PHYSICS 190 –
INTRODUCTION TO ASTRONOMY:
EXPERIENTIAL ACTIVITY GUIDE

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Cover Image

The image on the cover was taken by the award-winning astro-photographer Wally Pacholka, on December 13 2004 (http://www.astropics.com, reproduced with permission). It captures some of the many wondrous astronomical phenomena that can be seen by observing the night sky with the most readily-accessible instrument of all: the unaided eye.

On the bottom left, just over the hill, is *Sirius*, the brightest star in the sky. Well above *Sirius* is part of the constellation of *Orion the Hunter*. The three stars running down the image near the top-left are imagined to be jewels in *Orion's* belt, the three stars running diagonally down and to the right just below the belt form *Orion's* sword, while the two bright stars beyond the sword are his knees. The middle "star" in the sword (visible as a fuzzy patch to the naked eye) isn't really a star at all: rather, it is a "nebula," an enormous cloud of gas and dust, where thousands of new stars are being born. Off the top of this image lie stars forming *Orion's* head and shoulders, along with his shield and club, which he is using to battle *Taurus the Bull*, while in pursuit of the beautiful seven sisters known as the *Pleiades.* These imaginary patterns make this one of the most evocative regions of the night sky, and are easily recognized by beginning amateur astronomers, even in brightly-lit city skies, in the evenings of late fall and early winter.

A meteor streaks across the sky below and to the right of *Orion* while, above and to the right of the meteor, what looks like another fuzzy patch, lies a comet. This is comet *Machholz*, which was visible to the naked eye for a few months in late 2004 and early 2005, coming within about 50 million kilometers of the Earth, as it very gradually moved across the background of fixed stars; this comet will not approach the Earth again for over one-hundred thousand years.

This black-and-white reproduction cannot capture the fact that many objects in the sky have vivid colours which can easily be discerned by the naked eye. A colour reproduction of this image was featured in the December 22 2004 edition of *Astronomy Picture of the Day*, go to http://antwrp.gsfc.nasa.gov/apod/ap041222.html.

Acknowledgments

This activity guide draws extensively on several freshman-level physics labs developed by Neil Alberding and Mehrdad Rastan for Physics 100, and their input and advice is gratefully acknowledged. Leigh Palmer, Jeff Rudd, and Laura Schmidt also helped in the design of the "triangulation" experiment. Valuable input in the development of the astronomy projects was provided by Leigh Palmer, Jeff Rudd, Laura Schmidt, and especially Yvonne Yuan, who tried out several early versions of the astronomy projects, and found out what works, and what doesn't. Sarah Johnson, Mike Anderson, and Greg Millar provided valuable feedback after teaching the course with its full experiential content. Barbara Frisken provided encouragement and advice in the redesign of Physics 190 to fulfill the breadth- and quantitative-course requirements for non-science students, and also offered helpful comments on this activity guide.

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Astronomical Symbols

Solar System

☿ ... Mercury	♀ ... Venus	⊕ ... Earth
♂ ... Mars	♃ ... Jupiter	♄ ... Saturn
♅ ... Uranus	♆ ... Neptune	♇ ... Pluto
☉ ... Sun		

Signs of the Zodiac

♈ ... Aries	♉ ... Taurus	♊ ... Gemini
♋ ... Cancer	♌ ... Leo	♍ ... Virgo
♎ ... Libra	♏ ... Scorpius	♐ ... Sagittarius
♑ ... Capricornus	♒ ... Aquarius	♓ ... Pisces

The Greek Alphabet

Α, α ... alpha	Β, β ... beta	Γ, γ ... gamma
Δ, δ ... delta	Ε, ε ... epsilon	Ζ, ζ ... zeta
Η, η ... eta	Θ, θ ... theta	Ι, ι ... iota
Κ, κ ... kappa	Λ, λ ... lambda	Μ, μ ... mu
Ν, ν ... nu	Ξ, ξ ... xi	Ο, ο ... omicron
Π, π ... pi	Ρ, ρ ... rho	Σ, σ ... sigma
Τ, τ ... tau	Υ, υ ... upsilon	Φ, φ ... phi
Χ, χ ... chi	Ψ, ψ ... psi	Ω, ω ... omega

Physics 190: Preparations for Starry Nights with the Naked Eye

Overview

The scientific revolution has fundamentally and unalterably transformed our conception of the universe, and of humankind's place in it. The breadth and depth of our present understanding of the cosmos owe to a fundamental principle of the scientific method, which is to perform experiments that confront our preconceptions with data, thereby approaching the truth of nature's mysteries. In this course you can participate in the thrill of scientific discovery in a small, but potentially rewarding way, by doing a series of basic experiments in astronomy and physics.

The experiments in this activity guide are roughly divided into two categories: a set of astronomy projects, which involve observations of the night sky, to be done on several evenings over the course of the semester; and a set of physics labs, to be done in a traditional laboratory setting, in our undergraduate physics lab.

The first two sections of this activity guide are required reading in the first week of classes: read this section, *Preparations for Starry Nights with the Naked Eye*; and read the excerpts which have been reproduced from the textbook *365 Starry Nights,* by Chet Raymo. These readings are required in order to prepare for the experiential activities which constitute a significant portion of the graded work in this course.

The **astronomy projects** consist of observations of the stars, planets, and the Moon, which you make outside of classroom time. No special equipment or telescope is needed: the observations are done using the naked eye. Each project has a detailed set of instructions. <u>You should carefully review the instructions for each project well in advance</u>, and once again shortly before going outside to conduct your observations.

The **first experiential activity** of the semester is the *Astro Computer Lab: Getting Around the Night Sky with SkyChart III*, which <u>takes place in the undergraduate physics lab in the second week of class</u>. You do this computer lab, as well as the physics labs, in the lab section that you were assigned when you registered for the course. <u>Read over the script for the *Astro Computer Lab* before you come to the lab</u>. All other astronomy activities consist of outdoor observations. More information on the observation projects is given below.

The **physics experiments** are designed to explore a few of the more basic principles and tools that are used by astronomers, as well as some basic principles of data analysis and visualization. Physics labs are a natural part of an astronomy course, because physics provides the universal laws of nature, and the associated experimental tools, that are used by astronomers to infer the properties of objects that are far removed from direct contact. The first physics lab takes place in the third week of class. Consult the course web page for the complete lab schedule.

You must bring the script for a physics lab with you to your assigned lab section. Attendance will be taken; you cannot change your lab section without permission. You will record and analyze the data for the physics labs on your lab scripts, which will be handed-in at the lab. Read over the scripts before you come to the lab.

This course has a scheduled weekly **tutorial** section. The tutorials will be used to provide a preview of the upcoming physics labs and astronomy projects, and are essential preparation for these experiential activities; attendance is required.

Astronomy Observation Projects

You are required to write a short report on each astronomy project that is selected by the course instructor. Reports must be typewritten. Two double-spaced typewritten pages is sufficient, but must include the following labeled sections:

★*Title:* Include project name, your name, partner names, & date report submitted;

★*Overview:* Provide a one-paragraph description of the project, including its purpose;

★*Narrative:* One or two paragraphs summarizing your experiences, including how you prepared for the project, and giving your overall impressions of your activities as they unfolded over the course of your observation sessions;

★*Observations & Analysis*: One or two paragraphs detailing the observations that you made, and providing an analysis of the results;

★*Conclusions*: Include a one-paragraph discussion of how successful the observations were, and what concepts or relationships were demonstrated;

You must keep a logbook where you record your astronomy project observations. A blank log is included in this activity guide, and copies can also be obtained from the course web page; you should use a separate copy of the log to record each night of observations. Record your data in the log as soon as you take it; do not wait until after your observations to record the information.

★The relevant logbook records must be attached with each project report. Project reports are separate from logbook records, and must satisfy the above criteria.

Note: Completed projects must be handed-in according to a schedule to be announced in class. You may be required to do only a portion of the astronomy projects for course credit: your instructor will provide details. You may also be requested to show your log-book to your course TA at selected times during the term.

The course instructor and TAs will hold several on-campus "star nights," in order to orient you to the night sky, as early in the term as possible. A small telescope or two may also be on hand. The class will meet, at a location to be announced, usually around 6:30PM, but only on specific nights which will only be announced earlier in the day, when the weather looks promising. Star nights will be subject to cancellation late in the day, depending on how the weather develops (if a possible star night has been announced you will receive a confirmation, "good to go," or not, either in class, or by email late in the afternoon). Several star nights will be scheduled as early in the term as possible, in order to give everyone a reasonable opportunity to attend one. You should therefore regularly check your email and the course web site for messages from the instructor.

Attendance at one star night and full participation in the astronomy projects throughout the term are required parts of this course. If your evenings are too busy to allow you to make evening observations when the weather permits, and to accommodate the star-night and astronomy project schedules, then you must drop the course.

The astronomy observation projects require careful advanced preparation. Read the project instructions before you go outside. Scheduling of the various projects also requires advanced planning; in particular, some objects can only be observed during specific periods of time. Projects I & II can be done together in one or two nights. The other projects each require a few nights of observation, but you will only have to spend a few minutes outdoors for each observation. Consult the project instructions for scheduling details.

With advanced preparation you may be able to do most of *Astro Projects I & II* during one on-campus star night. After you attend one star night you are expected to work on the remaining astronomy projects on your own time, and you can conduct your observations from any convenient location (you do not have to stay on campus; for example, try to find a reasonably dark location close to home).

Take full advantage of the earliest clear nights in the term. Vancouver weather is unpredictable so do the projects ASAP: do not put them off.

Here are a few tips for successful observations:

★*Dress warmly* (including on the star nights): even if it seems relatively mild during the day, you can get very cold standing around looking at the sky at night!

★Before starting your observations *give your eyes at least ten to fifteen minutes to adapt to the dark*, so you are more sensitive to faint starlight.

★You will need a flashlight to read your sky charts and notes. *Cover the flashlight with red paper or cellophane*: red light doesn't spoil your eye's adaptation to the dark the way white light does

You are also strongly encouraged to work in groups of two or three, both on the physics labs and the astronomy projects. Working in a group is particularly helpful in doing the astronomy projects: the extra set of eyes and perspective provided by a partner can be invaluable in finding one's way around the sky. You must record the names of any partners on the observation logs, project reports, and physics labs reports.

The textbook *365 Starry Nights,* by Chet Raymo, excerpts of which are reproduced in this activity guide, gives an introduction to the sky, month-by-month, suitable for beginning amateur astronomers. The excerpts included here primarily cover the months of January through April, and most of the objects described in these portions of the text can be seen throughout the winter and into early spring. Note that you do **not** have to go out precisely on the date specified in each excerpt of the Raymo text, as the sky changes very slowly from month to month.

Winter skies feature some of the most beautiful and prominent star patterns in the entire sky, including *Orion*, *Taurus the Bull*, the *Pleiades,* and *Leo the Lion.* These and other features of winter skies are described in detail in the excerpts of *365 Starry Nights,* and will be explored in *Astro Projects I & II*, in the *Astro Computer Lab,* and during the star nights. We will also study the *Big and Little Dippers*, described in the May excerpts; these are "circumpolar" star patterns, which means that they can be seen year-round in much of the northern hemisphere. The final excerpt from *365 Starry Nights* is from November & December, and describe the variable star *Algol*, and the related constellations of *Perseus* and *Cassiopeia*, which are all circumpolar objects, and will be explored in *Astro Project III*.

Academic Honesty

You have an obligation to understand our university's policies on academic honesty and student conduct. Ignorance of university policies is no excuse. Be sure to carefully review the following information, which includes particular issues relating to this course. Also consult the course web page for links to relevant SFU policy documents and helpful information from the library on written coursework.

A major portion of the grade in this course comes from the physics labs and astronomy projects. These experiential activities include data collection and making observations, and in doing this work you are strongly encouraged to collaborate with other students, in groups of two or three. However, each partner must actively contribute to the data collection and project observations. You are also free to discuss the significance of the results with your partners, but each partner must be an active participant in such discussions, and must make significant contributions to the resulting ideas.

Although you are to collaborate with partners in taking data for the labs and projects, the work you hand in must be your own***.*** In particular, while you share the data with your partners, you must write your work in your own words. Do not share your written work.

Copying whole or part of another's work, and fabrication of even part of your data, are serious forms of dishonesty, and will be severely dealt with. The instructor and TAs will closely monitor work for plagiarism and falsification, in the physics lab scripts, the astronomy project reports, any assignments, and the exams.

OBSERVER'S LOG

Name________________________ Student #________________

Project Partners ____

Astronomy Project Title: ________________________________

Date: ________________ **Start Time**: ________ **End Time:** ________

General Location (e.g. Burnaby) ______________________

Weather and sky condition (e.g. partly cloudy or hazy, etc.) ________________

Limiting magnitude: _____ based on ___ UMi (see *Little Dipper* chart in Project I)

Moon's phase & direction (e.g. First Quarter, West): ________________

Notes (use boxes below to sketch and label relevant parts of the sky): __________

Label compass directions

Edmund Scientific Star and Planet Locator Star Magnitudes:

●	●	●	●	•	•
-1	0	1	2	3	4

Phys 190: Astro Computer Lab

Getting Around the Night Sky with SkyChart III Software

Goals

★Learn how to use the *SkyChart III* planetarium software to identify some prominent features of seasonal skies, and to gather information for an observation project.

Material

★Bring your copy of the *Edmund Scientific Star and Planet Locator*, which came with your textbook, to the undergraduate physics laboratory.

★Computers will be provided at the laboratory, with *SkyChart III* software installed.

Background

Amateur and professional astronomers alike know that advanced planning is essential to successful observations. The sky is full of change, even though the stars and constellations remain essentially fixed in position relative to each other (over many thousands of years). Many changes are regular and predictable. The stars appear to move together gradually across the sky over the course of a night, as the Earth rotates on its axis. The sky also appears to change slowly from one night to the next, as the Earth moves in its orbit around the Sun. Moreover, the Moon travels around the ecliptic each (lunar) month, with its phase changing from day to day, while the planets gradually change their positions relative to the stars, due to the combined motion of the planets and the Earth in their orbits.

An observer is also presented with an almost endless variety of celestial objects to choose from, some plainly visible to the naked eye (including stars of breathtaking colour, as well as planets and the Moon), and with a spectacular array of "deep sky" objects accessible to binoculars and small telescopes (such as distant star clusters, nebulae, and galaxies). The objects that are "up" in the sky change over the night and with the seasons. New and unexpected phenomena also occur, such as the appearance of a new comet.

It can therefore be advantageous to organize a observing plan in advance, by consulting an up-to-date source of astronomical information (though it's also pleasing to just go out and look at the night sky on a whim!). Fortunately, there are many resources for navigating one's way around the night sky. Popular monthly astronomy magazines, such as *Sky&Telescope*, and *Astronomy*, provide timely guides to the night sky (see the course web page for links to these and other sources). The textbook *365 Starry Nights*, by Chet Raymo, excerpts of which are reproduced in this activity guide, is particularly helpful as a guide for beginning amateur astronomers.

Planetarium software such as *SkyChart III*, which we explore in this lab, provide a powerful resource for keeping track of regularities in the changing sky, and for planning observation sessions. As in a physical planetarium, the software displays an easy-to-interpret "virtual" sky, and contains a huge catalogue of celestial objects (a free and fully functional demo copy of *SkyChart III* can be downloaded at http://www.southernstars.com/skychart/).

The *Edmund Scientific Star and Planet Locator*, which came with your textbook, is a more modest but very convenient and useful paper star chart, and is another indispensable tool, particularly for use "in the field." The use of the *Edmund Star Locator* (also referred to as a *planisphere*) is the subject of *Astro Project I.*

Another fantastic resource for what to see in the night sky with the naked eye is a weekly five-minute video by Jack Horkheimer, the wacky director of the Miami planetarium. This feature is produced for PBS Television, and can be viewed on the web at:

http://www.jackstargazer.com.

About half-way down that web page is a link to past and upcoming installments; the link is easy to miss, so look along the left-hand margin for: *"To see any episode produced in the last 12 months."*

In this lab you will learn to use *SkyChart III* to familiarize yourself with some prominent features of seasonal skies, and to gather information for an observation project. You will also watch the latest episode of *Jack Horkheimer* and, following Horkheimer's directions, you will see if you can identify what he is talking about in the "virtual" sky created by the *SkyChart III* software.

The rest of this script is organized in four parts. Part I) contains a set of instructions to initialize the program for use at home: these steps do not have to be done in the physics lab. In part II) you will learn how to use some of the basic features of the software to identify regions in the sky of interest. In part III) you will print a star chart for the current edition of *Jack Horkheimer*, and in part IV) you will gather information for an observation project.

Notes: You may find it helpful to compare the *SkyChart III* display of a particular region of the sky with the star chart on the *Edmund Scientific Star and Planet Locator.*

The > symbol below refers to a menu or submenu item in the *SkyChart III* program.

Part I): Initialize the program (for use at home)

Note: steps A) to D) have already been done on the computers in the physics labs.

A) One-time initialization to display "traditional" constellations

In its default configuration *SkyChart III* displays constellations in a "modern" form, which differs from the "traditional" constellations that are used in most other star charts (such as the *Edmund Star Locator*, which we use in our observation projects). If you use *SkyChart III* at home, you should consider installing traditional constellations, as follows.

First, you need to download the file "TraditionalConstellations.txt" from the SkyChart website http://www.southernstars.com/skychart (click the "Other Downloads" link in the left margin, and look at the end of the web page for the file).

Next, follow these instructions:

> File > Import > SkyChart Text File ... *Select the file "Traditional Constellations.txt".*

> File > Delete Database File ... *Select file "Figures.skd" in "Constell" folder, in the "Database" folder, in the SkyChart III program folder.*

B) One-time initialization for location to Vancouver

> Computation > Location > View From Earth

> *Enter Vancouver in* Location, *and enter the following information:*
> Longitude –123 11 00 *(include either a minus sign, or a "W")*
> Latitude +49 12
> Altitude 4
> Time Zone -8 *(Be sure to include the minus sign)*
> Add to Menu (*PC users*: Add to List)
> Use as "Here"
> OK

> File > Save Settings as Default

C) Set "virtual" sky to appear as it does to the naked eye in the city

> View > 90^{o} Field *(to get the "field of view" of a naked eye observer)*

> Draw > <u>Remove</u> check on Deep Sky Objects

> Draw > <u>Remove</u> check mark on: Automatic Limits

> Draw > Symbols & Grids ... > Brightest Magnitude: 0.0
> Faintest Magnitude: 5.0
> Labels to Magnitude: 3.5
> OK

File > Save Settings as Default

D) Additional setup

> Draw > Symbols & Grids ... > Check "Ecliptic" box (*near middle-right*)
> <u>Remove</u> check on "R.A./Dec." box
> <u>Remove</u> check on "Boundaries" (*bottom-left*).
> OK.

> Draw > Put check mark on : Grid Lines

> Draw > Put check mark on : Object labels

> File > Save Settings as Default

Part II): Try-out some basic features

i) Try "dragging" the sky around using the mouse

ii) > Computation > Date & Time *(For these examples, set to: 2008/01/11 20:00:00 to see the sky on January 11 2008 at 8PM.)*
> OK

iii) > View > Center Horizon > North *("Drag" the sky down see the Big & Little Dippers, with date/time set as above.)*

iv) > View > Center Horizon > East *("Drag" the sky down & left to see Gemini, Orion, Taurus, and Mars.)*
(Notice the colours of the stars and Mars!)

v) Click on any object (e.g. *Mars* or Moon or star) to pop-up an "Object Info" window.

★One needs to position the cursor arrow <u>very</u> close to an object symbol in order to get the "Object Info" window to open for the correct object.

vi) > Animation > 1 Minute
Animation > Animate Forward *(Watch objects rise from East and set to West)*
Animation > Animation Off

vii) > View > Center Object .... > Polaris > Find > Select

★Now run animation again to see stars circling the pole star!

viii) Reset the date & time to *2008/01/11 20:00:00.*

ix) > View > Center Planet > Moon
> Animation > 1 Day
> Animation > <u>Step</u> Forward (<u>*single*</u> *steps, do* <u>*not*</u> *run a continuous animation*)

★Repeatedly step forward 1 day at a time to follow the Moon's changing position relative to the background stars (for about 13 days, until January 24, after which it disappears below the Eastern horizon, since thereafter it rises after 8PM).

★Notice how the Moon stays within a few degrees of the ecliptic, first somewhat above the plane of our orbit around the Sun, and then somewhat below it.

★You can also follow the changing lunar phase (reduce the field of view to get a close-up of the Moon's disk, for example: View > 5^{o} Field).

x) Measure the angular separation between the stars *Castor* and *Pollux* in the constellation of *Gemini*, as follows (see February 21-22 in *365 Starry Nights*):
> Date & Time: 2008/01/11 20:00:00.
> View > 90^{o}
> View > Center Horizon > East
★*"Drag" the sky down a bit to view Gemini.*
> Draw > Put check mark on: Mouse Coordinates.
★Click on *Castor* (α Gem) and drag the mouse to *Pollux* (β Gem),
and <u>continue to hold the mouse button down for the next step</u>.
★Read the angle ("Sep") near the upper-left corner of the screen (here about 4.5^{0}).
> Draw > <u>Remove</u> check mark on: Mouse Coordinates.

Part III): Print a map of Jack Horkheimer's sky

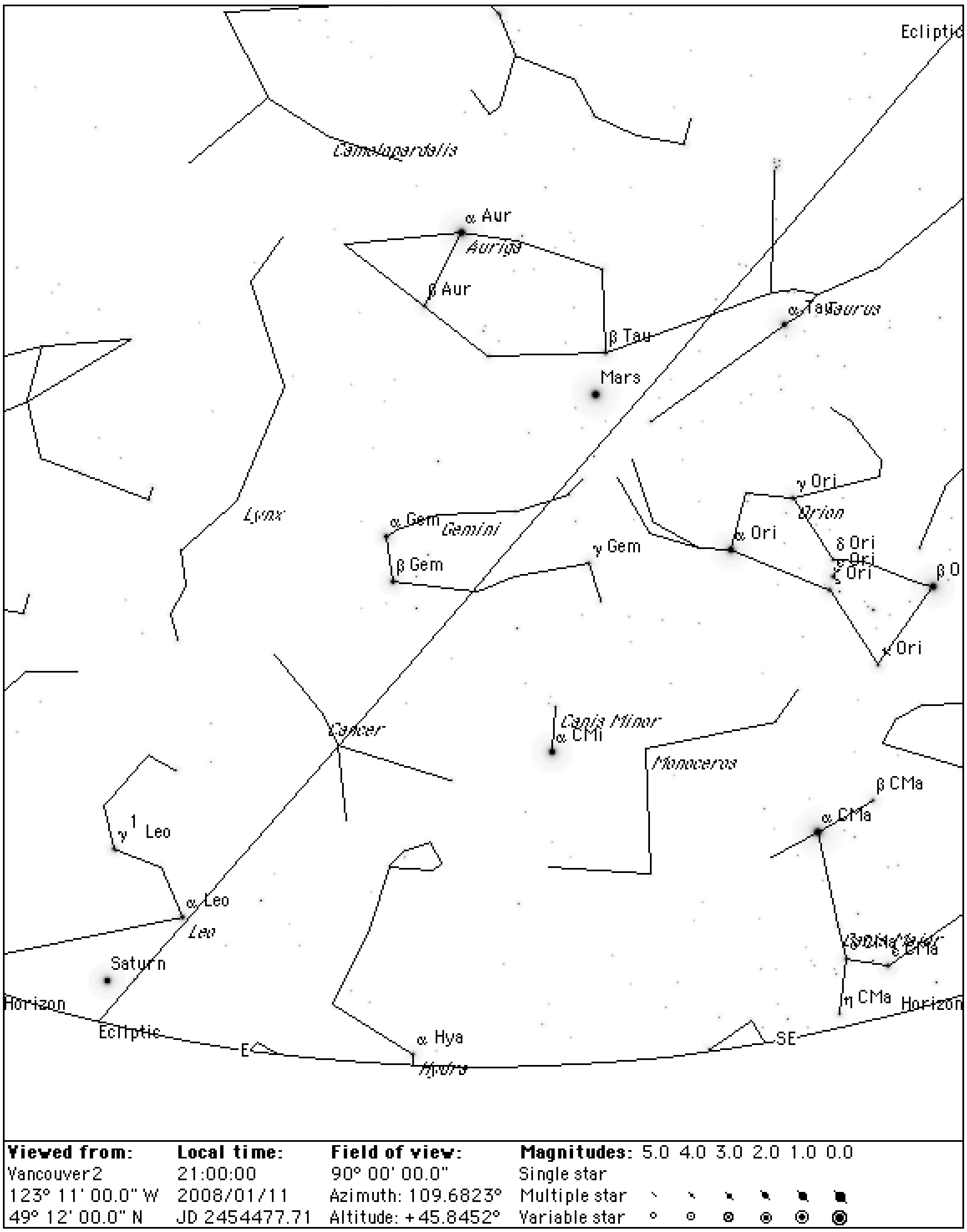
Go to Jack Horkheimer's web site (see pg. 2 of this script) and listen to the 5 minute episode for this week. Use *SkyChart III* to see if you can identify some of the objects described by Horkeimer.

<u>Print a star chart of some region described by Horkeimer</u>, as follows:

First, roughly centre the planetarium viewer on the region of sky of interest, and then select: > File > Print. You get the following dialog box: *"The chart will print better if ... the sky background is changed to white. Make changes now?"* Be sure to click on "Yes." You may need to experiment with the portion the sky that is actually printed: try dragging the sky around and print again until you get a satisfactory printout.

A sample map produced by the software is shown below. This map was made for January 11 2008 at 9PM (the view of the constellations will be identical in early-winter of any year, but the positions of *Mars* and *Saturn* apply only around the specified date).

The constellations *Orion* and *Taurus* are on the far right, with *Gemini* near the centre, and part of *Leo the Lion* on the bottom left. The stars α Ori and β Ori in *Orion* are *Betelgeuse* and *Rigel*, respectively, while the brightest star in the sky, *Sirius,* is α CMa (near the bottom-right). The brightest star in *Leo* is *Regulus,* and is labeled α Leo. Notice *Mars* and *Saturn*, both very close to the ecliptic.



Part IV): Planning an observation project

To illustrate the use of *SkyChart III* in planning observations, make a plot of the motion of *Mars* over the course of the term (the subject of *Astro Project IV*), as follows:

> Computation > Date & Time: 2008/01/11 20:00:00 (Jan. 11 2008 at 8PM)

> View > Center Planet > Mars

★Click the symbol for Mars in the window centre to pop-up an “Object Info” window

★Click “Trail On” in the “Object Info” window: an “Edit Object Trail” window opens

★Click OK in “Edit Object Trail” window.

★Leave the Object Info window open for the rest of the exercise.

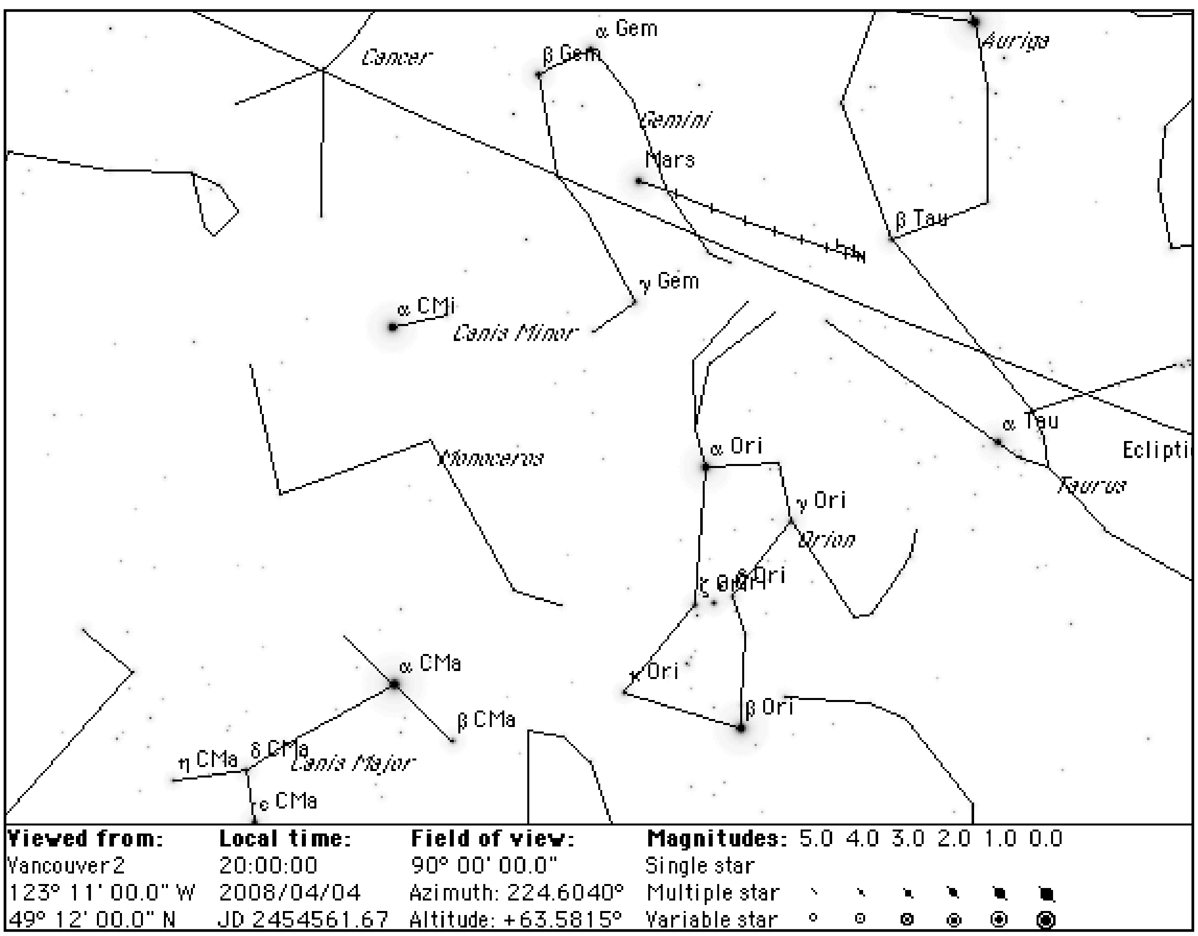
★Set the Animation in steps of one week, and Step Forward in single steps, until the end of term.

★As Mars changes position, take note of its changing magnitude, as recorded in the Object Info window

★Notice how *Mars* is in retrograde motion during the early part of term, moving to the West relative to the stars. It reverses its motion near the end of January, thereafter heading to the East in its prograde cycle. Also notice how *Mars* dims substantially over the term.

★<u>Questions</u>: What are the magnitudes of *Mars* near the beginning and end of term? Approximately how far in angle does *Mars* move relative to the stars?

★Here is a sample map produced using the above instructions.



Physics 190: Astro Project I

Getting Around the Night Sky with the Edmund Star Locator

Goals

★Learn to use the *Edmund Scientific Star & Planet Locator,* which came with the textbook, to plan and conduct some observations of the night sky, including the identification of some prominent constellations, stars, and planets.

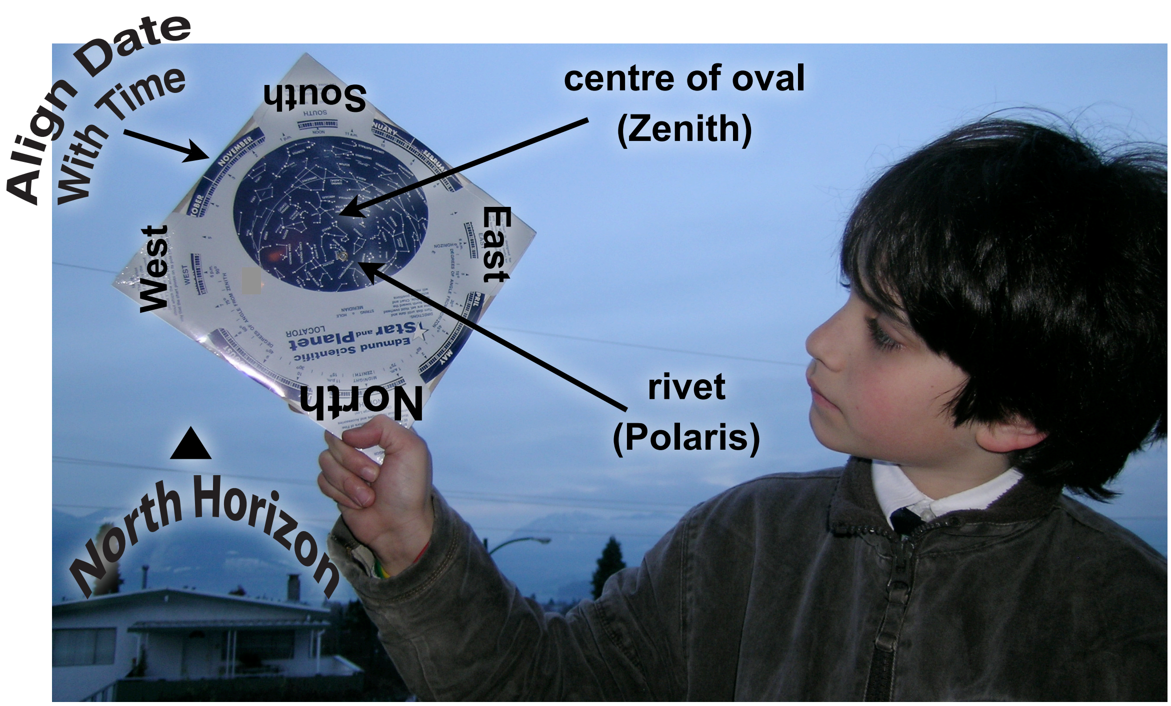
★Learn to estimate the magnitudes of stars and planets.

Observation Plan

★With thorough advanced preparation and planning, the observations for this project can be done in a single evening. <u>You may be able to do most of this project, and the next one, during the first on-campus star night</u>.

Background

The *Edmund Star Locator* is a star chart, or "planisphere" (which literally means "flattened sphere"). It can be used to identify prominent features in the night sky, at any time of the year, and at any time of night. This type of planisphere is also called a "star wheel," because the chart is printed on a disk that can be rotated about a rivet in the disk's centre.



The above photograph illustrates the use of a planisphere. A planisphere is helpful for planning an observing session, because it shows at a glance what will be "up" in the sky at a particular time, and it is handy for use "in the field," in order to identify constellations and stars of interest. It provides a portable "snapshot" of the entire sky, and you should use it routinely in planning your observing sessions, and in finding your way around the sky at night.

You may also find it helpful to consult the planisphere when using the *SkyChart III* planetarium software to “zero in” on a more detailed region of the sky.

A star wheel is designed for use at a particular latitude: the entire portion of the celestial sphere that can be viewed from that latitude, over 24 hours, is projected onto a flat disk. The *Edmund* planisphere is designed for latitude 45 degrees north, which gives a good representation of the sky as seen from Vancouver. <u>Note that the projection of the celestial sphere onto a flat disk means that some regions of the sky will appear distorted on such a star chart</u>; constellations near the southern horizon are shown on this chart in an elongated (“stretched”) form, compared to their actual appearance.

Only half of the celestial sphere can be seen from the surface of the Earth at a given time. That celestial “dome” is represented by a large oval which is cut into a grey sheet covering the rest of the star wheel (see the photograph). The edges of the oval represent the horizon in different directions. The centre of the oval represents the point directly above an observer’s head, also known as the *zenith.*

The Earth’s rotation on its axis causes celestial objects to appear to rotate in great circles, about an axis through the celestial poles, once every 24 hours (as we will discuss in class). It so happens that the star *Polaris*, also known as the “Pole Star,” is very close to the north celestial pole. The rivet on the star wheel, about which it can be rotated, corresponds to the location of *Polaris* in the sky.

Also shown on the planisphere is a solid white line marked *“EQUATOR,”* which represents the projection of the Earth’s equator onto the celestial sphere, and a dotted white line marked *“ECLIPTIC,”* showing the apparent path taken by the Sun, Moon and planets against the background of fixed stars.

The *Edmund* planisphere bills itself as star *and* planet locator, however the planets cannot be printed on the star chart because their positions are too changeable. The flip-side of the planisphere does give a table which lists the constellation in which each planet is found, month-by-month, over several years.

You may also find it useful to consult popular magazines such as *Astronomy,* and *Sky & Telescope*, which provide monthly summaries of interesting objects in the sky, as well as somewhat more detailed monthly sky charts.

How to use the Star Wheel

To use the star wheel you must follow two steps:

1) The star wheel must first be “set” to a particular date and time.

   To do this, find the desired date printed on the edge of the blue disk, and rotate the disk until the date is lined up with the desired time, which is printed in small blue letters near the edge of the grey sheet covering the star chart. If you observe the sky over a period of time, you will want to periodically update the current time on the star wheel, rotating the disk to mimic the apparent rotation of the celestial sphere.

Note: The times printed on the planisphere are in “Standard Time.” If you are on Daylight Savings Time (DST), generally from the second Sunday in March to the first Sunday in November, then *subtract* one hour from your local DST to convert to standard time on the planisphere.

2) Your view of the sky will depend on the direction you face.

   For example, to use the chart while facing north, *hold the planisphere over your head*, with the word “North” at the bottom (see the photograph). If you then turn to the left to face west, for example, you must rotate the planisphere so that “West” is then at the bottom, and so on.

   Note: To orient the star wheel it is very helpful to start with a known constellation, or from a well-defined compass direction (such as “North”). Then, as you turn your head to face towards another constellation or direction, turn the star wheel at the same time, so that the orientation of the star patterns on the planisphere matches their orientation in the sky.

Star magnitudes

As we will discuss in class, astronomers use an apparent “magnitude” scale to “rank” stars according to how bright they appear as viewed from Earth. This scale originated with the ancient Greek philosopher Hipparchus in the 2nd century BC.

Fainter stars are assigned *larger* magnitudes. In the modern magnitude scale the faintest stars that can be seen by the naked eye have magnitude about 6.

The brightest stars in the sky generally have magnitude around 0, including the blue-giant *Rigel* in the right knee of *Orion*. Magnitude 1 stars are also very prominent: a winter-sky example is the red-giant star *Aldebaran*, the red “eye” in Taurus the Bull..

Magnitude 2 stars are also quite noticeable, even in bright city skies, and these stars often form the outline of constellations: examples are the three stars in Orion’s belt, and the pole star *Polaris* (which many people mistakenly believe is the brightest star in the sky).

Magnitude 3 stars are much less notable: examples are the three stars in Orion’s head. Magnitude 4 stars are generally quite hard to see in city skies; the stars in the middle of the “handle” of the *Little Dipper* are of fourth magnitude.

Negative magnitudes are also used: the brightest star in the entire sky, blue-white *Sirius* (south-east of *Orion*), has a magnitude of about -1.5. *Venus* is the brightest celestial object, apart from the Sun and Moon, and it has a magnitude of around -4.

The size of a star’s “dot” on the planisphere is used to roughly indicate its relative brightness. Bigger dots are brighter stars. The magnitudes associated with different-sized dots are printed at the bottom of the Observer’s Log Book.

Two objects which differ by 5 magnitudes differ in intensity by a **factor** of 100. Magnitudes form an exponential scale, similar to the Richter scale that is used to rate earthquakes. A difference of precisely one magnitude means a difference in intensity by a factor of $100^{1/5} \approx 2.51$. Try this example: compare *Rigel* (magnitude 0.18) with *Betelgeuse* (magnitude 0.45). *Rigel* is $2.51^{(0.45-0.18)} \approx 1.3$ times (or 30%) brighter than *Betelgeuse.*

How to estimate magnitudes

To measure an object's magnitude you should compare its observed brightness with that of other stars whose magnitudes are known from a reference such as planetarium software or a star chart. Ideally one should use two comparison stars, one a little brighter than the object under study, and another a little dimmer. One can then estimate that the magnitude of the object must lie in between the magnitudes of the comparison stars.

Instead of using the size of the dots on a planisphere, which provide only very rough guides to star magnitudes, you can use *SkyChartIII* to get accurate magnitudes for thousands of objects. An example of a useful comparison chart is given on the next page.

Another consideration is that the eye responds differently to different colours (with greatest sensitivity to yellow-green in weak light). Colour sensitivity also varies from one person to another. Hence ideally one should compare objects of roughly the same colour.

For example, many people actually find that *Betelgeuse* appears to be brighter than *Rigel*. In fact *Betelgeuse* has historically been considered the "prime" star in Orion, and is designated "alpha" (α *Ori*), while Rigel is designated as the "second" star, or "beta" (β *Ori*), despite the fact that it is actually brighter.

Another interesting comparison, in the same region of the sky, is between *Betelgeuse* and *Aldebaran* (magnitude 0.87), both of which are reddish-orange in colour. Most observers will agree that *Betelgeuse* is easily the brighter of the two (the magnitude calculation is that *Betelgeuse* is $2.51^{(0.87-0.45)} \approx 1.5$ times, or 50%, brighter than *Aldebaran)*.

Project Preparations

Familiarize yourself with some prominent features in seasonal skies by reading the excerpts from *365 Starry Nights*. Note that you do not have to do the observations described in *365 Starry Nights* precisely on the specified days or even months. Also consult *Jack Horkheimer's* weekly video digest, described in *Astro Computer Lab: Getting Around the Night Sky,* for a current and lively guide to observing the night sky with the naked eye.

Since this is your first observation project re-read the introductory section of this activity guide, *Starry Nights with the Naked Eye,* for important information on how to conduct and report your observations.

For optimal viewing of the stars you want to pick a clear night without too much moonlight so, if possible, avoid nights near a Full Moon. You can do your observations from anywhere that is convenient, even in front of your residence, although you will see more and fainter objects if you find a dark location, away from direct lighting. If the Moon is in the sky, make a note of its phase and location relative to the region of sky that you observe.

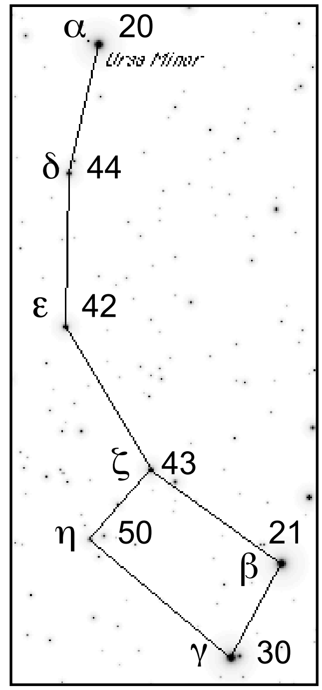
Observation Details

(i) Make a sketch in your log-book of two constellations that you observe. Include *Orion* as one of the two constellations.

Do not reproduce what is shown on the planisphere. Instead, sketch the actual stars that you see. The planisphere is only a guide to help you find objects in the sky; *your log book should only record the genuine data produced by your own observations.*

(ii) Compare the stars *Betelgeuse* & *Rigel* – which one appears brighter to you? Also, estimate how much brighter *Betelgeuse* appears compared to *Aldebaran* in percentage terms; does your observation agree with the calculation on the last page?

(iii) Estimate the magnitude of the faintest star you can see (called the "limiting magnitude"). The stars in the *Little Dipper* are very convenient for estimating the limiting magnitude, since these stars span a range of magnitudes from about 2 to 5. Magnitude 5 can rarely be achieved in city skies, and frequently even the fainter 4th magnitude stars in the handle of the *Little Dipper* can't be seen.



***Little Dipper* Magnitude Chart**

The limiting magnitude should be recorded in your log on every night of observation.

Note: Decimal points in the star magnitudes are omitted on the *Little Dipper* Magnitude Chart, in order to avoid confusion with star symbols (e.g. the number "21" next to a star means it has magnitude 2.1)

How to find Polaris

★As measured by its brightness *Polaris* is a very average star, only magnitude 2, neither exceptionally bright nor especially faint. The other stars in the *Little Dipper* are generally quite dim. It can therefore be difficult to positively identify *Polaris*, even when looking in the right part of the sky, without using other more familiar stars to confirm its location.

★A common trick favoured by amateur astronomers to identify *Polaris* is to use the *Big Dipper*, which is very noticeable because it is big and bright, to "point" the way to *Polaris*. In fact, the two stars at the end of the bowl in the *Big Dipper* point almost directly to *Polaris,* as described in the May 8-9 excerpt from *365 Starry Nights* on pg. NIGHTS-20.

★A helpful drawing of the pointer is shown on the November sky chart on pg. NIGHTS-23, and is also printed on the *Edmund Scientific Star and Planet Locator*.

Physics 190: Astro Project II

Angles in the Sky

Goals

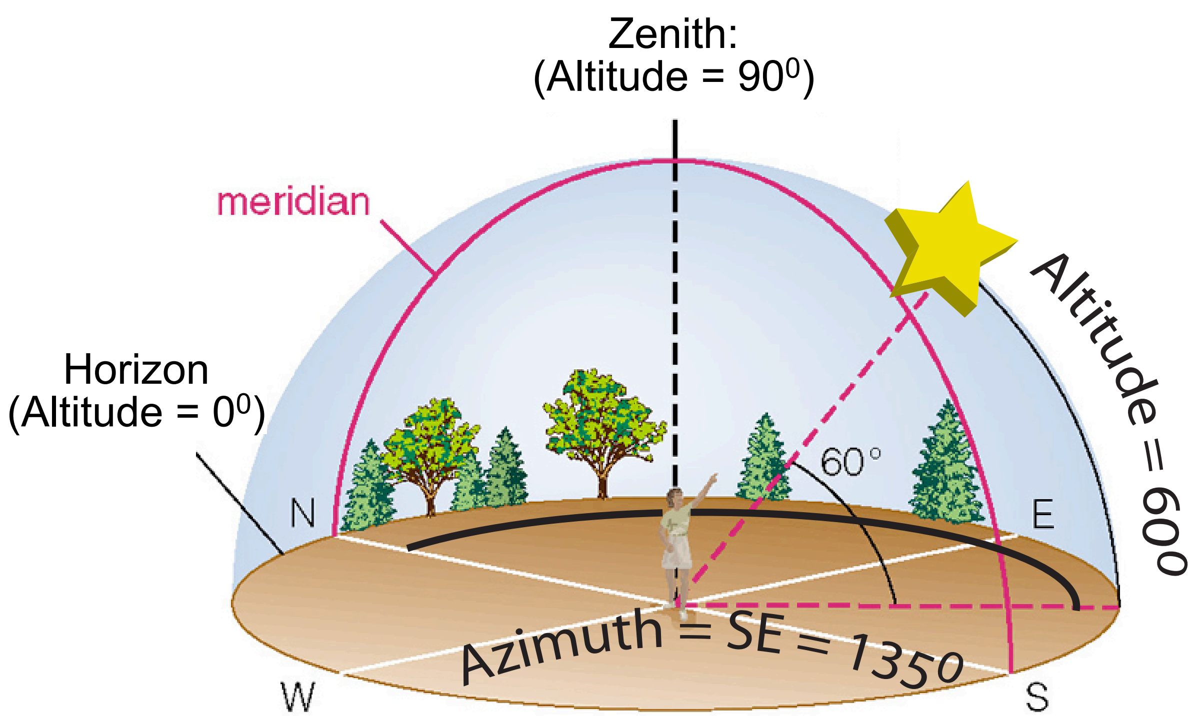
★Familiarize yourself with the concepts of *altitude* and *azimuth* on the celestial sphere. Learn how to quantitatively estimate angular positions and the angular separation between celestial objects. Estimate the altitude of the "pole star," *Polaris*, which is approximately equal to an observer's latitude.

Observation Plan

★With thorough advanced preparation and planning the observations for this project can be done in a single evening. <u>You should be able to do most of the project during the first on-campus star night</u>.

Background

Two coordinates are needed to specify the location of an object on the celestial sphere (as we will discuss in class). *Altitude* and *azimuth* define one convenient set of angular coordinates.



The **altitude** of an object on the celestial sphere is defined as the angular height above the observer's horizon (taking the shortest angular distance, that is, from the object to the point on the horizon directly underneath it).

The point directly over an observer's head, known as the **zenith**, has the maximum possible altitude of 90^0, while the horizon has an altitude of 0^0, as illustrated above.

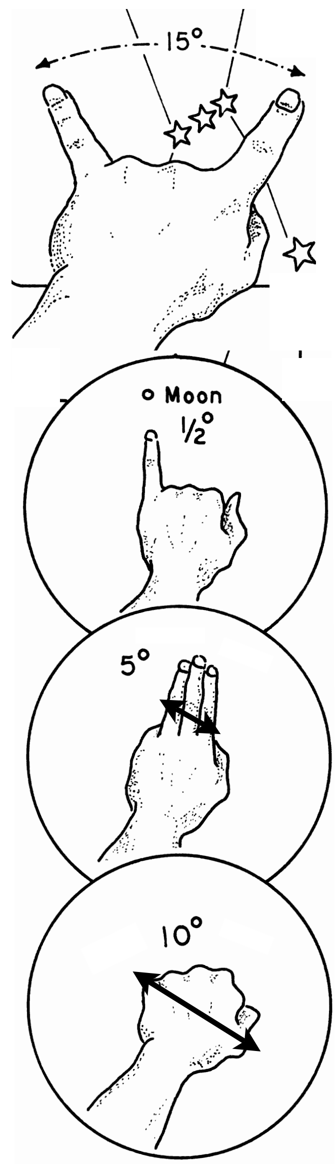
Azimuth is defined along the horizon, and is measured starting from North, heading towards the East, and ending at the point directly below the celestial object of interest. For example, an object due East has an azimuth of 90^0, while a point due South has an azimuth of 180^0.

The illustration shows a hypothetical star with an altitude of 60^0, which is 2/3 of the way from the horizon to the zenith. The star is to the south-east (half-way between east and south), and therefore has an azimuth of 135^0 (half-way between azimuths 90^0 and 180^0).

Project preparations

Your hands and fingers can be used to make rough estimates of the angular positions of objects on the celestial sphere, and the angular separation between objects:

For example, if you stretch your arm in front of you, and sight along your arm with one eye, the angle "subtended" by your fist will be about 10^0.



Taken from
365 Starry Nights
©1982 Prentice-Hall

As part of your project report, calibrate the 10^0 fist rule for yourself, as follows.

★Make a fist with your knuckles running up-and-down vertically. Hold your fully-stretched arm out in front of you, and sight along your arm with one eye while it is held horizontally (ask a friend to verify that your arm is horizontal).

★Then place your other first on top of the first, and continue stacking fist-over-fist, until your line of sight is vertical.

★Be sure to stack one fist against the thumb-knuckle of the other fist, with the knuckle "sticking out" as illustrated to the right.

★Count how many fists were stacked (not counting the first "horizontal" fist, which is at 0^0). Since these covered 90^0, deduce the angle subtended by a single fist.

★Detail the results in your project report.

Observation Details

Begin your observations by testing some of the angle guides illustrated on the right on the actual night-time sky. We'll use the known angular separation between some stars in *Orion,* and the nearby constellation of *Gemini* (just to the East of *Orion*).

(i) **Start with the 5^0 "three-finger rule:"** the angle subtended from the top of the index finger to the bottom of the ring finger (which is next to the little finger) is about 5^0. Test this rule using the "twin" stars *Castor* and *Pollux* in the constellation of *Gemini* (see *365 Starry Nights*, February 21-22), which are separated by 4.5^0. How many fingers "fit" in between the two stars? Try to estimate to within a half-finger or so. Always remember to sight along your arm with one eye.

(ii) **Test the 10^0-rule**.by sighting your fist between *Orion's* left shoulder (the star *Betelguese*) and the left star in *Orion's* belt (the star *Alnitak*), whose separation is very close to 10^0 (see *365 Starry Nights*, January 5). How closely does the 10^0-rule agree with observations using your own fingers?

(iii) **Test the 15^0-rule**. the space between the little finger and the index finger, when fully spread out, subtends an angle of about 15^0. Test this rule against the angular separation between the star in *Orion's* right shoulder, called *Bellatrix,* and the blue-giant star *Rigel* in the right knee, which is 14.8^0 (see *365 Starry Nights*, January 5). How closely does the 15^0-rule agree with observations using your own fingers?

(iv) **Test the "pinky" rule:** it subtends an angle of about 1/2 degree. An interesting example is provided by the Full Moon, which subtends an angle of about 1/2 degree. It will likely surprise you that you can can block a Full Moon with your pinkie! The Moon generally gives the impression of subtending a much larger angle, because it is usually the largest object in the sky, with nothing else to set its scale (for this reason photographs of the Moon, without appreciable magnification, are usually disappointing). If the Moon is not visible, you can also test the pinky rule with the stars in the head of *Orion*, as illustrated in *365 Starry Nights* (January 6). Recognize that the Full Moon could easily fit inside the small region occupied by *Orion's* head!

(v) **A popular and interesting example** of two stars separated by a small angle is the double star *Mizar* and *Alcor,* located in the handle of the *Big Dipper*, which are described in the May 14-15 excerpt of *365 Starry Nights*. These stars are separated by only $2/10^o$, about half the width of a pinkie. See if you can verify the small angular separation of *Mizar* & *Alcor* for yourself. This pair is also interesting to observe because, in addition to being so close, they are also very different in brightness: *Mizar* is magnitude 2.2 while *Alcor* is mag 3.9, a factor of almost five in brightness.

(vi) **The final part of this project** is to use the finger and fist rules, either alone or in combination (for example, by "stacking" fists or fingers), to estimate the angular positions (altitude and azimuth) of the following objects:

★*Polaris* (note that the azimuth of the celestial pole is defined as 0^0).

★*Betelgeuse* (the red star in the left shoulder of Orion)

★*Rigel* (the blue star in the right knee)

(...continued overleaf)

Notes:

★When measuring altitude, say by stacking fists, ask a friend to make sure that your first outstretched arm and fist are horizontal. Do not count the "first" fist, since it is at zero altitude.

★When stacking fists, be sure to stack one fist against the thumb-knuckle of the other fist (the knuckle should "stick out" as illustrated on pg. APRO-II-2).

★Be sure to record the exact time of your observations, since the angular coordinates of all celestial objects will change with time (except *Polaris)*.

★To determine the azimuth, you will need to know the direction of North. Use a compass, or a known landmark, or *Polaris* itself (if you can find it without knowing which way is North!).

★Do not forget to "calibrate" the angle subtended by your fist, according to the procedure under Project Preparations on the second page of this script, and describe the results in your project report.

★You may be surprised to learn that the angle subtended by fingers and fists are the same for most people, whether they have bigger or smaller bodies. This is because the proportions of the body plan are roughly the same for most people, regardless of their overall size.

Notes on *Polaris* measurements:

★Take several measurements of the altitude of *Polaris* and average the results. (See *Physics Lab I, Triangulation & Scientific Error Analysis*, for a discussion of scientific uncertainties.) Estimate the scientific uncertainty in your angular measurement of the altitude of *Polaris*. Be sure to consider the source(s) of "systematic" uncertainty, which may be larger than the "statistical" uncertainty.

★Aim for the most accurate measurement possible of the altitude of *Polaris*. You may be able to manage a degree of precision or better by using a combination of fists and fingers (for example, the pinkie subtends an angle of about $1/2^0$, while the tip of one finger subtends about 1^0).

★We see in class that the altitude of *Polaris* closely approximates the observer's latitude. How well do your measurements agree with the latitude of Vancouver? How significant is the agreement or disagreement, in the light of the scientific uncertainty in your measurement?

PHYSICS 190: ASTRO PROJECT III

OBSERVATION OF VARIABLE STAR ALGOL

Goals

The goals of this project are two-fold:

★Measure and record the variable magnitudes of the eclipsing-binary star *Algol.*

★Gather together observations from the entire class, which may allows us as a group to plot a *light curve* of the magnitude data, near the deepest part of the eclipse.

Observation Plan

★Observations should be done in two parts, on two separate evenings:

1) Observe *Algol* on at least one night when there is ***no*** eclipse*;*

2) Observe *Algol* on a night when there ***is*** an eclipse, ideally roughly every 20 minutes, over about two hours around the time of a minimum

★Eclipses of *Algol* can only be seen on specific dates, within a few hours of the deepest part of the eclipse (called the minimum). Dates and times of suitable minima in the spring term of 2008 are:

★ Jan. 9 @ 9:42 PM ★ Jan. 12 @ 6:31 PM

★ Jan. 29 @ 11:27 PM ★ Feb. 1 @ 8:16 PM ★ Feb. 4 @ 5:06 PM

★ Feb. 21 @ 10:02 PM ★ Feb. 24 @ 6:51 PM

★ Mar. 13 @ 00:47 AM ★ Mar. 15 @ 9:36 PM

★ Apr. 4 @ 11:21 PM ★ Apr. 7 @ 8:10 PM

Background

Algol (β *Persei*) is an eclipsing-binary star system in the constellation of *Perseus*. Eclipsing binaries are two stars in orbit around each other, with each star periodically passing in front of the other, along the line of sight from Earth. These star systems will be discussed in class, based on Chapter 10.7 of our textbook, *Astronomy: A Beginner's Guide*, see Figure 10.18 (5th edition).

Figure 1 on the next page shows a "light curve" for a typical eclipsing binary, taken from another textbook (*The Cosmic Perspective* by Bennett et al.). A light curve plots the combined brightness of the star system as a function of time; the timing details given in Fig. 1 provide rough guides to the actual light curve for *Algol*. Normally, *Algol* is magnitude 2.1, easily bright enough to be seen in city skies. However, during the deepest part of the eclipse, its magnitude drops to about 3.4 (a change by a factor of about $2.5^{(3.4-2.1)} \approx 3.3$). *Algol* is by far the most prominent variable star that is visible to the naked-eye.

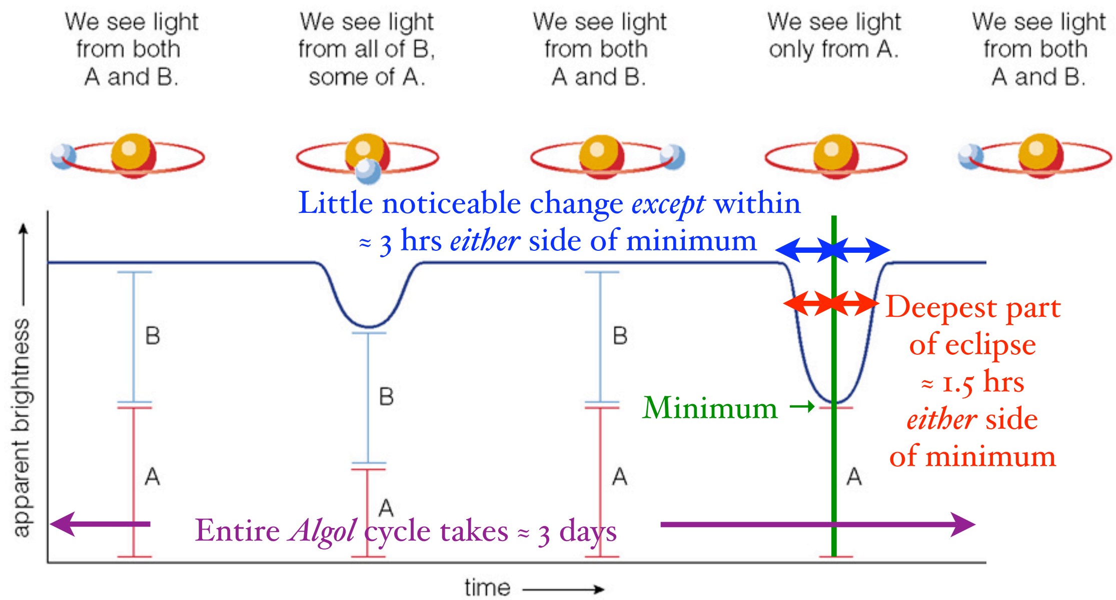


 FIG. 1

In the case of *Algol* we can't see the two stars separately ("A" and "B" in Fig.1), even in a large telescope, because they are so close together, and at a tremendous distance; instead we see what looks like a single star (many other binary stars can be seen separately, or "split," in a telescope — we will look at some examples during the star nights). We can however infer that this is a binary system, from the shape of the light curve; more direct evidence for the binary nature comes from spectroscopy, as we will discuss in class.

The biggest drop in the brightness of *Algol* takes place when the smaller brighter star is eclipsed by its larger and fainter companion; in addition to this *primary minimum*, there is also a *secondary* minimum, when a portion of the larger star is eclipsed by the smaller one. In the case of *Algol* the secondary minimum is not very noticeable to the naked eye.

Algol derives from the Arabic for *"The Ghoul,"* revealing that its peculiar properties were known to the ancients. According to the ancient Greek legend, the hero *Perseus* slew the *Medusa*, a monster whose gaze turned people to stone, using his shield to look only at the *Medusa's* reflection. As imagined on the sky, *Perseus* is holding his sword in one hand, while grasping the *Medusa's* severed head with the other, the "evil eye" periodically blinking as a continuing reminder of the monster's malevolence.

Although the period of the binary star orbit (and hence of the entire light curve) is about three days, there is little noticeable change in *Algol's* brightness except within about three hours either before or after the deepest part of the eclipse. The change is brightness is most noticeable within a very short short time-span of about 1.5 hours, either before or after the minimum, and the drop in brightness in that interval is quite striking.

Observation of variable stars is a popular past-time of amateur astronomers. For example, some variable stars change brightness irregularly, due to instabilities in the star's internal processes, or to accretion of matter from a companion star, and careful observations of their light-curves can yield useful information about such processes (see the web site of the *American Association of Variable Star Observers*, http://www.aavso.org/).

Preparations

This project may be a little more challenging that the others, for two reasons. First, while *Algol* is not a faint star, nether is it exceptionally bright, even in its "normal" state (when it is about as bright as *Polaris*), and it is in a very unremarkable part of the sky, with few bright star patterns nearby. Second, *Algol* shows little change except during the deepest part of the eclipse, which lasts for only a few hours, and which happens only once roughly every three days. Thus advance preparation and planning is crucial for a successful observation of an eclipse. On the other hand, your effort will be amply rewarded when you witness the drama of the eclipse for yourself, informed by your understanding of the physics of this distant star system, seen across a gulf of space and time which spans a distance of some one-hundred light-years, and with an eclipse having actually taken place almost one hundred years before you observe it.

Figure 2 on the last page of this script is a star chart of a region of the sky to the West on Feb. 28 2007 at 8PM (this view of the constellations will be identical any evening in early winter of any year).

Algol is indicated by the open circle in Fig. 2. Compare this chart with the planisphere, where *Algol* is the last "dot" in the constellation line just above the "E" in "PERSEUS." Read the November & December sky maps and highlights in the excerpts from *365 Starry Nights* for helpful background on this part of the sky.

Familiar nearby regions of the sky that help in locating *Algol* include the constellation of *Cassiopeia*, which is very prominent by virtue of its "W" shape (see *365 Starry Nights,* November 3-4), and the constellation of *Auriga,* whose brightest star, *Capella* (α *Aur*), is part of the Winter Hexagon *(Auriga* is described in *365 Starry Nights,* January 29-30).

A common trick used by amateur astronomers to locate objects in an unremarkable or unfamiliar part of the sky is to start from a relatively nearby constellation or star pattern that is more recognizable. The trick is to use a star chart to identify a pair of familiar stars that can be used to "point" to the object in question.

Figure 2 includes a useful pointer for locating *Algol*, using two stars in *Cassiopeia*: draw an imaginary line from β Cas ("beta," the 2nd brightest star in the constellation, at magnitude 2.3) through nearby η Cas ("eta," not very prominent at magnitude 3.5), and continue for about 25^{o} to reach *Algol*.

Figure 2 also gives the magnitudes of several comparison stars near *Algol*. Note that decimal points in the magnitudes are omitted on the star chart, so as to avoid confusing the decimal with a star. For example, the number "29" next to a star means that it has magnitude 2.9.

There are two particularly useful comparison stars. The first is γ Andromedae ("gamma")*,* which has magnitude 2.1, the same as *Algol* in its "normal" state. You will need a "pointer" to properly identify γ And. Once again we can use two stars in *Cassiopeia*: this time, draw an imaginary line from β *Cas* through nearby α *Cas* ("alpha," the brightest star in the constellation), and continue for about 20° to reach γ *And*.

A second very useful comparison star is ρ *Persei* ("rho"), which is only about 2^0 south of *Algol*, and which, at magnitude 3.3, will be only slightly brighter than *Algol* during the deepest part of the eclipse (although the colour contrast may give some people the impression that ρ *Persei* is a bit fainter than *Algol* at the minimum).

Scheduling Issues

Algol's brightness does not change much outside a narrow window of a few hours around the time of the deepest part of the eclipse. Although there is an eclipse every 2.87 days, only a few eclipses occur at a convenient time of night (most eclipses occur during daylight hours or late at night).

Convenient eclipses typically occur in pairs about every two weeks. It is therefore essential that you plan in advance for those dates and times.

A very handy resource for planning observations is an on-line calculator provided by *Sky & Telescope* magazine, which computes the times at which *Algol* reaches its minima:

http://skyandtelescope.com/observing/objects/variablestars/article_108_1.asp

Sky & Telescope also has a useful on-line article about *Algol*, see:

http://skyandtelescope.com/observing/objects/variablestars/article_160_1.asp

★Suitable dates and times of *Algol* minima for the current semester are given at the beginning of this script, under Observation Plan.

Observation Details

★You should be sure to compare *Algol* with γ *And* on a night when there is **no** eclipse, to form a good impression of *Algol* in its "normal" state.

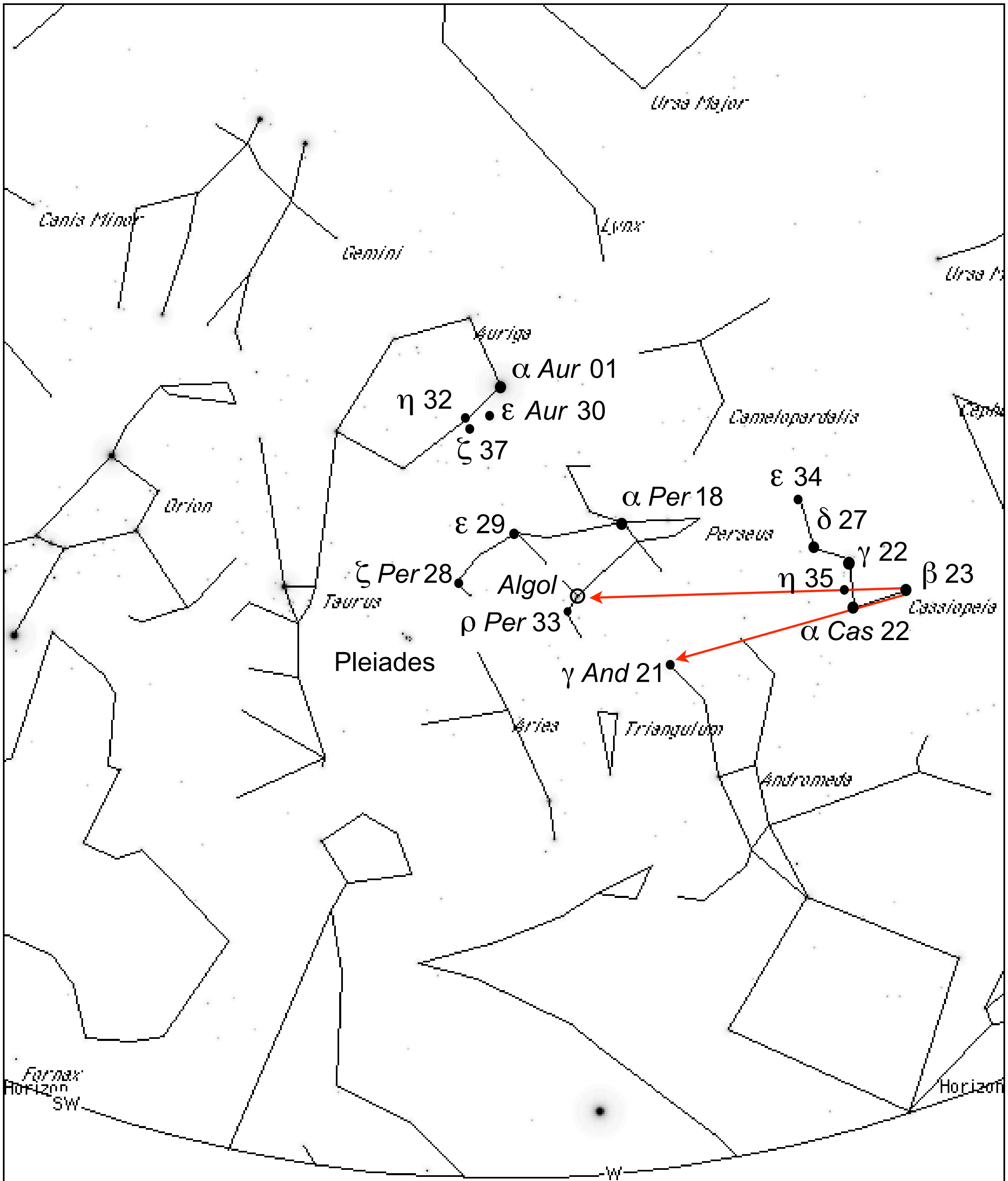
★During an eclipse, compare *Algol* frequently with the comparison stars, especially γ *And* and ρ *Per*, which together more-or-less "bracket" the entire range of magnitudes.

★Ideally you should observe *Algol* every 20 minutes or so within about 1.5 to 2 hours of a minimum.

★Bear in mind that you can start observing either before the minimum, and follow *Algol* as it progressively gets fainter, or you can start around the time of the minimum, and track *Algol* as it progressively returns to its normal brightness.

★You may be able to estimate *Algol's* brightness to a small fraction of a magnitude by making use of all of the comparison in *Perseus*, *Auriga,* and *Cassiopeia*, given in Fig. 2; changes as small as 0.1 magnitudes (which represents a change in brightness of 10%) might be noticeable, especially near the minimum of *Algol*, if you use two comparison stars that are close in magnitude, in order to "bracket" the observed brightness of *Algol*.

Beware: This chart was drawn using *SkyChart III* “modern” constellation outlines, which may by differ somewhat from the outlines on the *Edmund Scientific Star and Planet Locator.*



Viewed from:	Local time:	Field of view:
Vancouver2	20:00:00	100° 00' 00.0"
123° 11' 00.0" W	2007/02/28	Azimuth: 260.7789°
49° 12' 00.0" N	JD 2454160.67	Altitude: +56.4747°

FIG. 2

Physics 190: Astro Project IV

Mars — Wanderer in the Sky

Goals

★Plot the motion of Mars relative to the background stars, and measure changes in its magnitude, over the course of the semester.

Observation Plan

★Observe Mars at least twice during the term; make the first observation as early in the term as possible, and make your last observation as late in the term as possible.

Background

The "wandering" motion of the planets against the background of fixed stars puzzled the ancients. Copernicus' model of a Sun-centered universe eventually overturned the Ptolemaic system, and ushered in the scientific age. However, it was more precise observational data, due to Tycho Brahe, that proved decisive: both the Ptolemaic and the Copernican systems were inconsistent with this data, and while Copernicus' model was more "elegant," it was clear to Brahe and his assistant, Johannes Kepler, that a more accurate theory was needed.

In this project you will observe the wandering motion of Mars for yourself. As you work through this project, bear in mind that Brahe himself conducted his observations with the naked eye, just as you will do. Recall as well that Brahe's precise observations of the motion of Mars caused Kepler to reject circular orbits for the planets, and ultimately led to his "complete reformation in astronomy." Kepler's three laws of planetary motion would in turn be explained by Newton with his universal laws of gravity and motion, in a unified scientific description of all mechanical phenomena, in the Heavens and on Earth. Hence in observing Mars you are, in a sense, retracing the very origins of the scientific revolution!

A time-lapse movie of the motion of Jupiter and Saturn against the background stars, over nearly a full year, can be seen at *Astronomy Picture of the Day* for December 20 2001:

http://antwrp.gsfc.nasa.gov/apod/ap011220.html.

Preparations

Whether or not a particular planet will "wander" against the background of stars in a significant way, in a relatively short period of time, such as a few months, depends on the relative position of the Earth and the planet in their orbits.

In order to plan an observation project like this, it is very helpful to use planetarium software, such as *SkyChart III*, in order to decide which planets, if any, are suitable for observations in a given period. This was one goal of the *Astro Computer Lab*, which we will have done in the second week of class, and where we will have found that Mars provides a spectacular opportunity to view planetary motion in the spring of 2008. Mars is the best planet for observing motion against the background stars, since it is the closest outer planet, and thus exhibits the most spectacular changes in position and brightness, while being easy to observe.

Mars will finish retrograde motion at the end of January, thereafter undergoing very rapid prograde motion, moving East relative to the stars as much as a few degrees each week. Over the semester Mars will also noticeably decrease in brightness, by just over two full magnitudes, as it crosses from the constellation of Taurus to Gemini.

You should read the January & February excerpts of *365 Starry Nights* in order to familiarize yourself with the stars and constellations in this part of the sky. Of particular importance is *Aldebaran* (α Tau), the brightest star in the constellation of Taurus the Bull, and the "twin" stars in the constellation of Gemini, *Castor* (α Gem) and *Pollux* (β Gem). You will use these stars to measure the position and magnitude changes of Mars.

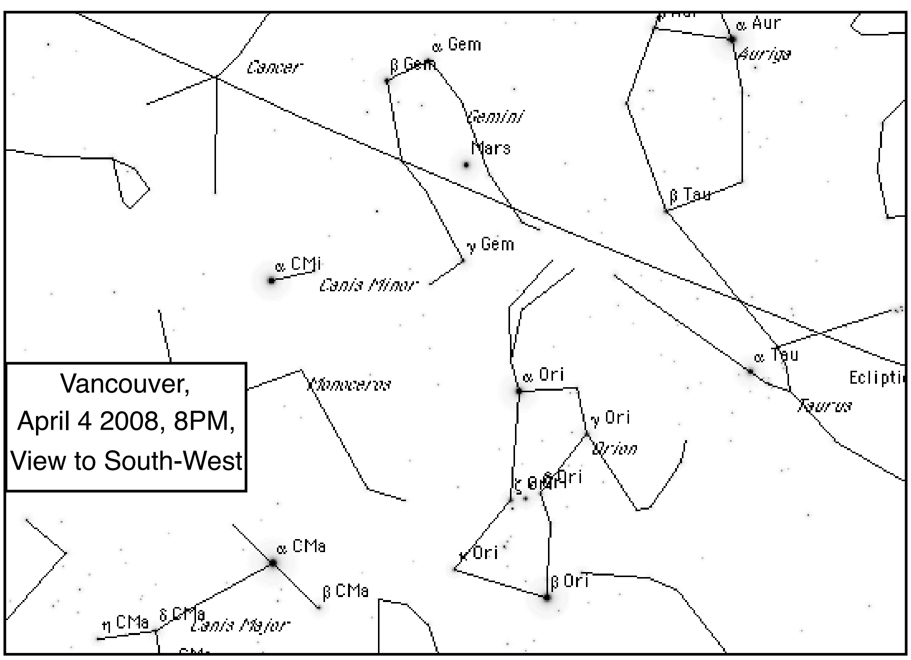
Observations

★<u>Observe Mars at least twice during the term; make your first observation as early in the term as possible, and make your last observation as late in the term as possible</u>, in order to record the greatest possible change in its position and brightness.

★On each night of observations, carefully measure and record the angle of Mars with respect to the star *Aldebaran*. Consider using *Castor* and *Pollux* as well to get the most precise measurements possible.

★Also measure the brightness of Mars with respect to *Aldebaran.*

★Record each evening of observations in a separate logbook entry. Use a star chart, such as the one below, to collectively record all of your position observations.



Physics 190: Astro Project V

Period of the Moon's Orbit

Goals

★To measure the Moon's angular position relative to a fixed star or planet, over two nights, and deduce the sidereal period of its orbit around the Earth.

Observation Plan

Observations must be done on two consecutive evenings, and only on nights which fall in one of the following intervals:

★ Jan.15 to 22 ★ Feb. 12 to 19 ★ Mar. 10 to 17

Background

The time it takes for the Moon to complete one 360^0 orbit around the Earth is known as its *sidereal* period, because the Moon will return to the same point in the sky relative to a star. There is another lunar cycle, of perhaps greater interest to the inhabitants of planet Earth, which is the cycle related to the Moon's phase, say from one New Moon to the next; the period of that cycle is known as the *synodic* period (from the ancient Greek word for "meeting," as in the "meeting" of Moon and Sun at New Moon).

The sidereal and synodic periods are different, because the percentage of the lunar disk that is illuminated by the Sun, as viewed from the Earth, depends on the relative angles of the three bodies, which is affected by the Earth's motion around the Sun, as well as the motion of the Moon around the Earth. The geometry is similar to the illustration in Figure E.7 on page 8 of our textbook (5th edition), and will be discussed in class.

In this project you will estimate the Moon's sidereal period by measuring its angular motion relative to a star or planet. By measuring the change in the Moon's angular position over two days, you can estimate how many days it would take for it to cover a full 360^0 relative to the distant celestial object. (If one was to measure the period of the *synodic* cycle instead, how could that be done?)

Preparations & Observation Details

The illustration on the next page shows how the position of the Moon relative to a particular star or planet might change from one night to the next. You are to measure the angle between the Moon and the same star or planet on two consecutive nights.

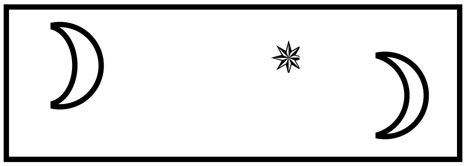
It is important to find good dates for making these observations, when the Moon is up at a reasonable time after sunset, and when it is near a bright star or planet. It is also important that the reference object be as close to the ecliptic as possible ***(why is that?)***.

Try to use the planetarium software yourself to pick good dates: run the software animation over a whole month, tracking the motion of the Moon. In spring term 2008 convenient reference objects are the *Pleiades*, *Taurus*, *Gemini*, and *Mars*. The Moon can be seen within about 30^0 of a bright star or planet in this broad region of the sky, at a decent time of night (6-9 PM), during the periods listed above.

★Avoid making observations within a few days of a Full Moon, since the Moon is then so bright that it will tend to overwhelm the much fainter light of the reference object.

★Carefully record the precise time of your observations, and make as accurate a determination of the angle between the Moon and the reference object as possible. Include a sketch in your log book.

★Take several measurements of each angle and average the results (see *Physics Lab I, Triangulation & Scientific Error Analysis*, for a discussion of scientific uncertainties).



Analysis

To compute the sidereal period, let θ be the change in angular position of the Moon over the two nights, and let τ be the time elapsed in days between the two observations.

For example, let's suppose that in the illustration above the Moon is 5^0 to the right of the reference star at 7:30 PM one night, and to 10^0 the left at 9:00 PM the next night. Then the Moon changed its angular position by $\theta = 10^0 + 5^0 = 15^0$, in an elapsed time τ of 1 day plus 1.5 hours, or $\tau = 1 + (1.5/24) \approx 1.063$ days.

To find the Moon's sidereal period, use the proportional relation:

$$\frac{\theta}{\tau} = \frac{360^\circ}{\text{Sidereal Period}},$$

which implies

$$\text{Sidereal Period} = \frac{360^\circ}{\theta} \times \tau.$$

In our hypothetical example, Sidereal Period = $360^0 / 15^0 \times 1.063 \approx 25.5$ days.

Note: In the above example the Moon was to the right of the reference object one night, and to the left on the next. It may happen that the Moon is on the same side of the reference object on both nights of your observations; in that case, the change in angular position of the Moon is given by the difference in the two measured angles.

Compare your result with the known sidereal period of 27.3 days. How close is your answer, as a percentage difference?

For the fullest analysis of your results, estimate the scientific uncertainty in the sidereal period. The uncertainty in the sidereal period, as a percentage error, is the same as the percentage error in the measured angle. Don't forget to include possible sources of systematic error in the measured angle. Does your estimate of the sidereal period agree with the known value, within the scientific errors?

PHYSICS 190: ASTRO PROJECT VI

PHASES OF THE MOON

Goals

★Observe and record the location and phases of the Moon over several weeks.

Observation Plan

Observations must be done at about the same hour on three or four evenings (not necessarily on consecutive nights), within two weeks following a New Moon.

In spring term of 2008 New Moon begins on the following dates:

★Jan. 8 ★Feb. 6 ★Mar. 7

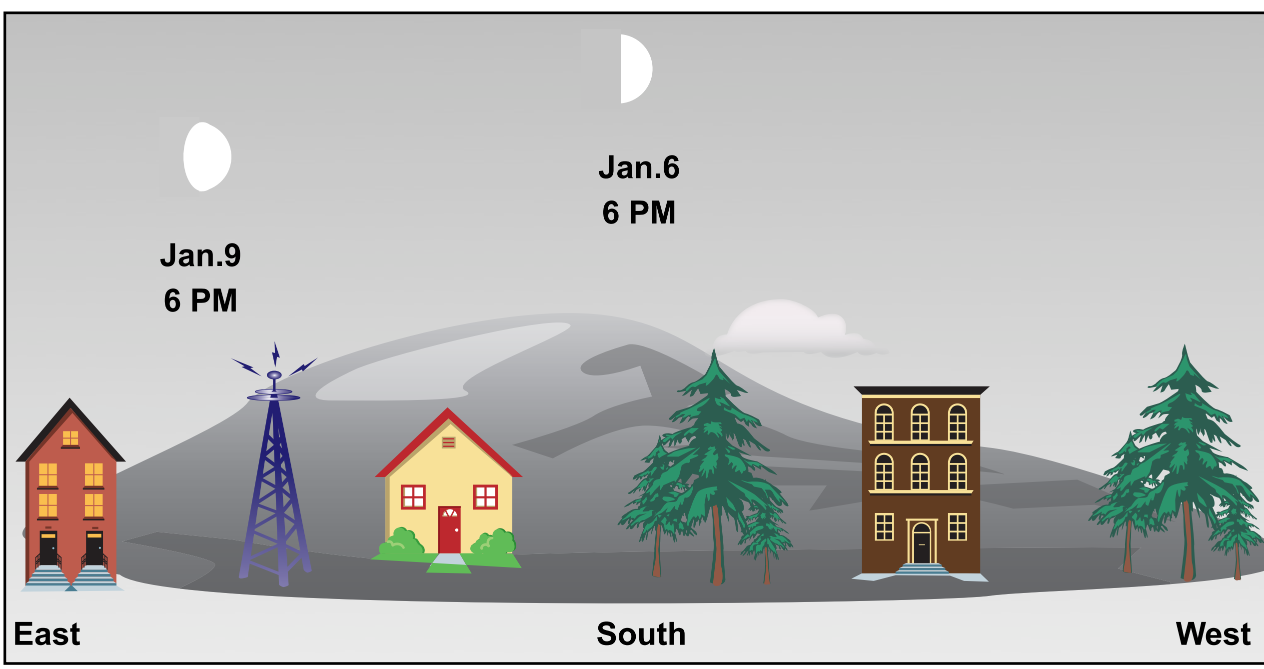
Note: You will not be able to make useful observations much after Full Moon, since the Moon will then rise too late after sunset, hence you should begin the sequence of observations as close to a New Moon as possible.

Background

Most people know that the Moon's phases change over the course of a month, but remarkably few people know that the Moon shines by reflected sunlight, with its phase determined by its position relative to the Sun and Earth. In this project you will qualitatively record the Moon's location and phase over several weeks, to track these connections for yourself.

Preparations

Find a convenient location from which you have a relatively unobstructed view of the



horizon, facing South, and such that you are able to look to the East (to the left) and to the West (to the right). Your view of the horizon should also include some landmarks, such as some nearby buildings, power lines, trees, etc. Ideally, there should be landmarks at several points on the horizon along the way from East to West.

Make a sketch of the horizon including the landmarks, with enough space to fill in the position of the Moon in the sky, as in the above illustration. Place South in the center, and label East and West (use the setting Sun to locate West if you don't have a compass).

Observation Details

Conduct your observations at the same time after sunset each night (about 30 minutes to 1 hour after sunset), and from the same location.

Refer to the note on the previous page about scheduling observations during the two weeks following a New Moon.

Since we want to have some idea of the relative position of the Moon and Sun, it is convenient to choose a fixed time that will be within an hour or so of sunset, when the Sun is not too far below the Western horizon. From January to the end of February pick a time around 5-6PM, while in March pick a time around 6-7PM.

Record the position of the Moon, relative to the landmarks on your sketch, during each observation. Draw the shape of the Moon, taking care to distinguish between crescent, waxing, and full phases. Also be sure to estimate the Moon's altitude. Record the date and time on your sketch with each observation of the Moon, similar to the diagram on the last page.

Also estimate the percentage of the lunar disk (the so-called phase) that is illuminated on each observation. Include a table of the observation dates and estimated lunar phases (from 0% to 100%) and altitudes in your project report.

Start making your observations, if possible, within a day or two of a New Moon, and record the Moon's location and phase every few days, up to Full Moon. If the weather is a problem, you can try to accumulate observations over several lunar cycles.

In your project report use your sketches and estimated lunar phases to summarize how the positions and phases of the Moon change with time, starting from New Moon.

Can you see evidence in your data for the relation between the Moon's phase and its angle from the Sun> How does the Moon's altitude change (i.e., always higher later into the lunar cycles)?

Name________________________________ Student #________________________

Lab Partners ____

Physics 190: Physics Lab I

Triangulation &

Scientific Error Analysis

Goals **1.** Measure the distance of an object by triangulation.
2. Learn about some aspects of scientific error analysis.

Equipment **1**. Calculator, pencil, ruler. **[Bring your own, including a calculator.]**
2. Laser pointer that turns through an angle and moves along a baseline.
3. Large and small protractors for measuring & plotting laser turn angle..
4. Tape measure for determining the length of the baseline, and (<u>after</u> you predict the distance by triangulation!) the "actual" distance to the object

[<u>All equipment is provided at the physics lab, unless otherwise indicated</u>.]

CAUTION: DO NOT LOOK DIRECTLY AT THE LASER

BACKGROUND

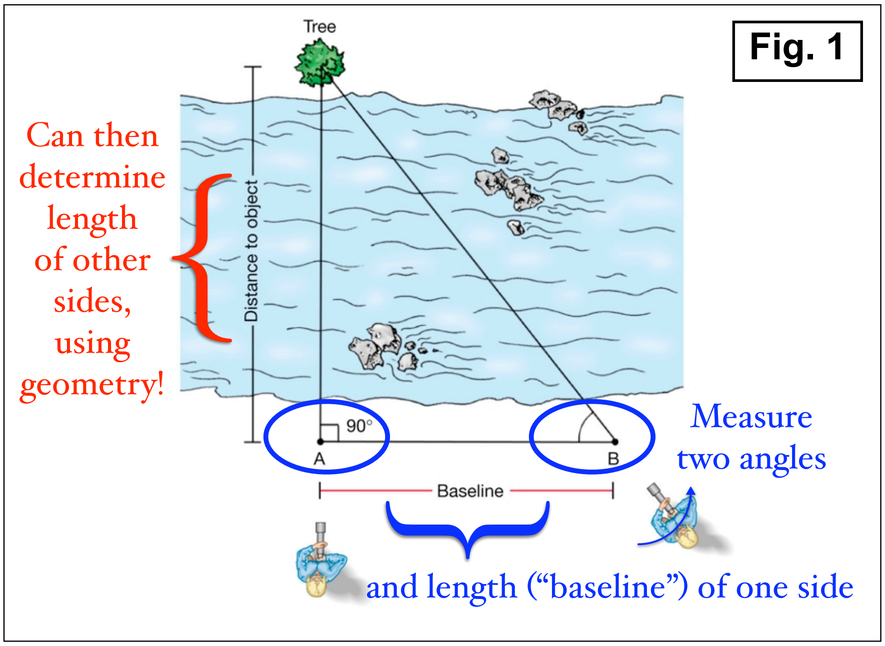
The method of triangulation and its relation to distance measurements in astronomy, by the technique of parallax, are discussed in the first or second weeks of class, and in the opening section *Exploring the Heavens* of our textbook, *Astronomy: A Beginner's Guide.*

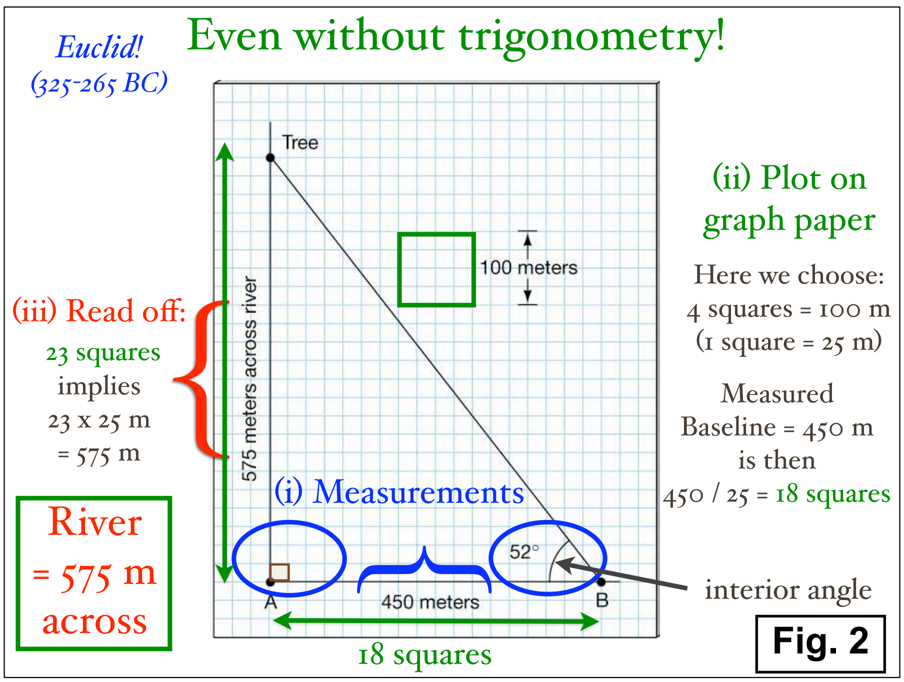
A detailed set of instructions on how to perform this experiment is given later in this lab script under <u>Procedure</u>.

Before you begin the experiment you should thoroughly read this background section, which gives an introduction to the concepts of scientific error analysis, which is a major theme of this lab. This section also contains some worked examples that you should go through in order to understand the data analysis that you will perform during the lab.

Figure 1 on the next page shows an illustration of a hypothetical triangulation experiment, taken from Fig. E19 on page 17 of our textbook (5th edition). The experiment consists of measuring the length of the baseline along which the laser sight is moved, and an angle when the laser is turned, at one end of the baseline, in order to line up with the object whose distance is to be determined.

The distance to the object can be estimated from the measured values of the length of the baseline, and the turn angle of the laser. The analysis in this lab is to be done graphically, even if you know trigonometry! The graphical analysis technique for the physical setup in Fig. 1 was discussed in class using the illustration that is reproduced in Fig. 2 on the next page.





The most difficult quantity to measure in this experiment is the turn angle of the laser (see the "interior angle" in Fig. 2). As you will discover when you perform this experiment, the measured value of the angle generally changes each time a person measures it, and from person to person. This means that one cannot trust the result of a single measurement.

All measuring instruments, and the measurement of all scientific quantities, behave in this way. We say there is some **uncertainty** inherent in all scientific measurements. One thinks of the angle for instance as having a definite value, but our instruments and techniques have various limitations, perhaps a wobbly laser sight. (The same is true of the measurement of the baseline length, but this won't be as noticeable in our experiment as the uncertainty in the measurement of the angle.)

It seems reasonable to expect that one can obtain a more accurate result for the angle by combining the individual measurements. The old adage, that "the truth lies in the middle," suggests that the "best" estimate of the angle might be the measurement with the value in the middle or, perhaps, that the best value is the average of all the measurements:

$$\text{Average} = \frac{\text{Sum of the individual values}}{\mathbf{N} = \text{ number of measurements}}, \quad \text{Eq. (1).}$$

For example, if one measured the angle 4 times, with results of 48.00, 48.75, 52.25 and 54.00 degrees, then the average angle according to Eq. (1) would be:

$$\text{Example Average} = \frac{48.00 + 48.75 + 52.25 + 54.00}{(\mathbf{N} = 4)} = \frac{203.00}{4} = 50.75^\circ.$$

It is unlikely that the average will turn out to be exactly equal to the "true" angle, but it is likely to be closer than the individual measurements, which are more "directly" affected by limitations in the apparatus and techniques.

For example, if the apparatus wobbles, or "fluctuates," each time a measurement is made, it is reasonable to expect these fluctuations to "average out" when adding up over many measurements: sometimes the apparatus will wobble in one direction (resulting say in a somewhat larger angle), and sometimes in the opposite direction (giving a somewhat smaller angle).

Since the fluctuations won't cancel perfectly (in a finite set of measurements), it is important to estimate how much uncertainty is left in the average value, in order to know how confident we should be in the result.

We refer to uncertainties like those caused by random wobbles as "statistical" uncertainties. Here is a **very rough** rule of thumb for estimating the statistical uncertainty: Use the difference between the **largest** individual measurement, and the **smallest**, in the following approximate formula

$$\text{``Statistical'' Uncertainty in the Average} \approx \frac{\text{Largest - Smallest}}{2 \times \sqrt{N}}, \quad \text{Eq. (2).}$$

(The exact formula is known as "the standard deviation of the mean.") This formula shows that the uncertainty will be smaller (that is, the average value will be more accurate) if one makes more measurements.

For example, in our hypothetical experiment, the largest measured angle was 54.00 degrees, and the smallest was 48.00 degrees, so the statistical uncertainty is roughly estimated from Eq. (2) as:

$$\text{Example Statistical Uncertainty} \approx \frac{54.00 - 48.00}{2 \times \sqrt{N = 4}} = \frac{6.00}{2 \times 2} = 1.50^\circ.$$

Note that measurement results are reported using the **standard notation:**

$$\text{Measured Quantity} = \text{Average} \pm \text{Uncertainty}, \quad \text{Eq. (3).}$$

For example, in our hypothetical experiment, we would report the result of the experiment as Measured Angle = 50.75° ± 1.50°.

Discussion: When doing this laboratory experiment we will need to take account of one final "fact of life" in scientific error analysis. Most experiments, including this one, suffer from other kinds of uncertainty, which are often much more difficult to reduce than statistical uncertainties. For example, in this experiment, the protractor itself is fundamentally limited by the size of its markings: <u>our protractor's markings will limit the precision of the experiment to about 0.25°</u>, no matter how many measurements of the angle are taken! We call this an "instrumental resolution." Once the statistical error has been reduced below the instrumental resolution, by taking a sufficient number of measurements, there is no point taking more data! In that case, the only way to do better would be to build a "finer" instrument.

PROCEDURE

Step #1 Measure the baseline along which the laser sight travels. Record the result on the first line of the data sheet at the end of this lab script.

Step #2 Put the laser sight at one end of the baseline, to make sure the beam hits the object "dead on," with the laser pointing at right angles to the baseline.

Then move the laser sight to the other end of the baseline, and turn it until the beam hits the object.

Step #3 Use the protractor to measure the **interior angle** (refer to Fig. 2, which shows an example of an interior angle of 52○). This is a crucial step, because even a relatively small error in the measurement of the angle can result in a large error in the estimate of the object's distance.

Since the angle is so crucial to the experiment, **each partner should measure it a few times**. Alternate measurements with your partners.

Notes: **1)** Place the "tip" of the laser beam precisely at the "zero line" of the protractor, as illustrated in Fig. 3 on the next page.

2) One lab partner should hold the laser beam tip at the protractor zero line, while verifying that the laser beam hits the object. Another lab partner should read-off the interior angle.

3) <u>Do not force yourself to get the same angle each time</u>. Rather, try to get the most <u>accurate</u> value each time.Enter the results in the table next page.

4) <u>Try to measure the angle to an accuracy of 0.25°</u>, "interpolating" between the protractor markings, as discussed in tutorial.

5) Try to record your values independently of your partners. First record your measurements, and then record your partners' values.

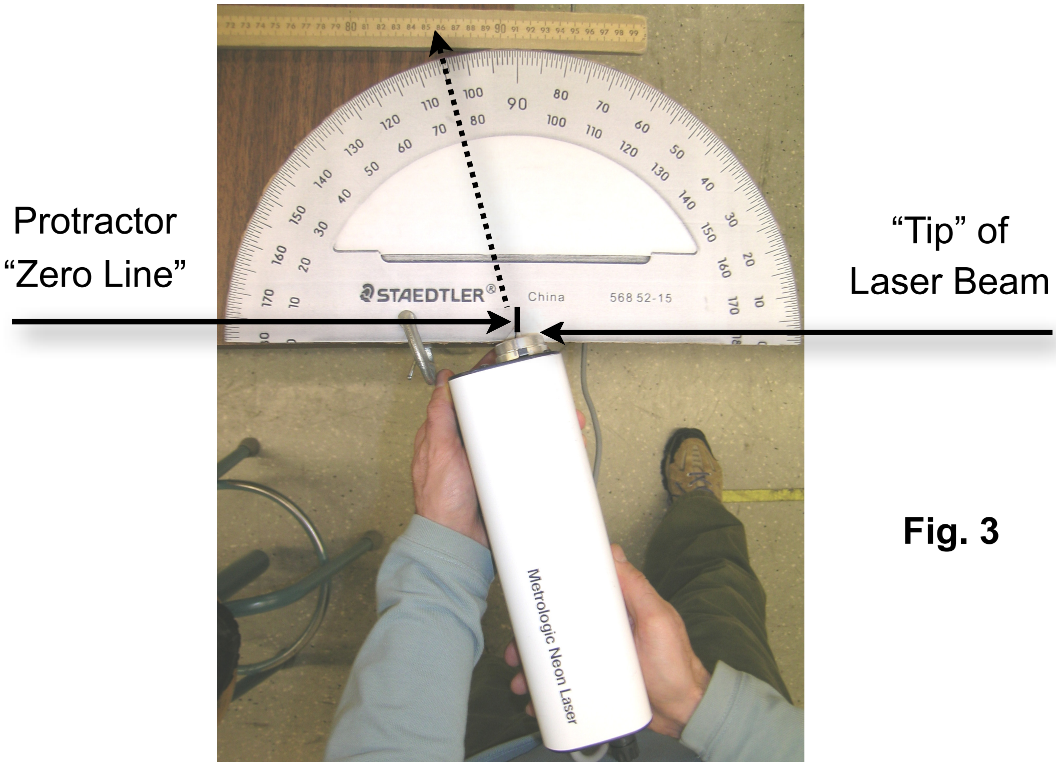


Fig. 3

	PARTNER #1	PARTNER #2	PARTNER #3
Measurement 1			
Measurement 2			
Average values	±	±	±
Overall Average	±		

Step #4 **Compute the average angle, using Eq. (1),** for each individual lab partner, and record the results in the table.

Note: Round all of your calculations to the nearest 0.25^o.

Step #5 **Use Eq. (2) to compute the statistical uncertainty** in the average value for each lab partner. Enter the results in the table, using the standard notation of Eq. (3).

Step #6 **Now compute an overall average angle**, using Eq. (1), combining all of your measured angle values and those of your partners. Then use Eq. (2) to **compute the statistical uncertainty in the overall average.**

Enter the result for the overall average with its error in the last row of the table, and in the second line of the worksheet at the end of the script.

Note: If the result of any statistical uncertainty calculation is under 0.25^o, use the instrumental resolution of ± 0.25^o as the actual uncertainty instead (see the discussion in the **Background** section, below Eq. (3)).

Step #7 W**ork through the graphical analysis** on the worksheet, using your groups' average value for the interior angle, to arrive at your group's "average" estimate of the distance to the object. Use a protractor to draw a scaled triangle on the grid in the worksheet.

Step #8 **Draw the scaled triangle a second time**, now using an angle at the "high" end of the uncertainty in the average interior angle.

(In the hypothetical experiment described in the Background section, the average angle was 52.25^o, and the angle at the "high end" of the uncertainty range was 50.75^o + 1.50^o = 52.25^o, as illustrated in Fig. 4).

Rework the graph for the distance to the object using the "high end" of the interior angle. **Read off the "plus" uncertainty** in the distance, as in Fig. 4, and enter the value in the worksheet.

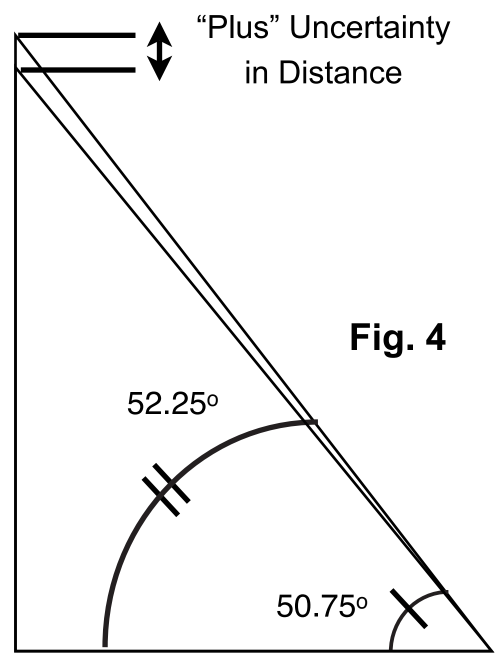


Fig. 4

Step #9 **Complete the rest of the worksheet.**

Measured Baseline **=** ________________ cm.

Overall Average Interior Angle = ________ ± ______ degrees.

From these measurements *plot a scaled version of the triangle on the grid* (compare with Figs. 2 and 4).

Use a scale of **1 square on grid = 10 cm distance**.

Compute the # of grid squares for the baseline as follows:

Baseline = __________cm physical distance / (10 cm / square)

= __________ grid squares

Draw this as horizontal line on the grid *starting at the bottom*.

Then use the protractor that was provided to you to complete the triangle.

Read off the distance to the object in grid squares, and convert to the physical distance of the object, as follows:

Predicted Object Distance = ________ ± ______ grid squares

x 10 cm / square

= ________ ± ______cm.

Use the tape measure to measure the "actual" distance to the object:

Measured Object Distance **=** ________________ cm.

Comment on the difference between the predicted and measured distances (first, compute a percentage difference). How significant is the difference, in light of the estimated uncertainty in the measured interior angle? Are there other experimental uncertainties, and if so, how important are they? What about an uncertainty in reading off grid squares on the graph?

(use other side of sheet if needed)

Name____________________________________ Student #_________________________

Lab Partners ____

PHYSICS 190: PHYSICS LAB II

NEWTONIAN PROJECTILE

(with thanks to Mehrdad Rastan & Neil Alberding for material from the SFU Physics 100 Open Lab Project)

Goals Study parabolic motion of a projectile, as an illustration of Newton's laws of gravity and motion.

Equipment **1.** Projectile launcher & ball; **2.** Plastic hoops; **3.** Paper and carbon paper.

What to do Analyze the trajectory of a ball fired from a projectile launcher. You will predict the vertical positions of four plastic hoops, to be placed at evenly-spaced positions along the trajectory, such that when you launch the ball it will pass through all the hoops.

How to do it The launcher is clamped to your bench (see figure 1). For horizontal launch, the launcher's plumb bob should hang over the zero degree mark.

Caution ▶ **Wear Safety Glasses**

▶ **Don't stick your finger into the Launcher. Use the aluminum push-rod to load the ball.**

▶ **DO NOT use your finger**. Place the steel ball in the barrel and push it down with the aluminum push-rod until the trigger catches the piston then push the ball again until you hear a second click; the launcher is now set at the medium range. Use the <u>second</u> setting. <u>Launch the ball by pulling up on the string</u>.

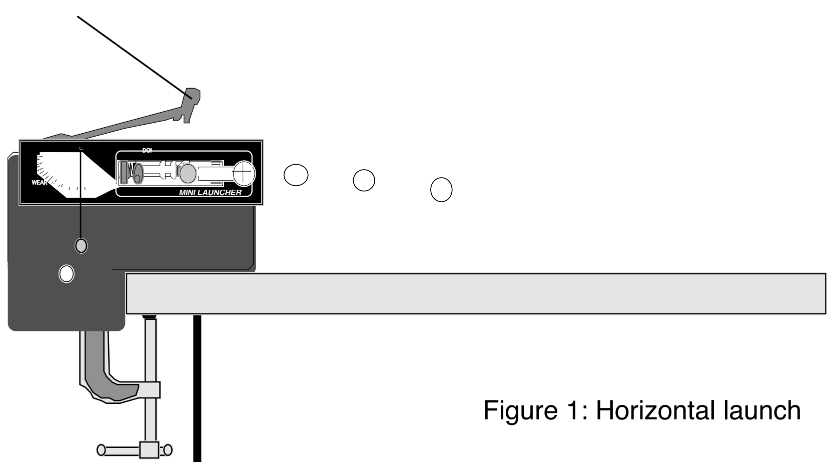


Figure 1: Horizontal launch

Procedure: #1. Record where the ball hits the ground, when fired by the launcher. To do this, tape a piece of paper on the floor, then tape a piece of carbon paper on top of the paper. Fire the ball so that it marks the paper at the point of impact. Use the other plumb bob (long one) to find and mark the point on the floor that is directly below the release point of the ball (this is marked by a cross at the side of the launcher).

#2. Measure the horizontal distance that the ball travels, and the vertical distance that the ball drops, and **record** the results in the following lines, and in the table below.

Horizontal distance h from launcher to point of impact on the floor:

h = ____________(m).

Vertical "drop" distance d from the launcher to the floor:

d = ___________(m).

#3. As we discussed in tutorial the trajectory is a simple parabola. In this case, when the particle has travelled a horizontal distance x, it has dropped a distance y, given by

$$y = c\,x^2, \qquad \text{Eq. (1)},$$

where c is a constant. In the case of the final point on the trajectory, we have

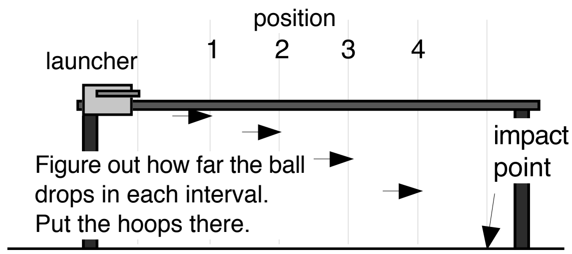
$$d = c\,h^2$$

hence the constant c is given by: $c = d/h^2 =$ _____________ / meter.

Compute the value of c in your experiment, and enter the result the above line.

#4. Divide the horizontal distance between the end of the launcher and the point of impact into five equal intervals. **Record** the values of these horizontal positions in the table.

#5 Compute the vertical drop at each horizontal position, using the general parabola formula Eq.(1) above, and using your value for the constant c, and record the results in the table.



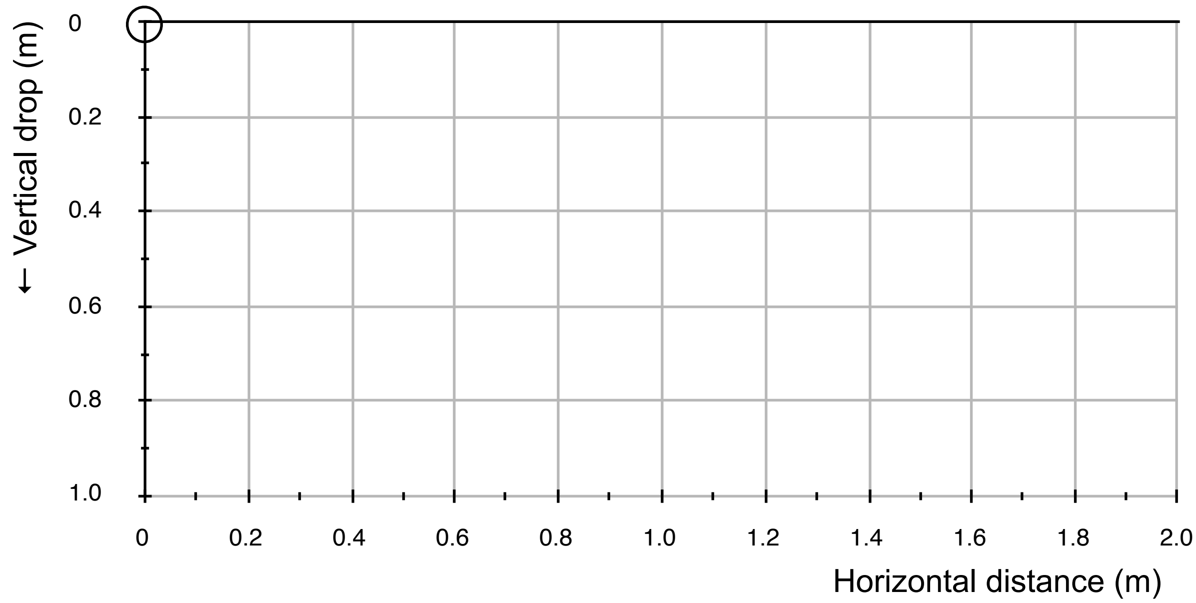
	x = horizontal distance	**y** = vertical drop
Launcher	0 m	0 m
Position 1		
Position 2		
Position 3		
Position 4		
Impact Position	**h** =	**d** =

#6. Measure the position for the **first hoop** (position 1) and attach it to the board.

Then **launch** the ball through the hoop. If the ball misses, re-measure the position (also re-check your calculations!) and make the necessary adjustments. Now that the first hoop is in place, continue with the **second hoop** and so on.

#7. When all the hoops are in the correct positions, **demonstrate** a successful launch to your instructor or TA.

#8. **Graph** your results of the vertical drop distance versus the horizontal distance of the hoop positions and impact position on the following graph paper.



#9. **Draw** as smooth a line as possible through the data points in your graph. How well does the shape of your curve agree with expectations? ___________________________

____

____

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Name_______________________________ Student #_____________________

Lab Partners ____

PHYSICS 190: PHYSICS LAB III

NEWTONIAN WHIRLIGIG

(with thanks to Neil Alberding for material from the SFU Physics 100 Open Lab Project)

Goals

1. Study circular motion, including the relationship between circular acceleration and the speed and radius of the circular orbit.

2. Measure the acceleration due to gravity using circular motion.

Equipment

1. Glass or plastic rod about 15 cm long and about 10 mm in diameter.

2. String about 1 m in length, and an alligator clip.

3. Four tennis balls, a meter stick, and a stop watch.

Introduction An object accelerates when moving in a circle, even if its speed is constant. Mathematically, acceleration characterizes any change in the velocity, either in its magnitude (speed), or in its direction (or both). Physically, we are familiar with the acceleration associated with circular motion: we know that we must exert a force on a ball moving in a circle at the end of a string, by pulling on the string, in order to prevent the ball from flying off on a tangent. We also routinely experience circular acceleration whenever we execute a turn in a moving vehicle.

To explore circular motion in this lab, we hang three tennis balls at one end of a string, and put another ball at the other end, with the string running through a glass tube, as shown in Fig. 1 below. We shake the tube back and forth, in such a way as to make the single tennis ball spin in a circle of some radius *R*. In this case, the force *F* that is required to accelerate the spinning ball is provided by the hanging weight of three balls.

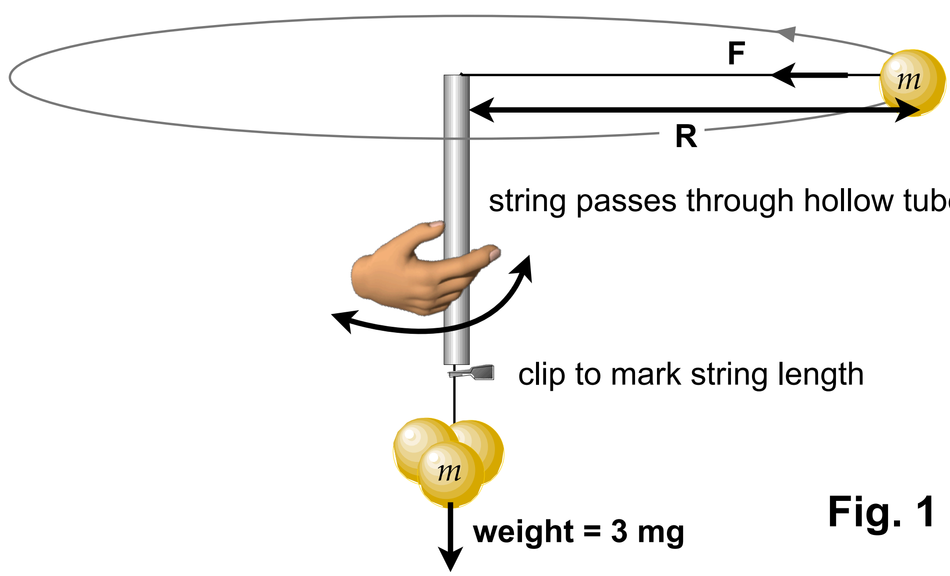


Fig. 1

Math Sidebar: (This mathematical interlude is optional: if you would rather avoid this math, you can take Eqs. (4) & (5) below for granted, and skip to Procedure!)

In class we saw that the circular acceleration a_{circular} of an object is determined by its speed *v* and circle radius *R* (we consider "uniform" or constant speed):

$$a_{\text{circular}} = \frac{v^2}{R}, \quad \text{Eq. (1)}$$

(see also Chaisson & McMillan, *Astronomy: A Beginner's Guide*, "More Precisely" 1-1, on pg. 39 of the 5th edition). We can understand the qualitative dependence of the acceleration on the speed and radius intuitively, since we know from experience that the acceleration increases when we move in faster and/or tighter turns.

In our analysis of this experiment we also use the relation between the speed *v* of the circular motion, the radius *R*, and the time *T* that it takes to complete one revolution (*T* = period of the circular motion):

$$v = v_{\text{circular}} = \frac{2\pi R}{T}, \quad \text{Eq. (2).}$$

Our goal is to measure the acceleration *g* due to gravity. The analysis of the experimental setup goes as follows. We apply Newton's 2nd law, *F* = *ma*, to the accelerated motion of the spinning tennis ball, where the force F acting on the ball is provided by the hanging weight of three balls:

$$3\cancel{m}g = \text{weight} = F = \cancel{m}a_{\text{circular}}, \quad \text{Eq. (3).}$$

Note how the tennis ball mass *m* cancels on the two sides. We then plug in the expression Eq. (1) for the circular acceleration, and use Eq. (2) to substitute for the speed. For the purposes of analyzing the data in this experiment, the resulting expression is conveniently written in the form

$$R = \underbrace{\boxed{(3g/4\pi^2)}}_{\uparrow\ \text{slope}} \times T^2, \quad \text{Eq. (4).}$$

We will measure the period *T* of the ball's motion for several different radii *R*; we will then plot the results as graph of *R* versus T^2, read off the slope, and then calculate *g* from Eq. (4), which gives

$$\boxed{g = (4\pi^2/3) \times \text{slope}}, \quad \text{Eq. (5).}$$

Procedure: **#1.** Set the radius *R* of the orbit of the single tennis ball to one of the values assigned in the table on the next page. To do this, use the meter stick to measure the distance from the top of the glass tube, to the centre of the tennis ball, as seen in the figure. Use the alligator clip to pinch the string just below the bottom of the tube (leaving a small gap of about 1 cm between the alligator clip and the bottom of the glass tube).

#2. Have one lab partner shake the glass tube back and forth in such a way as to make the single tennis ball go around in a circle. Try to get the ball to go around at a constant speed. Also make sure that the alligator clip does not touch the bottom of the tube, or else the clip will add an extra accelerating force to the spinning ball.

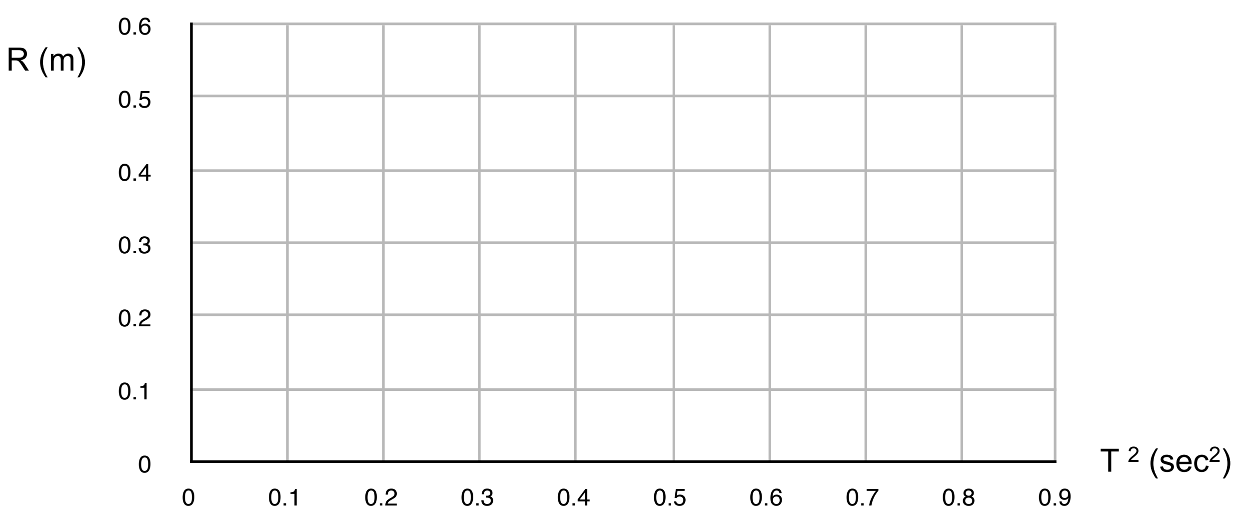
Practice getting a steady motion of the spinning ball, while ensuring that there is no contact of the alligator clip with the tube, before going on to the next step.

#3. Have another lab partner use the stop watch to time 10 full revolutions of the spinning ball, and enter the result in the table under the column 10*T* (timing multiple revolutions, instead of a single period, produces a more accurate estimate of *T*).

#4. Repeat the measurements for each *R*. Then fill in the rest of the table, and plot the results in the graph of *R* versus T^2.

R (*m*)	*10T* (*sec*)	*T* (*sec*)	T^2 (sec^2)
0.2			
0.3			
0.4			
0.5			

#5. Draw a straight line which runs as closely as possible through the data points on the graph. It won't be possible to perfectly fit a line through all the data points, since the data won't be perfect, due to scientific uncertainties. You should aim instead for the "best fit", the line that minimizes the spread of the data around the line.



#6. Compute the slope of the best-fit straight line:

$$\boxed{\text{slope}} = \frac{\text{rise}}{\text{run}} = \frac{\rule{10em}{0.4pt}\ \text{m}}{\text{sec}^2} = \boxed{\qquad\qquad\qquad \text{m/sec}^2}$$

#7. Use Eq. (5) to compute your estimate of g from your value of the slope in the last step:

g = m/sec^2

#8. How well does your measured value of g agree with the known value g = 9.81 m/sec^2? Quote a percentage difference.

How can you use your plot of R versus T^2 to estimate the scientific uncertainty in your measured value of g? Try to make a quantitative estimate of the accuracy of your result **Hint**: How much uncertainty is there in the slope of the best fit line due to the "scatter" in the data?

Name________________________________ Student #______________________

Lab Partners ____

PHYSICS 190: PHYSICS LAB IV

PULSES, RIPPLES AND WAVES

(with thanks to Neil Alberding for material from the
SFU Physics 100 Open Lab Project)

Goals You have seen various kinds of waves in everyday life. In this experiment you will conduct a scientific study of some basic wave properties, including wave propagation, the frequency-wavelength relation, parabolic reflectors, and diffraction.

Equipment **1.** Slinkies; **2.** Metronome; **3.** Tape Measure; **4.** Ripple Tank; **5.** Parabolic reflector; **6.** Barriers.

I. Pulse speed

While your partner holds one end of a coiled spring on a smooth floor, pull on the other end until the spring is stretched to a length of about 10 metres. With a little practice you will learn to generate a single, short, easily observed pulse.

1. Carefully monitor the pulse as it moves along the spring.
   Does its shape change by much (e.g. smaller as it moves)?____________________
   Does its speed change by much (e.g. faster as it moves)?_____________________
2. Now shake some pulses of different sizes and shapes. If you have two slinkies side-by-side, compare the speeds of two differently sized pulses, by starting a small pulse in one at the same time as a large pulse in the other. Does the speed depend on the size of the pulse (e.g. does one pulse "win" a race by a <u>substantial</u> margin, if so which one)? ____
3. Change the tension in one slinky by gathering up 15 to 20 coils in your hand. Compare the pulse in the tense slinky with that in the relaxed one. Does tension have a significant effect on the speed of the pulse? If so, how? ________________________

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II. Wavelength and Period

In this part of the lab you will estimate how the wavelength in a slinky changes, when its frequency of vibration is doubled (*<u>keeping its tension fixed</u>*). That is, you will measure the wavelength twice, shaking the slinky at two different rates, one shaking-rate about twice as fast as the other.

First, *<u>predict</u>* how you expect the wavelength of the slinky at the higher frequency will compare with the wavelength at the lower frequency? Explain your prediction!

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To measure the wavelengths, follow these instructions:

1. Stick a long stretch of tape on the floor to serve as a reference line. Shake the end of the slinky in a symmetrical way, back and forth with equal amplitude on either side of the reference line, as best you can (see Fig. 1 below).
2. One lab partner should shake the slinky at a steady rate, while another partner should try to estimate the wavelength. Use a metronome to time the vibrations.
3. The pattern that is generated in a medium with one or more fixed ends is known as a ***standing wave***. In a standing wave there are points along the wave that do not vibrate: these points are called ***nodes***. The nodes can be identified by locating points on the slinky that stay close to the reference line (see Fig. 1).
4. The distance from one node to the next is related to the wavelength of the standing wave according to (see Fig. 1):

   Wavelength (λ) = 2 x distance from one node to the next.

5. Measure the distance between adjacent nodes while shaking the slinky at the same frequency as the metronome (set it to 200 beats/minute). One node is located at the end of the spring which is fixed in place: measure the distance between the fixed end of the spring and the next node beyond the fixed point.

   Make a second wavelength measurement, now shaking the slinky twice as fast ("double time") compared to the metronome. Enter your results below.

   - Wavelength at metronome frequency _____________ (cm).
   - Wavelength at double the frequency _____________ (cm).

6. How well do the measured wavelengths agree with your predictions? Take into account the difficulty of shaking the slinky at frequencies that are exactly a factor of two different, and the difficulty in locating the nodes.

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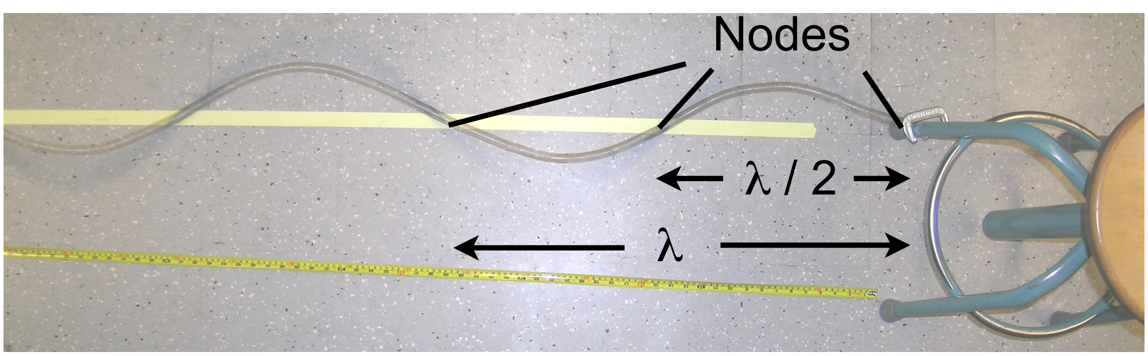

Fig.1

III. **Passage of a pulse from one medium to another**

We will now investigate the passage of waves from one medium to another. A familiar example is when an electromagnetic wave (light!) traveling through one medium, such as air, enters another, such as a pool of water. We will study this phenomenon by tying-together two coil springs in which waves travel with different speeds, as in Fig. 2.

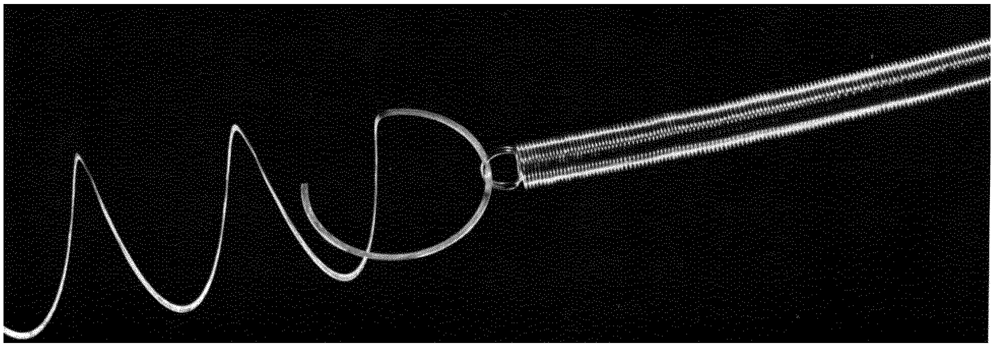

Fig. 2

Send a pulse first in one direction and then in the other. What happens when a pulse reaches the junction between the springs (e.g. does a pulse get reflected back, does a pulse propagate into the second spring, does the shape change, etc.)? ________________

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IV. **The Ripple Tank**

Another device for studying waves is a ripple tank. It has the advantage over the coiled spring in that pulses are not restricted to a line.

1. **Set up:** The ripple tank should be set up over a white screen with a light source above it. A clear light bulb with the filament oriented vertically gives the sharpest images. Water should fill the tank to a depth of 1/2 to 3/4 cm. Verify that the ripple tank is level by checking the depth at all four corners. The sponge dampers along the perimeter of the tank are to reduce reflections from the sides. They should be wet.
2. To start off, **dip your finger tip** in the tank.
   What is the shape of the pulse you see on the screen? ______________________
   Is the speed of the pulse the same in all directions? __________________________
3. **Generate straight pulses** in the ripple tank by rolling a dowel (round stick) through a fraction of a revolution in the water. Place your hand flat on top of the rod and then move it forward about a centimetre. Practice making such pulses until you get sharp, bright images on the screen. If the dowel extends all the way across the tank, the pulses should remain fairly straight as they travel. If the dowel is shorter, you may see some curvature of the ends of the pulses. Do the pulses remain straight as they move along the tank? ____
4. **Reflection**: Place a straight barrier in the tank and generate pulses that strike it “dead on” (at an “angle of incidence” of 0°). You can build a straight barrier out of

four paraffin blocks. Reflect pulses at **different** angles of incidence. How does the angle of reflection compare with the angle of incidence? This is an illustration of the so-called *“law of reflection.”*

5. **Parabolic reflector**

Place a parabolic reflector in the tank and send a straight pulse towards it. Find the orientation in which the reflection of the straight pulse converges at one point. This point is the focal point of the parabolic reflector. Using the box below, sketch how you oriented the reflector with respect to the straight pulse to focus it.
Mark this focal point on the screen with a coin or similar object. Dip you finger tip into the water over that point and describe the wave the emerges after reflecting from the parabolic reflector. Can you change the direction of the reflected pulse by changing the place where you dip your finger?

6. **Pulses passing through an aperture**

Arrange four paraffin blocks to form a barrier with a small hole in the middle. Send a straight pulse towards this barrier and draw what emerges after the pulse passes through the hole. Try varying the size of the hole. Sketch the pattern you observe in Fig. 3 below. This illustrates the phenomenon of ***diffraction***.

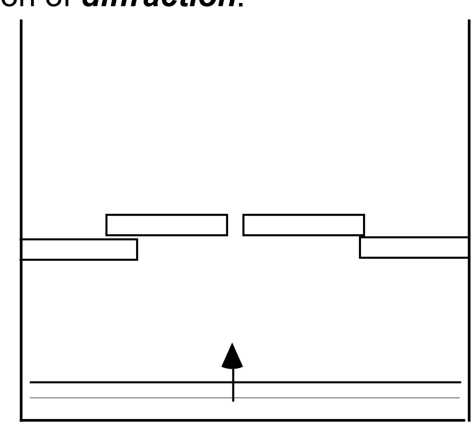


Fig. 3

Name________________________________ Student #______________________

Lab Partners ____

PHYSICS 190: PHYSICS LAB V

ATOMS & LIGHT: THREE KINDS OF SPECTRA

Goals

In this lab you will observe the visible radiation, or spectra, produced by a variety of sources, which together span the three categories of spectra that we discuss in class in some detail: i) the *continuous* spectrum produced by an ordinary incandescent filament; ii) the *emission* spectra produced by three different "mystery" gases, whose compositions will only be revealed at the end of the experiment; and iii) the *absorption* spectra in the Sun's light. You will conduct a "spectroscopic analysis" to identify the mystery gases, by comparing your observations of their emission spectra with a standard laboratory reference of the spectra of many different elements.

Equipment

1. Diffraction-grating and prism spectrometers; **2. "**Mystery gas" discharge tubes;
3. Wall chart of the spectral lines of various elements.

Background

These experiments will be mostly done with a small *diffraction-grating spectrometer*, which uses a plastic sheet (or grating) with many thousands of parallel groves. The grating reinforces the tendency of light to "diffract" (or bend) when going through an opening, causing light of different wavelengths to emerge at different angles: this enables the identification of the wavelength of a particular colour of light from the diffraction angle.

You will also examine how another spectrometer works, using a prism instead of a diffraction grating; the prism causes light of different colours to refract at different angles.

Activity 1: Incandescent filament

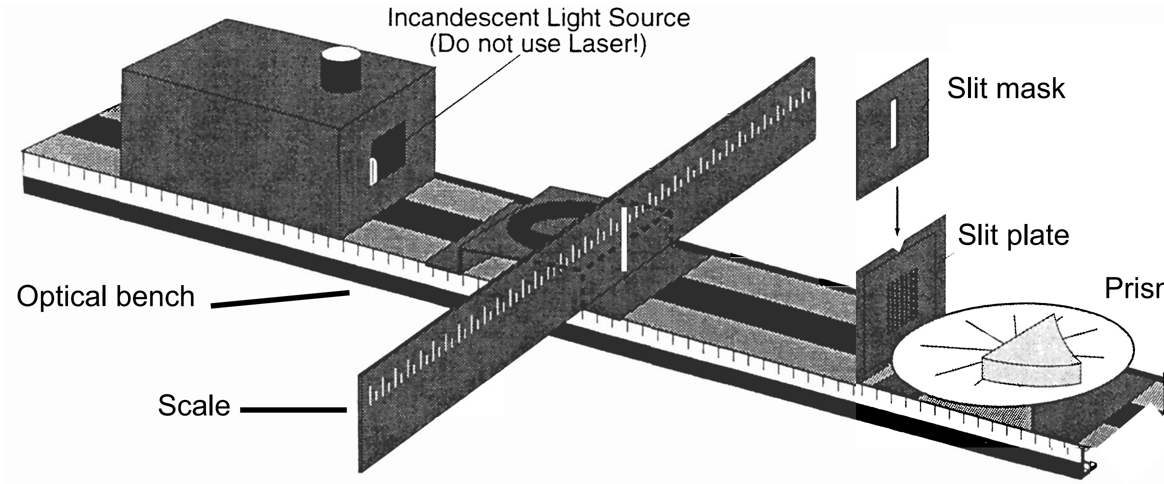
Follow the TAs instructions to view the filament through the plastic diffraction-grating spectrometer. Look at the filament through the viewing hole in the spectrometer: inside you will see a continuous spectrum of colours, and above the spectrum you will find a wavelength scale in nanometers (nm).

Measure and record the wavelength spread of each colour in the following table.

(units: nm)	RED	ORANGE	YELLOW	GREEN	BLUE	VIOLET
From:						
To:						

Activity 2: Examine a spectrometer

To get an idea of how the spectrometer you are using works, examine the large spectrometer on your lab bench, built from components as in the following illustration.



This spectrometer uses an "optical bench," a track along which various components can be fixed. The figure shows an incandescent light source at one end.

Across the middle of the optical bench is a scale, which has position markings, and a small slit in the middle through which light from the source can pass. At the other end of the track is a prism, which is used here in place of a diffraction grating, to bend the light from the source; a slit mask is placed in front of the prism to help collimate the light.

Look back through the prism towards various sources (including the "mystery gas" discharge tubes), to view their spectra against the background provided by the scale.

We are **not** going to ***"calibrate"*** this spectrometer (which means to convert the positions of spectral lines as viewed on the scale to their wavelengths in nm). We'll use the already-calibrated plastic spectrometer for the remaining activities.

Activity 3: Emission spectra of three "mystery" gases

There are three tubes containing "mystery gases." An electric voltage applied to the tube induces electric discharges in the gas; these cause electrons in the atoms to jump to higher-energy atomic levels, after which they make transitions to lower levels, with the release of radiation at specific wavelengths characteristic of each gas.

Make a rough sketch showing the placement of some of the brighter lines in each spectrum, in the table on the next page, and write down with each line the approximate wavelength. Represent the brighter spectral lines with thicker lines in your drawing.

Compare your observations of the three spectra with the standard chart of spectra on the wall of the laboratory, and try to identify the three mystery gases.

Note: Beware that the wall chart may show the colours in an orientation opposite to that in the spectrometer (i.e. Violet may be on the left on the wall chart, instead of Red).

(units: nm)	RED	ORANGE	YELLOW	GREEN	BLUE	VIOLET
Gas A						
Gas B						
Gas C						

Write your spectral-ID of the gases in the following table. Then ask the TA what they really are. How did you do? (Remember, this is a friendly competition, so no worries if you are wrong!)

	YOUR ID OF THE GAS	ACTUAL ID
Gas A		
Gas B		
Gas C		

Activity 4: Absorption spectrum of the Sun

The absorption spectrum of the Sun can be seen by looking at the light ***reflected*** off a bright sunlit concrete or white-cardboard surface.

NEVER LOOK DIRECTLY AT THE SUN, ONLY AT REFLECTED SUNLIGHT.

Before you go outside to look at the Sun's reflected light, *take another look at the continuous spectrum* produced by an incandescent filament, so you have a fresh mental image of a featureless spectrum, with which to compare during observations of the Sun's light.

In order to be able to see the spectra inside the spectrometer, you will have to find the right balance between shade for your eye, so you can see the pattern inside the spectrometer, while viewing a sunlit surface that is as brightly lit as possible.

Sketch the pattern that you see, indicating the wavelengths of several absorption lines. Compare with the solar spectrum on the wall chart in the lab.

	RED	ORANGE	YELLOW	GREEN	BLUE	VIOLET
Sun						

Use the chart of the solar spectrum printed on the spectrometer to identify some elements in the Sun from your observations of absorption line wavelengths:

Name______________________________ Student #____________________

Lab Partners ____

PHYSICS 190: PHYSICS LAB VI

PINHOLE IMAGING

(With thanks to Mehrdad Rastan)

Goals

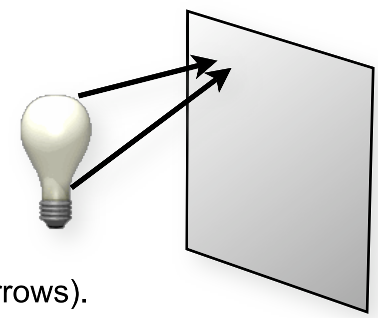
In this lab you will analyze the world's simplest imaging device, the pinhole "camera." You will also compare images produced by a pinhole camera and a lens.

Equipment

1. Shoe-box pinhole "camera"; **2.** Overhead projector and screen with cutout "L";
3. Ring stand with ring, pointing rod, source, and screen;
4. Optics bench with pinhole and crossed-arrow sources, lens, and viewing screen.

Background

Consider an object which casts light onto a screen, as illustrated to the right. We generally see only an indistinct "blob" of light on the screen, rather than a sharp image of the source. This is because rays of light from many parts of the object can end up on any given part of the screen (two such rays are represented in the figure by the black lines with arrows).



A lens works by redirecting light from each part of an object onto only one part of the screen. The same result however can be achieved using a pinhole "camera," the world's simplest imaging device.

The pinhole camera is nothing more than a box with a small hole to let light in, with a white sheet of paper as a viewing screen (instead of film) on the wall inside the box opposite the pinhole, and a tube through which the user can look to see the screen.

[Sidebar: The pinhole camera will be ready to use when you come to the lab. If you want to make one at home, you will need a box about the size of a shoe box, a piece of cardboard tubing about 3 cm long (such as a toilet paper role), a sheet of white paper, a nail, a knife, and opaque tape. On one side of the box, cut a hole for the eyepiece. The hole should be about 4 cm off-center, as illustrated above. Make sure the tube fits snugly about half-way into the hole. Pierce the box in the center with a nail: the hole should be about 5 mm in diameter. Inside the box, cover the opposite wall with a white sheet of paper. The box should not have any other holes: be sure to seal any cracks with tape, and check that the inside of the box is completely dark when you look through the eyepiece with the nail hole covered.]

Activity I: Pinhole on the world

1. Go into the physics lounge in the corridor outside the lab, and stand with your back to one of the windows. The TA will suggest a good location.

2. The pinhole camera has three holes. Start by covering the two smallest holes with tape. Look into the camera. You may need to shield your eye from stray light by blocking the side of your eye with your hands. You may also need a few minutes to let your eye adapt to the darkness in the box before you see anything. If you still do not see anything, move the box side-to-side or up-and-down. Ask the TA for help if necessary.

3. Record what you see:

4. Now repeat your observations using the two other holes, one at a time. How does the image compare with the different holes? For example, is the image larger or smaller, brighter or dimmer, sharper or fuzzier? Record your observations here:

5. Using the "best" pinhole, observe how the image changes as you move your body closer to and further away from the window. What do you find?

Activity II: Examination of the pinhole image

1. Return to the physics lab. The overhead projector will be set up to project a cutout of the letter "L" onto the projection screen. Use the pinhole camera to view the projected letter with your back to the screen.

2. How does the image in the camera compare with what is on the screen? Is this consistent with your observations in Activity I? Record your observations here:

Activity III: Formation of the pinhole image

1. To understand the formation of a pinhole image, use a small metal ring (supported by a ring stand) to represent the pinhole, as in the picture.

2. Use a rod to represent rays of light that emanate from various parts of the object, represented by the letter “L” on a piece of cardboard (supported by a stand), through the pinhole, to the corresponding parts on the screen, represented by a white sheet of paper on another stand.

3. This technique is called ray tracing. Trace the image formed by the pinhole by having one end of the rod move over the outline of the “L”, while tracing the pencil on the other end of the rod over the sheet of paper.

4. How does the orientation of the “image” traced out on the paper compare with the orientation of the “L” on the source? Draw your result here:

<u>Source</u>	<u>Image</u>
L	

Activity IV: Experiments with the optics bench

1. Place the lens on the optics bench, close to the light source. If the plastic viewing screen is on the bench, remove it.

2. Project the image formed by the lens onto the blackboard past the end of the table. Move the lens back and forth until you get a sharp image.

3. State what the image on the blackboard looks like and make a sketch:

4. Remove the lens, and place the component holder with the piece of aluminum foil right up against the light source.

5. Place the small plastic viewing screen close to the aluminum foil. Move the viewing screen back and forth until you get a sharp image.

6. State what you see on the viewing screen using the pinhole, and how it compares with the image you saw using the lens. Make a sketch:

7. Remove the aluminum foil, and place the crossed arrow target in front of the light source.

8. Put the lens back on the optics bench, this time near the center of the bench

9. Put the viewing screen near the far end of the optics bench, and then move the screen back and forth until you get a sharp image. Describe the image and how it is similar to and different from the source (for example, is the image right-side up or upside down?):

10. Compare your observations of the images formed by a pinhole and by lens. In what ways are they similar, and in what ways are they different? How does the ring stand experiment help you to understand the formation of these images?