 6) - 6 = (10) - 6$ $x = 4$
Example 2: $2x - 6 = -3$	To solve for x, a. add 6 to both sides of the equation b. divide both sides by 2.	$2x - 6 = -3$ $(2x - 6) + 6 = (-3) + 6$ $2x = 3$ $x = 3/2$ or 1.5
Example 3: $\frac{5x + 2}{6} = 2$	To solve for x, a. multiply both sides by 6, b. subtract 2 from both sides, c. divide both sides by 5.	$\frac{5x + 2}{6} = 2$ $6\left[\frac{5x + 2}{6}\right] = (6)(2)$ $5x + 2 = 12$ $(5x + 2) - 2 = 12 - 2$ $5x = 10$ $\frac{5x}{5} = \frac{10}{5}$ $x = 2$

Example 4: $\frac{2x+3}{4} = \frac{x+7}{3}$	To solve for x, a. multiply both sides of the equation by 4 and 3 to cancel out the denominators b. use the distributive law, c. by adding and subtracting, move the x terms to one side, and the non-x terms to the other side in line 5, d. use the associative law to simplify to get line 7, e. divide both sides by 2.	$\frac{2x+3}{4} = \frac{x+7}{3}$ $(4)(3)\left[\frac{2x+3}{4}\right] = (4)(3)\left[\frac{x+7}{3}\right]$ $(3)(2x+3) = (4)(x+7)$ $6x + 9 = 4x + 28$ $(6x - 4x) = (28 - 9)$ $x(6 - 4) = 19$ $2x = 19$ $x = 19/2 = 9.5$
Example 5: $49 = \frac{(3x+8)^2}{x^2}$	This problem could be very complicated and become a quadratic equation. However, if you a. take the square root of both sides b. you are left in line 3 with a straightforward algebra problem.	$49 = \frac{(3x+8)^2}{x^2}$ $\sqrt{49} = \sqrt{\frac{(3x+8)^2}{x^2}}$ $7 = \frac{3x+8}{x}$ $7x = 3x + 8$ $7x - 3x = 8$ $x(7 - 3) = 8$ $4x = 8$ $x = 2$

QUIZ: **Solve for x.**

Question 1	Question 2	Question 3	Question 4
$2x - 3 = 1$	$\frac{7x+2}{4} = 4$	$\frac{2x-4}{5} = \frac{4x+1}{8}$	$57 = \frac{(2x+3)^2}{(x-1)^2}$

Answers: **(1)** +2 **(2)** +2 **(3)** -9.25 **(4)** +1.90

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This page adapted from a math review for chemistry students at Texas A&M University

Scientific Methods: Scientific Notation

Scientific notation is the way that scientists handle very large or very small numbers, such as the size or age of the Universe, or the size of the national debt. For example, instead of writing 1,500,000,000,000, or 1.5 trillion, we write 1.5×10^{12}. There are two parts to this number: 1.5 (digits term) and 10^{12} (exponential term). Here are some examples of scientific notation used in astronomy (and a few just for comparison!).

THE CHART OF REALLY BIG NUMBERS

1,000,000,000,000,000,000,000,000,000,000 = 1×10^{30}	We don't even have a word for this. It's the mass of the Sun in kilograms.
100,000,000,000,000,000,000,000 = 1×10^{23}	One hundred trillion billion: The approximate number of stars in the Universe
40,100,000,000,000 = 4.01×10^{13}	40.1 Trillion: the distance (in km) to the nearest star, Proxima Centauri.
1,600,000,000,000 = 5.7×10^{12}	5.7 Trillion: the number of dollars in the U.S. national debt, circa 2000.
200,000,000,000 = 2×10^{11}	Two Hundred Billion: Approximate number of stars in the Milky Way Galaxy.
15,000,000,000 = 1.5×10^{10}	15 Billion: Approximate age of the Universe (in years).
6,000,000,000 = 6×10^{9}	Six Billion: Approximate number of people on the planet, circa 2000.
1,000,000,000 = 1×10^{9}	One Billion: The number of Earth-sized planets that would fit into the Sun; Also the speed of light in km/hr
100,000,000 = 1×10^{8}	One hundred million: the radius of the Sun in meters.
78,300,000 = 78.3×10^{6}	78.3 million: the minimum distance from the Earth to Mars.
	Three hundred eighty four

$384{,}400 = 3.844 \times 10^5$	thousand, four hundred: the distance to the moon from Earth (in km)
$40{,}000 = 4 \times 10^4$	Forty thousand: the distance around the Earth at the equator (in km).
$4{,}000 = 4 \times 10^3$	Four thousand: The circumference of Pluto (in km).

As you can see, the exponent of 10 is the number of places the decimal point must be shifted to give the number in long form. A **positive** exponent shows that the decimal point is shifted that number of places to the right. A **negative** exponent shows that the decimal point is shifted that number of places to the left. (None of these appear above, because they would be really SMALL numbers...but you get the idea!)

The number of digits reported indicates the number of significant figures. This can help you figure out when the zeroes are important, and when they are just "place-holders".

$$4.660 \times 10^7 = 46{,}600{,}000$$

This number has 4 significant figures. The first zero is the only one that is significant, the rest are only place-holders. As another example,

$$5.3 \times 10^{-4} = 0.00053$$

This number has 2 significant figures. LEADING zeroes are always place-holders.

How to do calculations:

On your scientific calculator:

Make sure that the number in scientific notation is put into your calculator correctly.
Read the directions for your particular calculator. For most scientific calculators:

1. Punch the number (the digits part) into your calculator.
2. Push the EE or EXP button. Do **NOT** use the x (times) button!!
3. Enter the exponent number. Use the +/- button to change its sign.
4. That's all. Now you are free to continue as normal. Usually your calculator will return numbers in scientific notation if they are input in scientific notation. Otherwise you have to count the places from the decimal point...

To check yourself, multiply 5×10^{10} by 6×10^{-4} on your calculator. Your answer should be 3×10^7 (your calculator may say"3E7", which is the same thing).

If you don't have a scientific calculator, you will need to know the following rules for combining numbers expressed in scientific notation:

Addition and Subtraction:

- All numbers are converted to the same power of 10, and the digit terms are added or subtracted.
- Example: $(4.215 \text{ x } 10^{-2}) + (3.2 \text{ x } 10^{-4}) = (4.215 \text{ x } 10^{-2}) + (0.032 \text{ x } 10^{-2}) = 4.247 \text{ x } 10^{-2}$
- Example: $(8.97 \text{ x } 10^{4}) - (2.62 \text{ x } 10^{3}) = (8.97 \text{ x } 10^{4}) - (0.262 \text{ x } 10^{4}) = 8.71 \text{ x } 10^{4}$

Multiplication:

- The digit terms are multiplied in the normal way and the exponents are added. The end result is formatted so that there is only one nonzero digit to the left of the decimal.
- Example: $(3.4 \text{ x } 10^{6})(4.2 \text{ x } 10^{3}) = (3.4)(4.2) \text{ x } 10^{(6+3)} = 14.28 \text{ x } 10^{9} = 1.4 \text{ x } 10^{10}$
  (to 2 significant figures)
- Example: $(6.73 \text{ x } 10^{-5})(2.91 \text{ x } 10^{2}) = (6.73)(2.91) \text{ x } 10^{(-5+2)} = 19.58 \text{ x } 10^{-3} = 1.96 \text{ x } 10^{-2}$
  (to 3 significant figures)

Division:

- The digit terms are divided in the normal way and the exponents are subtracted. The quotient is changed (if necessary) so that there is only one nonzero digit to the left of the decimal.
- Example: $(6.4 \text{ x } 10^{6})/(8.9 \text{ x } 10^{2}) = (6.4)/(8.9) \text{ x } 10^{(6-2)} = 0.719 \text{ x } 10^{4} = 7.2 \text{ x } 10^{3}$
  (to 2 significant figures)
- Example: $(3.2 \text{ x } 10^{3})/(5.7 \text{ x } 10^{-2}) = (3.2)/(5.7) \text{ x } 10^{3-(-2)} = 0.561 \text{ x } 10^{5} = 5.6 \text{ x } 10^{4}$
  (to 2 significant figures)

Powers of Exponentials:

- The digit term is raised to the indicated power and the exponent is multiplied by the number that indicates the power.
- Example: $(2.4 \text{ x } 10^{4})^{3} = (2.4)^{3} \text{ x } 10^{(4\text{x}3)} = 13.824 \text{ x } 10^{12} = 1.4 \text{ x } 10^{12}$
  (to 2 significant figures)
- Example: $(6.53 \text{ x } 10^{-3})^{2} = (6.53)^{2} \text{ x } 10^{(-3)\text{x}2} = 42.64 \text{ x } 10^{-6} = 4.26 \text{ x } 10^{-5}$
  (to 3 significant figures)

Roots of Exponentials:

- Change the exponent if necessary so that the number is divisible by the root. Remember that taking the square root is the same as raising the number to the one-half power.
- Example:

$$\sqrt{3.6 \text{ x } 10^{5}} = \sqrt{36 \text{ x } 10^{4}} = \sqrt{36} \text{ x } \sqrt{10^{4}} = 6.0 \text{ x } 10^{2}$$

- Example:

$$\sqrt[3]{7.3 \text{ x } 10^{-8}} = \sqrt[3]{73 \text{ x } 10^{-9}} = \sqrt[3]{73} \text{ x } \sqrt[3]{10^{-9}} = 4.2 \text{ x } 10^{-3}$$

QUIZ:

Question 1 Write in scientific notation: 0.000467 and 32000000

Question 2 Express 5.43×10^{-3} as a number.

Question 3 $(4.5 \times 10^{-14}) \times (5.2 \times 10^{3}) = ?$

Question 4 $(6.1 \times 10^{5})/(1.2 \times 10^{-3}) = ?$

Question 5 $(3.74 \times 10^{-3})^{4} = ?$

Question 6 The fifth root of $7.20 \times 10^{22} = ?$

Answers: (1) 4.67×10^{-4}; 3.2×10^{7} **(2)**0.00543 **(3)** 2.3×10^{-10} (2 significant figures) **(4)** 5.1×10^{8} (2 significant figures) **(5)** 1.96×10^{-10} (3 significant figures) **(6)** 3.73×10^{4} (3 significant figures)

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This page adapted from a math review for chemistry students at Texas A & M University.

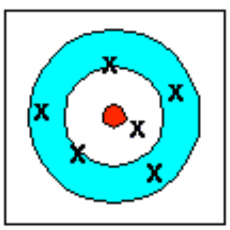
Scientific Methods: Significant figures

There are two kinds of numbers in the world**:**

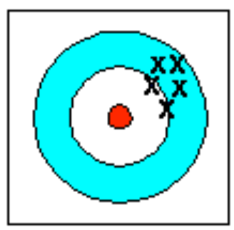
- **exact:**
    - example: There are exactly 12 eggs in a dozen.
- **inexact numbers:**
    - example: any measurement.
      If I quickly measure the width of a piece of notebook paper, I might get 220 mm (2 significant figures). If I am more precise, I might get 216 mm (3 significant figures). An even more precise measurement would be 215.6 mm (4 significant figures).

PRECISION VERSUS ACCURACY

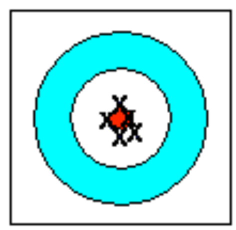
Accuracy refers to how closely a measured value agrees with the correct value.
Precision refers to how closely individual measurements agree with each other.



accurate
(the average is accurate)
not precise



precise
not accurate



accurate
and
precise

In any measurement, the number of significant figures is critical. The number of significant figures is the number of digits believed to be correct by the person doing the measuring. It includes one **estimated** digit.

A rule of thumb: read a measurement to 1/10 or 0.1 of the smallest division. This means that the error in reading (called the reading error) is ±1/10 or 0.1 of the smallest division on the ruler or other instrument. If you are less sure of yourself, you can read to 1/5 or 0.2 of the smallest division.

Rules for Significant Figures:

1. **Leading zeros are never significant.
   Imbedded zeros are always significant.
   Trailing zeros are significant only if the decimal point is specified.
   Hint: Change the number to scientific notation. It is easier to see.**

2. **Addition or Subtraction:**
   The last digit retained is set by the first doubtful digit.

3. **Multiplication or Division:**
   The answer contains no more significant figures than the least accurately known number.

EXAMPLES:

Example	Number of Significant Figures	Scientific Notation	
0.00682	3	6.82×10^{-3}	Leading zeros are not significant.
1.072	4	$1.072\ (\times 10^{0})$	Imbedded zeros are always significant.
300	1	3×10^{2}	Trailing zeroes are significant only if the decimal point is specified.
300**.**	3	3.00×10^{2}	
300**.**0	4	3.000×10^{2}	

EXAMPLES

Addition

```
  4.7832
  1.234
+ 2.02
  8.0372
   ⇓ rounding
  8.04
```

Even though your calculator gives you the answer 8.0372, you must round off to 8.04. Your answer must only contain 1 doubtful number. Note that the doubtful digits are underlined.

Subtraction

```
  1.0236
- 0.97268
  0.05092
    ⇓ rounding
  0.0509
```

Subtraction is interesting when concerned with significant figures. Even though both numbers involved in the subtraction have 5 significant figures, the answer only has 3 significant figures when rounded correctly. Remember, the answer must only have 1 doubtful digit.

Multiplication

```
  2.8723
x    1.6
  4.59568
    ⇓ rounding
    4.6
```

The answer must be rounded off to 2 significant figures, since 1.6 only has 2 significant figures.

Division

```
  45.2
÷ 6.3578
  7.1093775
    ⇓ rounding
    7.11
```

The answer must be rounded off to 3 significant figures, since 45.2 has only 3 significant figures.

Notes on Rounding

- **When rounding off numbers to a certain number of significant figures, do so to the nearest value.**
  - **example: Round to 3 significant figures: 2.3467×10^4 (Answer: 2.35×10^4)**
  - **example: Round to 2 significant figures: 1.612×10^3 (Answer: 1.6×10^3)**

- **What happens if there is a 5? There is an arbitrary rule:**
  - **If the number before the 5 is odd, round up.**
  - **If the number before the 5 is even, let it be.**
    The justification for this is that in the course of a series of many calculations, any rounding errors will be averaged out.

  - **example: Round to 2 significant figures: 2.35×10^2 (Answer: 2.4×10^2)**
  - **example: Round to 2 significant figures: 2.45×10^2 (Answer: 2.4×10^2)**

  - **Of course, if we round to 2 significant figures: 2.451×10^2, the answer is definitely 2.5×10^2 since 2.451×10^2 is closer to 2.5×10^2 than 2.4×10^2.**

QUIZ:

Question 1 Give the correct number of significant figures for 4500, 4500**.**, 0.0032, 0.04050

Question 2 Give the answer to the correct number of significant figures:
4503 + 34.90 + 550 = ?

Question 3 Give the answer to the correct number of significant figures:
1.367 - 1.34 = ?

Question 4 Give the answer to the correct number of significant figures:
$(1.3 \times 10^3)(5.724 \times 10^4) = ?$

Question 5 Give the answer to the correct number of significant figures:
(6305)/(0.010) = ?

Answers: (1) 2, 4, 2, 4 (2) 5090 (3 significant figures - round to the tens place - set by 550) (3) 0.03 (1 significant figure - round to hundredths place) (4) 7.4×10^7 (2 significant figures - set by 1.3×10^3) (5) 6.3×10^5 (2 significant figures - set by 0.010)

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This page adapted from a math review for chemistry students at Texas A&M University

Scientific Methods Answer Sheet

I. **Scientific Notation**

A. Multiply: 3.1×10^7 by 3×10^5

B. Multiply: 1.496×10^{11} by 5.2

C. Divide: $(6.4 \times 10^6)^2$ by 6.7×10^{-11}

II. **Measurement Errors and Uncertainties**

A. Measurement Errors

1. Wavelengths:

2. What is the uncertainty in your answer? That is, how far off (in *nm*) could your determinations be?

3. How could you make your answer more precise?

4. Blue and yellow:

   yellow and red:

   blue and red:

5. Scale Factor:

6. If you had a friend measure the distances, would her/his results differ from yours? Why or why not?

B. How does an "accurate" measurement differ from a "precise" measurement?

C. Diameters of galaxies:

1.

2.

3.

1. What criteria did you use when determining each diameter?

2. In determining the relative distances of these galaxies:
   a. Would it matter if you used a different criterion for measuring each galaxy? Why or why not?

   b. Would it matter if one of your class mates used different criteria than you did? Why or why not?

3. Distances
   a. Which galaxy is the nearest? Farthest?

   b. How much farther away from us is the farthest galaxy compared to the nearest?

   c. What assumption (stated above) is necessary for you to feel confident your answer is correct?

III. **Statistics**

1. Using a piece of graph paper, plot the magnitude (brightness) of the star against its size.

2. What is the slope of the line?

3. Does the equation, $y = mx + b$ seem familiar?

4. Do you see that for all future measurements, all we need to do is measure the size of the star and use our relationship to find the corresponding magnitude?

IV. **Significant Digits**

A. How many significant digits are in the following numbers?

1. 1.5
2. 3.5689
3. 4000
4. 3.68

B. Multiply 1.5, 3.5689, 4000, and 3.68. Round your answer to the correct number of significant digits.

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