Physics 406 Indoor Labs

Bring calculators to the Indoor labs.

Since some of the labs are long, it is very important that you read the labs ahead of time. You have to come prepared!
[Copies are on reserve in the Physics Library. The file is on the www]
You may even do some of the calculations in advance if you wish.

This is a Workbook, so use the empty pages for notes and calculations!

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Lab Grades

The Lab Grades of Physics 406 are composed of the individual Grades from 5 Labs that you will take:
• Indoor Labs 1., 2., 3.
• Planetarium Lecture
• Observatory Visit and Write-Up (Described in Outdoor Lab Manual)

and the
• Term Paper (Described in Outdoor Lab Manual)

Each Lab counts 12.5% of the Lab Grade and the Term Paper counts 3 times the credit of 1 Lab, i.e. 37.5% of the Lab Grade.
The Lab Grade makes up 35% of your Final Course Grade!!

All Labs count towards your Grade!!
Even more importantly, if more than 1 Lab is missing and/or the Term Paper your Lab Grade will be automatically an F,
unless you present a valid excuse and make up your requirement!
An F in the Lab Grade will turn your Course Grade automatically into an F!!
1. ANGLES, DISTANCES (PARALLAX), AND SIZES

I. INTRODUCTION (Read: Kuhn pp. 47-48, 154-160, 372-373)

Before the invention of the telescope, the only things astronomers could measure accurately were angles. (They could also measure time, but early “clocks” were very inaccurate.) They used pointing devices, such as gun-sights, which they could swing around to point at various objects in the sky. The amount of swing is an angle. A full swing in a circle is 360 degrees. The degree is further divided into minutes of arc (60 in a degree) and seconds of arc (60 in a minute of arc, or 3600 in a degree). The moon’s diameter is about 1/2 degree. The span of a man’s spread hand viewed at arm’s length is ≈ 15 degrees and the fist at arm’s length is ≈ 10 degrees.

Astronomers measure the angles separating various stars in the sky, the angles which the moon and planets move amongst the stars from night to night, and the angular sizes of objects (1/2 degree for the moon).

Most angles in astronomy are small and one can use the “skinny triangle equation”

\[
\theta \text{ (measured in degrees)} = \frac{d}{r} \times \frac{180}{\pi}
\]

or

\[
\theta \text{ (measured in degrees)} = 57.3 \times \frac{d}{r}
\]

Figure 1

To practice the use of angles in astronomy you will use your thumb as the most simple tool and for more precise work a simple version of an angle table. However, before we do this, we will discuss how the measurement of angles also helps us to deduce the distance and the size of an object in astronomy.
II. PARALLAX

For sure you have observed how objects closer to your car (for example trees) are apparently moving with respect to more distant background (for example a mountain chain), when you are riding along in a car. (Don’t do this, while you are driving yourselves!) This apparent shift of position of closer objects with respect to the background is called “parallax”. The distance your car traveled is the baseline of the measurement. From a car you observe substantial shifts, i.e. you can measure large angles. This can be used, for example, to deduce distances across a river.

Astronomical distances are generally very large compared with any practical baseline, thus leading to only very small angles. Therefore, the skinny triangle equation is the basis of distance measurements in astronomy. The method is called the “parallax” method. As the earth moves in its orbit about the sun (see Figure 2), the apparent displacement of nearby objects can be measured against a background of more distant stars. The diameter of the earth’s orbit forms the baseline for the distance determination. When the earth is in position A, the near star (for example) appears to be in region 1 of the distant background stars. Six months later at B the star appears to be shifted into region 2 of the distant background stars. This angular displacement can be measured from photographs of the stars taken six months apart. (The triangle in this figure is not skinny, but we have drawn it this way for clarity.)

![Figure 2](image-url)
a) Rather than wait six months, we’ll practice the idea by measuring the distance from your eyes to your thumb held at arm’s length in front of you. The blackboard will represent the distant background stars, your thumb will represent a nearby star, and each eye will represent an observation from earth taken six months apart. Thus the separation of your eyes is the baseline of this measurement.

An angle scale is given on the blackboard. **NOTE:** the angle scale is correct only if you stand at the tape on the floor.

**Step 1.** Go to the tape on the floor. Put your thumb at arm’s length in front of you. **Do not move your thumb.** Blink one eye at a time and see the thumb “move” against the background stars. How many degrees did it move?

\[ \square = \underline{\phantom{0}} \text{ degrees} \]

**Step 2.** You should really measure the distance \( d \) (which is your baseline) between your eyes but to avoid the possibility of eye injury take

\[ d = 5.5 \text{ cm} \]

**Step 3.** Use the skinny triangle equation to get \( r \), the distance to your thumb.

\[ r = \frac{57.3}{d} \]

\[ r = \underline{\phantom{0}} \text{ cm} \]

**Step 4.** Is your answer reasonable? List possible sources of error.
b) We will improve our method by using a simple gun-sight which aims at a little "planet" drawn on the blackboard. The gun-sight in its left and right position (50 cm, i.e. 20 inches, apart fixed by 2 stops, the baseline of this measurement) will represent an observation from earth taken six months apart.

An angle scale is found on the round table under the gun-sight. A schematic drawing of the set-up is shown in Fig. 5.

Figure 4

**Step 1.** Gun-sight in left position. Look with one of your eyes through the eyepiece of the gun-sight. Aim over backsight and foresight at the left edge of the "planet". Read the angle on the scale of the gun-sight. (Don't move the gun-sight!)

\[ \theta_1 = \text{_____ degrees} \]

**Step 2.** Gun-sight in right position. Aim over backsight and foresight at the left edge of the "planet". Read the angle on the scale of the gun-sight.

\[ \theta_2 = \text{_____ degrees} \]

**Step 3.** Calculate the change of the angle from Step 1 to Step 2

\[ \theta = \theta_2 - \theta_1 = \text{_____ degrees} \]

The distance \( d \) between the 2 positions of the gun-sight (your baseline) is \( d = 50 \text{ cm} \).

**Step 4.** Use the skinny triangle equation to get \( r \), the distance from the "planet".

\[ r = \frac{57.3 \times d}{\theta_2} \]

\[ r = \text{_____ cm} \]

Give your result to your TA.
Figure 5: Using the gun-sight you should make sure that you close one eye and that you see the individual pieces of the gun-sight as shown in the inset (lower left corner of the figure).

Hint: The best results may be achieved, if you move with your head backwards by about 20 - 30 cm from the eyepiece of the gun-sight.

At the end of the Lab the TA will compile all results on the blackboard and give the distance of the blackboard from the gun-sight as measured with a tape measure. Why are not all of your results identical and differ somewhat from the tape measure result? Give some potential reasons:
You will see that no measurement is perfect. No matter how much effort you put into the measurement there will always be an error in the result. By measuring the same thing several times and averaging the results a better answer can be obtained.

III. SIZES

a) The skinny triangle equation has three quantities \( r, q, d \), and you need to know two of them to solve for the third. In Section II you measured \( d \) and \( q \) and solved for \( r \). We will now use our result from II.a) for the distance \( r \) to your thumb, to get its size. In this case we can imagine your thumb to be a planet whose distance has already been determined by parallax; getting the size of your thumb is like getting the size of a planet.

We will redraw Figure 3:

![Figure 6](image)

**Step 1.** Go to the tape on the floor, hold your thumb at arm’s length in front of you, look at it with one eye, and use the angle scale on the blackboard to get

\[ \theta = \text{____ degrees} \]

**Step 2.** Use the skinny triangle equation to get \( d \):

\[ d = \frac{\theta r}{57.3} \]

With your previous result from II.a) for \( r \) (in cm) get

\[ d = \text{____ cm} \]

Is your answer reasonable? (Measure your thumb!)
b) Now we will measure the size of "planet" "A" on the blackboard in a similar way with our gun-sight. The gun-sight remains in the same position (left or right is fine) for the determination of both angles $\theta_1$ and $\theta_2$.

![Diagram of blackboard with gun-sight]  

**Figure 7**

**Step 1.** Look with one of your eyes through the eyepiece of the gun-sight. Aim over backsight and foresight at the right edge of the "planet". Read the angle.

$\theta_1 = \underline{\hspace{2cm}}$ degrees

**Step 2.** Aim at the left edge of the "planet". Read the angle.

$\theta_2 = \underline{\hspace{2cm}}$ degrees

**Step 3.** Calculate the change of the angle from Step 1 to Step 2

$\Delta \theta = \theta_2 - \theta_1 = \underline{\hspace{2cm}}$ degrees

**Step 4.** With your previous result from II.b) for the distance $r$ (in cm) from the blackboard use the skinny triangle equation to get the diameter $d$:

$d = (\Delta \theta r)/57.3$

**Do you get a reasonable size?**

Give your result to your TA. Compare your result with the size the TA puts up.
c) We can also determine the distance \( r \) of an object in a similar way, if we already know the size (diameter \( d \)) of the object. For this task we will measure the size of "planet" “B” on the blackboard in a similar way with our gun-sight. The gun-sight remains in the same position (left or right is fine) for the determination of both angles \( q_1 \) and \( q_2 \). Refer again to Figure 7.

**Step 1.** Look with one of your eyes through the eyepiece of the gun-sight. Aim over backsight and foresight at the right edge of the "planet". Read the angle.

\[ q_1 = \text{_____} \text{ degrees} \]

**Step 2.** Aim at the left edge of the "planet". Read the angle.

\[ q_2 = \text{_____} \text{ degrees} \]

**Step 3.** Calculate the change of the angle from Step 1 to Step 2

\[ q = q_2 - q_1 = \text{_____} \text{ degrees} \]

**Step 4.** Given that \( d = 10 \text{ cm} \) for “planet B” we can use the skinny triangle equation again to get the distance \( r \):

\[ r = \frac{d}{q} \cdot 57.3 \]

Do you get a reasonable distance (i.e. about the same distance as in IIIa)?

Discuss possible sources for inaccuracies in the measurement.
IV. A REAL PROBLEM

Here’s one we could in principle do by taking photographs of Jupiter’s changing position relative to the stars over the course of several nights. But rather than depending on the fickleness of Durham’s weather, we’ll use “data” from a computer program which calculates where Jupiter appears in the sky at any time. The goal will be to get Jupiter’s distance from earth, using parallax. But be warned at the outset that this is a bit complicated, even after we do everything we can to simplify the problem. So this is just a taste of what astronomers have to go through to determine the orbits of the planets. The fact is that real astronomy cannot be done without a lot of math.

We will determine Jupiter’s distance when it is at “opposition”, i.e. when Jupiter is opposite the sun (your TA will give you more information about this if we haven’t yet covered it in the lectures). We then have

![Figure 8](image)

We will use the opposition on February 1, 1991.

To simplify things we will assume
a. Both Earth and Jupiter move in circular orbits centered on the sun.
b. The orbits are in the same plane, i.e. earth and Jupiter never get above or below the page.

to start off we will note that Jupiter moves much more slowly than the earth does, and we will add one further simplification:
c. Assume Jupiter does not move at all.
Now we have to get our skinny triangle. Just as with stellar parallax, we will use the earth’s motion to establish the base of the triangle. If we make observations of Jupiter a few days before and a few days after opposition we have our triangle:

![Diagram of Earth's orbit, Jupiter, and distant stars](image)

**Step 1:** Figure 10 shows the path of Jupiter from 10:00 PM on 1/20/91 to 10:00 PM on 2/10/91:

Jupiter: 1/20/91 - 2/10/91 at 10:00PM as seen from Durham
Angular movement during those dates: 2.77 degrees
(For comparison Orion’s belt is 2.73 degrees across)
During those 20 days it has moved 2.77 degrees in the sky. You could easily measure this from photographs of the sky taken on those two dates. Thus

\[ \theta = 2.77 \text{ degrees} \]

**Step 2:** Now we have to get d, the distance the earth has moved during those 20 days. We know the distance the earth moves in one year; it is \( 2\pi \) times the radius of the earth’s orbit (which is 1 AU). One year is 365.25 days so in 20 days the earth moved

\[
d = \frac{20}{365.25} \times 2\pi \text{ AU}
\]

\[ d = \_\_\_ \text{ AU} \]

**Step 3:** Use the skinny triangle formula to get r:

\[
r = \frac{57.3}{\tan \theta} \times d
\]

\[ r = \_\_\_ \text{ AU} \]

The actual distance on 2/1/91 is 4.31 AU. Your answer is probably bigger than this. Something has gone wrong. One of our assumptions is bad.

The bad assumption is (c), that Jupiter doesn’t move. Jupiter goes around the sun in 4,333 days (11.86 years). So in 20 days Jupiter has moved \((20/4,333)\) times \(2\pi\) times the radius of Jupiter’s orbit. OOPS! We don’t know the radius of Jupiter’s orbit! It is the distance from the sun to the earth (1 AU) plus the distance from the earth to Jupiter (r, which is what we are trying to find!); see Figure 5 or Figure 6. So

\[
\text{Radius of Jupiter’s orbit} = (1+r) \text{ AU}
\]

Thus

\[
d_2 = \text{distance J. moved} = \frac{20}{4,333} \times 2\pi (1+r) \text{ AU}
\]
So Figure 9 has to be redrawn

Drat, we no longer have a triangle. Instead we have a four-sided shape with the two positions of the earth and the two positions of Jupiter at the corners; the four-sided shape is made by the solid lines in Figure 11. We will make a triangle by moving the top line down the distance \( d_2 \):

Now use the skinny triangle formula

\[
r = \frac{57.3 \ (d - d_2)}{\tan \theta}
\]

But...
But $d_2$ involves $r$ (which we don’t yet know) and we get an equation (horrors!) which has to be solved for $r$. We will solve it for you (WHEW!). The answer is

$$r = \frac{d - \frac{(20q)}{4333}}{\frac{1}{57.3} + \frac{20q}{4333}}$$

or

$$r = \frac{d - 0.029}{\frac{q}{57.3} + 0.029} \text{ AU}$$

**Step 4.** Use your value of $q$ from Step 1 and your value of $d$ from Step 2.

$r = \underline{\text{_____}} \text{ AU}$

**Step 5.** Now compare your answer with the correct distance on 2/1/91, i.e. 4.31 AU. Your result should be rather close to this. Now suggest why we didn’t get exactly the right result.

**Hint:** Review all our assumptions again!
2. THE CELESTIAL SPHERE: 
THE EFFECTS OF DECLINATION

I. INTRODUCTION.  
(Read Kuhn pp. 16-28; http://www.skypub.com/tips/basics/coordinates.html  
Consult also pp. 8-10 of the Course Review)

Note:
• We will use *Italic letters*, when explicit computer instructions are described. Names of Menu Items in the program are put in "quotes".
• We will use **Bold Face Letters** for questions or instructions that you have to respond to in writing in the appropriate places this Lab Manual.

In this lab we try to make you familiar with the orientation of the celestial sphere, the effects of declination, and how the positions of the planets in the solar system relate to what we see in the sky. You will perform some exercises on the computer by using "Voyager", which works like a small "desktop" planetarium. It can show you the sky for any time and from any location on Earth. Therefore you will have to select your location first. Open Voyager. Under the "Control" menu, go to "Set Location" and select "World Map". You see a map of the globe, which we will use to review your understanding of maps on the spherical Earth, because the mapping of the celestial sphere is very similar.

The Earth is a sphere (almost). It has two poles, the North Geographic Pole and the South Geographic Pole; the line passing through them is the earth's axis of rotation. The Earth also has an equator, which is a great circle cutting the Earth in half mid-way between the two poles.

Positions on the Earth are specified in terms of latitude and longitude. Both latitude and longitude are angles, measured in degrees. [An angle is an amount of swing (of your arm, for example, when you point from one direction to another direction). A full swing in a circle is 360 degrees. The degree is further divided into minutes of arc (60 in a degree) and seconds of arc (60 in one minute of arc, or 3600 in one degree).]

Latitude is 0 degrees at the equator, and ranges from -90 degrees at the south pole to +90 degrees at the north pole. (Note the minus sign south of the equator and the plus sign north of the equator.) 'Lines' of constant latitude on the earth's surface are really circles parallel to the equator.

Longitude is measured in terms of "meridians", which are great circles passing through the north and south poles. Longitude has arbitrarily been defined to be 0 degrees along the meridian ("the Greenwich meridian") passing through an observatory in Greenwich England. Longitude is given as degrees west or east of the Greenwich meridian.
Identify both sets of lines in the diagram below and on the map in Voyager. *Double click on a certain location*, and see how this location rotates into the center of view. Now find the following positions by *double clicking on the positions in the Voyager map* (latitude and longitude are shown below the map) and then label them on the diagram below:

a. The Greenwich Meridian (zero degrees Longitude)
b. The Equator (0 degrees Latitude)
c. Latitude +30 degrees North
d. Latitude +60 degrees North
e. Latitude +90 degrees North
f. Latitude -30 degrees South
g. Sketch in the meridian having the Longitude of Durham
h. Sketch in the circle having the Latitude of Durham

(If you can't approximately locate Durham on the map, go to jail, go directly to jail, do not collect $200! Give your TA $200 for showing you where Durham is.)

*Double click on the position of Durham. Use the zoom 4x or 8x feature to zero in on Durham. Durham has 43° North Latitude and is approximately on the coast. When you are satisfied that you have located Durham, click "ok".*
II. THE CELESTIAL SPHERE.

Astronomers have found it convenient to describe the stars and planets and other celestial objects as lying on a "Celestial Sphere" (which, unlike the Earth, is a true sphere). We are in the center of the sphere looking out. Go to "Chart Coordinates" in the "Chart" menu and select "Star Atlas Equatorial". Click on "Zoom" (on the bottom left of the screen) and select 180°. You see half of a celestial sphere, viewed from the inside looking out.

The celestial sphere has two poles. The "North Celestial Pole" (NCP) is directly above the earth's north geographic pole. So if you were at the earth's north pole the NCP would be directly overhead. The "South Celestial Pole" (SCP) is directly below the earth's south geographic pole. So if you were at the earth's south pole the SCP would be directly overhead. There is also a "Celestial Equator" dividing the celestial sphere in half. [If you were at the earth's equator, the celestial equator would pass overhead, and the NCP and SCP would be on the horizon.]

Positions of stars, planets, etc. on the celestial sphere are defined in terms exactly equivalent to latitude and longitude, except that the words are different. The position equivalent to latitude is called "Declination". It is measured in terms of degrees north (positive declination) or south (negative declination) of the celestial equator. (The celestial equator has 0 degrees declination; the north celestial pole has ___ degrees declination; the south celestial pole has ___ degrees declination.)

To see the coordinate lines on the celestial sphere, click on the grid in the lower left. Now use the slide bar on the right to bring either one of the celestial poles into the center of the view. A small dial appears that shows the declination in the center of the chart. Note that there is a bright star, Polaris, or the "North Star", near the North Celestial Pole, but there is no bright star near the South Celestial Pole. Now use the slide bar to bring the celestial equator into the center.

The position equivalent to longitude is called "Right Ascension". But instead of degrees, right ascension is measured in hours, from 0 to 24, increasing eastward. (Right ascension is furthermore divided into minutes and seconds of time.) Zero right ascension is arbitrarily put in the constellation Pisces at the point where the Sun appears to cross the celestial equator at the Vernal (Spring) Equinox on March 20. Use the slide bar on the bottom to bring different positions into the center. Try centering the Vernal Equinox, Declination = 0, Right Ascension = 0. Do you see Pisces? Not much of a constellation!

Go to declination = 0° (i.e. on the celestial equator) and right ascension = 12 hours. The two zodiacal constellations close to this point are

__________ and _________

We will henceforth forget about right ascension.
III. THE EFFECTS OF THE LATITUDE OF THE OBSERVER.

Here are a few exercises, which might help with the "data-taking" part of the lab.

The sketch below is an imaginary view of the celestial meridian, looking toward the east, so south is to the right and north is to the left. The sketch below is drawn for Durham or for any place with 43° (degrees) latitude.

The "Meridian" is an imaginary line going from the due south point on the horizon, through the overhead point (the "Zenith"), to the due north point on the horizon. The meridian does not move with the celestial sphere. The north celestial pole (NCP) is on the meridian, and its height is 43 degrees above the north horizon. Do you understand why it is 43 degrees in this case?

The sketch also shows the point where the celestial equator crosses the meridian. Its height is 47 degrees above the south horizon.
Answer the following questions [don’t forget that the angle between the celestial equator and the NCP is 90 degrees]:

1. The declination of a star, which passes through the zenith, is _______ degrees.

2. In order **for a star never to rise**, its **declination** must be **further south than _______ degrees**.

3. The brightest star in the sky is Sirius (decl. = −17 degrees). It can be seen from Durham on winter nights below and to the left of Orion. The second brightest star in the sky is Canopus (below and a little to the left of Orion). Canopus' declination is −53 degrees.
   Can we see Canopus from Durham? ____________
   Explain: ____________________________________________________________________

4. In order **for a star never to set**, its **declination** must be **further north than _______ degrees**.

5. The declination of the **Sun** is +23.5 degrees on the **summer solstice** (June 22). Its maximum height is _______ degrees at noon.

6. The declination of the **Sun** is −23.5 degrees on the **winter solstice** (Dec. 22). Its maximum height is _______ degrees at noon.
IV. DECLINATION: WHERE THINGS RISE AND SET etc.

To follow the arguments set Voyager to a view with a horizon. Go to "Chart Coordinates" in the "Chart" menu, but now select "Local Horizon - Altazimuth". The view switches to one that shades part of the sky, i.e. the part that is below the horizon in Durham (recall that we selected Durham earlier). We also have to set the time and date. In the "Control" menu, or in the "Control Panel", select "Set Time" and then "Local Mean Time". Insert the current time and date. (Do we have Daylight Savings Time?) Now you view the current sky. Check out what the slide bars do. The one on the bottom changes the view from North to East etc. The slide bar on the right changes how high we are looking. You may want to Zoom to 150° now. (Change the Zoom setting whenever it helps you.) Also turn on the coordinate lines (click on the grid in the lower left), and turn on the meridian (go to the "Display" Menu, then "Coordinate Lines", and click on "Meridian", which will show up as a dashed red line). Turn on the zenith (the point overhead) by going to the "Display" menu, then "Reference Points", and click on "Zenith". Finally, turn on the declination and right ascension readout by going to the "Control" menu, then to "Chart Panel".

In this 'lab' we'll try to help you get somewhat familiar with a few of the stars and constellations by asking you to use Voyager to measure the declination of some of the brightest stars visible from Durham. This may be time-consuming, so one lab partner should measure declination from Voyager, while another partner writes it down in the spaces provided below. Switch roles so each partner has a chance to use Voyager.

Declination has three major effects on what we see in the sky. We'll consider only cases of observers on the northern hemisphere of the Earth.

1. Declination determines, where on the horizon objects appear to rise and set. Objects with zero declination rise due east and set due west. Objects with north (positive) declination rise to the north of east and set to the north of west. Objects with south declination rise to the south of east and set to the south of west.

2. Declination determines how long objects are above the horizon. For us on the northern hemisphere of the Earth, objects with north declination are 'up' more than half a day; objects with large north declination never set. Objects with south declination are 'up' less than half a day; objects with large south declination never rise. (This situation is reversed for observers in the earth's southern hemisphere.)

3. Declination determines how high objects can get in the sky. The summer constellation Scorpius has south declination and is never very high in our sky; that's too bad because it's a beautiful constellation and we in Durham have a tough time seeing all of it. The winter constellations Taurus and Gemini have north declination and they are high in the sky on winter nights.

(If you wish you can take a look at the large antique celestial globe in the room. You can verify the above three points by spinning the globe so that objects rise in the east and set in the west.)
We now want to first verify the things you deduced from the sketch in section III. Use the bottom slide bar to face due south. The meridian (the red line) should be straight and vertical.

1. Locate the zenith. Move the cursor to the zenith. **What is declination of the zenith ("Dec" in the Chart panel)?** ________ Does it agree with question '1' in section III?

2. When a star crosses the meridian, it is at its highest point. A star on the meridian and on the southern horizon is one, which is just barely rising. To verify this, go to the "Control Menu" and turn on the "Control Panel" if it is not already on. Set the time step to 1 minute, and click the forward arrow. The stars appear to rotate, coming up in the east (to the left) and going down in the west (to the right). **Stop the motion by clicking anywhere. What is the declination of a star, which barely rises?** ________ Does it agree with question '2' in section III?

3. Go the "Field" Menu, then "Center on Star", and choose "Canopus", which will jump to center of the screen. **Does it look like you will ever see Canopus rise?**

4. Now use the slide bar to face due north. The meridian will still be straight and vertical. The grid lines come together at the north celestial pole. Any star which circles just above the northern horizon will never set. Verify this by moving time forward by **clicking on the forward arrow in the "Control Panel". The stars appear to rotate around the north celestial pole. Look at the ones skimming the north horizon. They never set. **Stop the motion by clicking anywhere. What is the declination of the point where the meridian touches the north horizon?** ________ Does it agree with the answer to question '4' in section III?

5. Now reset the time again to June 23, at 12:00 PM Daylight time. Face due south. The Sun should be visible, as the yellow filled circle. Use the forward or backward arrows to position the Sun on the meridian. Move the cursor to the Sun. **What is the Sun's declination ("Dec" in the Chart panel)?** ________ **What is the altitude of the Sun above the horizon ("Alt" in the panel)?** ________ Does it agree with the answer to question '5' in section III?

6. Reset the time to Dec. 22, at 12:00 PM Standard Time. Look South. Move the Sun to the meridian. **What is the Sun's declination now?** ________ **What is the altitude of the Sun now?** ________ Does it agree with '6' in section III?

While you are here, note the Constellations Scorpio and Sagittarius. Can you see the scorpion? Sagittarius is supposed to be an archer; I see it as a teapot. They are really summer nighttime constellations. We see them on the screen in winter because we are looking in daylight; they show up in Voyager, but really can't be seen from Earth because it is daylight.
Now we will look at some new things not covered in Section III. We are going to look at the three effects of declination.

7. Reset to Feb.1, next year, 8:00 PM EST. Look due south. You should see the following constellations, and their brightest stars. By using the cursor and clicking on a star, you will bring up a data panel with the star’s name; use this to make sure you have found the correct star. **Record the declinations of the brightest stars in each constellation.** Also include Mintaka, the rightmost star in Orion’s belt.

<table>
<thead>
<tr>
<th>Constell.</th>
<th>Star</th>
<th>Declination</th>
<th>Rise</th>
<th>Set</th>
<th>Time Up (hrs.mins.)</th>
<th>Direction of Rising</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canis Maj.</td>
<td>Sirius</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orion</td>
<td>Mintaka</td>
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<tr>
<td>Orion</td>
<td>Betelgeuse</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Taurus</td>
<td>Aldebaran</td>
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<tr>
<td>Gemini</td>
<td>Castor (alpha Gem)</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Capella</td>
<td></td>
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</tr>
</tbody>
</table>

8. By going forward or back in time in 1 minute steps, note how high these stars are above the horizon when they cross the meridian. **Rank the stars, from lowest to highest above the horizon.**

<table>
<thead>
<tr>
<th>Star</th>
<th>lowest</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
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</tbody>
</table>

Write a short sentence about how declination affects the height of a star when it crosses the meridian:
9. Now look at just three stars, Sirius, Mintaka, and Castor. We want to see how declination affects the amount of time a star is above the horizon. So from the data panel (click on each star) we will look at the rise and set times (at the bottom of the data panel). Enter your data in the same table you used in step 7.

   Write a short sentence about how declination affects the amount of time a star is above the horizon:

   If a star were exactly on the celestial equator, with declination = 0°, how long do you think it would be up? __________

10. Now face due east. Run time backwards until Sirius is just on the horizon, (ready to rise). Note its general direction (NE, ENE, E, ESE etc.). Do the same for some other stars. Enter your data in the same table you used in step 7.

   Write a sentence or two about how declination affects where things rise:

   If an object is exactly on the celestial equator, with declination = 0°, it will rise in which direction exactly? __________

   If an object rises NE, it will set __________.
   If an object rises SE, it will set __________.
   If an object rises due east, it will set __________.
11. The full moon is very nearly opposite the Sun in the sky. In summer the Sun has north declination. So in summer the full moon has negative/positive declination (circle the correct choice).

The full moon will be (circle the correct choice)

low     high

in the sky on summer nights.

Verify this using Voyager. Set the date to June 24, 2002, at 8:40 PM Daylight Time. Look to the NW and you will see the Sun setting. Look to the SE (the opposite direction from the Sun) and you will see the full moon rising (doing the opposite of what the Sun is doing). From the Chart Panel with the cursor on the moon, what is the moon's declination? ________ Now look south. Let the time advance in 4 minute steps until the full moon is on the meridian. Put the cursor on the moon and look at the Chart Panel.

What is the altitude (“Alt” in the panel) of the moon above the horizon? ________

Is this high or low? ________

Comparing with questions 5 and 6 above, this is roughly the same as the Sun's altitude on (circle the correct one)

the summer solstice     the winter solstice.

12. Now look at the full moon on winter nights. The Sun is low in the sky in winter, so the full moon should do the opposite, and be high in the sky when it crosses the meridian.

Set the date to Dec. 30, 2001, 4:40 PM EST. In which direction do you expect to see the Sun setting? ________

In which direction do you expect to see the full moon rising? ________

From Voyager, are your expectations verified? ________

From the readout, or by clicking on the moon, what is the moon's declination? ________ Now look south. Let the time advance in 4 minute steps until the full moon is on the meridian. Put the cursor on the moon and look at the chart panel.

What is the altitude (“Alt” in the chart panel) of the moon above the horizon? ________

Is this low or high? ________

Comparing with questions 5 and 6 above, this is roughly the same as the Sun's altitude on (circle the correct one)

the summer solstice     the winter solstice.

While you're here, scroll east and look at the constellation Leo. A nice springtime constellation.

What is the brightest star in Leo (at the base of the backwards question mark)?

__________
V. THE PLANETS SEEN FROM SPACE AND EARTH.

The picture shows the Earth and Sun looking down on the northern hemispheres (as usual in this class). The Earth’s orbit is sketched. The other planets (not shown) will also be roughly in the plane of the paper (except for Pluto, which could be substantially above or below the paper). A planet in the gray part of the paper is said to be "eastward" of the Sun, and would be visible in the evening sky after sunset. A planet in the other part of the sky is said to be "westward" of the Sun and would be visible in the morning sky before sunrise.

Here's a blank, and not to scale, view of the solar system with the orbits of Mercury, Venus, Earth, Mars, Jupiter, and Saturn included. We will want you to add some planet positions onto this later.
1. We will now look at where the planets are on the infamous "planetary alignment" of May 5, 2000. Set date to May 5, 2000 at 6:00 PM Daylight Time. Go to the "Display" menu, then to "Sky Labels", and turn on "Planets". Look to the west and you will see the Sun, and the five naked-eye planets (along with the crescent moon, which we will ignore). The planets above the Sun are "eastward" and could in principle be seen after the Sun sets. The planets below the Sun are "westward" and clearly can't be seen after sunset, since they will have already set too.
Now on the figure above, sketch in where you think the planets are, using the Earth - Sun Line as a guide. Be careful to note which planets appear the greatest angles from the Sun, and in which direction. Also note that **there will be two possible positions for Mercury, and two possible positions for Venus. Sketch them both in.**

2. Let’s see how well you did. We’ll use Voyager to go off into space, and look down on the solar system (looking down on the northern hemisphere of Earth). In the "Control" Menu, go to "Observe from Point". **Insert these data:**

\[
\begin{align*}
\text{Heliocentric longitude: } & \ 0 \\
\text{Heliocentric Latitude: } & \ 90^\circ \\
\text{Distance from Sun: } & \ 10 \text{ AU}
\end{align*}
\]

and click "OK". Set "Zoom" to 120°. Turn off the grid in the lower left. There are the planets. Which of the two possible choices for Mercury and Venus happens to be true? **Circle them** on the figure above. How did you do otherwise?

By the way, look in the lower left part of the image. "Crux" is the very famous "Southern Cross".

For an article on planetary groupings, go to http://www.skypub.com/news/special/whypanic.html

JVH, EM 1/2002
3. LENSES, MIRRORS, AND TELESCOPES

I. INTRODUCTION  
(Read: Kuhn pp. 121-138)

In this lab, you will see how lenses and mirrors change light paths to form images. You will also see how two lenses are used to make a "refractor" telescope, and you will see how a mirror and a lens are combined to make a "reflector" telescope.

Telescopes consist of two parts: a "primary", and an "eyepiece". In a refractor the primary is a large lens, also called the "objective". In a reflector the primary is a curved "primary mirror". In both types of telescope the eyepiece is a small lens.

The primary has two functions:

- The first function is to gather as much light as possible. So the primary has to be as big as possible (large diameter).

- The second function of the primary is to make an image; the image is called a "real image" because you can actually find it forming on a piece of paper (as you will see). The image must be of good quality, so the primary lens or mirror must have a very accurate shape. (Before its repair by astronauts in December 1993, the Hubble Space Telescope [a reflector] was not working as well as planned because the primary mirror was made in a slightly wrong shape!)

The function of the eyepiece is very simple. It is nothing more than a magnifying glass used to look at the real image formed by the primary.

II. LENSES AND IMAGES

We will use lenses, which are thicker in the center than on the edges; lenses, which are thicker on the edges, do not make real images. If an object is placed on one side of the lens, a real image will form on the other side. As the object is moved further away, the image comes closer to the lens. The image will stop approaching at a particular distance, even if the object is moved still further. This distance is called the "focal length". For example, if you burn a leaf with a magnifying glass, the bright spot (an image of the Sun) is the focal length away from the glass, because the Sun (the object) is extremely far away. Imagine light rays which come from infinity and therefore are exactly parallel. This light will in principle be focused in one point, the "focal point", at one focal length (f) away from the lens.
In general the focal length \( f \), object distance \( o \) and the image distance \( i \) are related in this way: \( 1/f = 1/o + 1/i \).

If any two of these three are known, the third can be determined. The formula can be rewritten in a more useful form:

\[
f = \frac{oi}{o+i}.
\]

You will use this formula along with measurements of 'o' and 'i' to find 'f' for the lenses you will be given.

**Step 1.** Clamp the light down at the end of the bench; this will be the object. Put a lens in the holder. Move both the lens and the screen until a **real** image forms on the screen. Record 'o' and 'i' in the Table below, along with the calculated value of 'f'. Also put in a description of the image relative to the object.

**Step 2.** Now leave the screen and lamp alone and move the lens. You should find another lens position that gives an image. Record 'o' and 'i' and calculate 'f' again.

Do Steps 1 and 2 for the other lens as well.

<table>
<thead>
<tr>
<th>Lens 1</th>
<th>Lens 2</th>
</tr>
</thead>
<tbody>
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<td></td>
<td></td>
</tr>
</tbody>
</table>
Is there a pattern in the 'o' and 'i' distances?
Why? (Hint: Look at their relation to the focal length 'f')

III. A BENCH-TOP REFRACTOR

Step 1. To see how a refracting telescope works, set up the lenses as shown below. One lens (the objective) has \( f = 20 \text{ cm} \) and the other (the eyepiece) has \( f = 5 \text{ cm} \). Use the screen to convince yourself that things are set up so that there is a real image between the objective and the eyepiece.

Step 2. Now remove the screen. Look through the eyepiece and move it back and forth until you see a focused enlarged image of the lamp. (Note: the eyepiece must be farther away from the objective than the sum of their focal lengths.) You are using the 5 cm (focal length) lens as a magnifying glass to look at the real image formed by the objective.
**Step 3.** Now remove the lamp and look through the telescope at something else in the room (page of your lab manual, writing on the blackboard etc.). Move the eyepiece so that things look in focus. Describe what you see. Estimate how much bigger the object looks through the telescope than with the unaided eye.

**Step 4.** Magnification can be calculated by $M = f_o/f_e$, where $f_o$ is the focal length of the objective, and $f_e$ is that of the eyepiece. This is angular magnification. For example, if $M = 4$, the telescope image takes up four times the angle of view as the object itself:

Calculate the magnification of your telescope.

If you want to increase the magnification by changing the eyepiece, would you increase or decrease the eyepiece's focal length? Explain your reasoning.

Refractor telescopes tend to be very long. Why?
IV. A BENCH-TOP REFLECTOR

Instead of a lens a concave (i.e., curved inward) mirror can be used to make the real image in a telescope:

Now we would like to put in an eyepiece to be used as a magnifying glass to view the real image, just as we did with the refractor. However, since the rays of light that make the image are bouncing off the mirror and going to the left, this means the observer would have to put the eyepiece and his/her head between the object and the real image. This would block the light coming from the object. This problem can be dealt with in two ways. A small "secondary mirror" is put in at 45° to reflect the real image off to the side. This is a Newtonian reflector: one will be set up in the lab so you can see the mirror arrangement (see Kuhn Figure 5-14). Alternatively a mirror can send the light back through a small hole in the center of the primary mirror. This is a Cassegrain reflector, the kind you will see in the observatory (see also Kuhn 5-16). An example is shown below.
Note that a small portion of the light rays in the center is blocked by the secondary mirror. However, the loss of light is small, and what is more important the obstacle does not show up in the image as a shadow.

- Suggest a reason why this is the case!

These assemblies are too complicated for our simple bench-top reflector, so we'll cheat a bit and tilt the mirror so the image forms off to the side. This will distort the image somewhat, but it’s good enough to show you how the reflector works: (In fact, the astronomer William Herschel has used such a telescope.)

We'll have this all set up for you in the lab, so there's not much to do.

**Step 1.** Use a card to find the real image. Then look through the eyepiece.

**Step 2.** The focal length of a mirror is one-half of its curvature radius, measured from the center of the mirror. If you wanted to make a reflector with a large magnification, would you use a flatter primary mirror or a more deeply curved mirror (like a bowl)? Explain your reasoning. (Hint: look at the expression for the magnification of a telescope with 2 lenses!)
Thought questions:

1. Why are reflectors shorter than refractors? (The Cassegrain reflector in the observatory is only a few feet long. For your answer refer to the figure.)

2. Even though one would like to make objective lenses or primary mirrors very large (so that they can gather more light), there are practical limits to how large they can be. What factors might determine how big the objective lens or primary mirror can be built?

3. Nowadays astronomers using the big telescopes really never look through them. Instead they put film in the telescope and take a picture (like in a photo camera), or use CCD’s (charge-coupled devices) to electronically record the image (like the device which takes the pictures in a video camcorder). What part of the telescope is then no longer necessary?

Where in the telescope would the film or CCD (to record the image) be put?

To do at home: Find a shaving mirror and use it to make a real image on a wall or piece of paper.
This Lab is not in general use for the class. However, it may be used for those groups, which may not have a chance to go to the observatory in case of extremely bad weather during the semester or for make-up of a missed Planetarium Visit.

4. IMPACT CRATERS

This lab deals with the formation of impact craters, and consists of two parts. In Part I you will be given color-coded maps of the Kuiper region of Mercury and the Syrtis Major region of Mars and will be asked to determine the cratering rates in these regions. In Part II you will be asked to carry out a scaling experiment to determine how the size of an impact crater depends upon the energy of the object which forms it. These results will then be applied to a map of the Copernicus crater on the Moon to estimate the energy and size of the asteroid that formed it. For both parts you should work together in groups of two or three.

I. CRATERING RATES ON MERCURY AND MARS

Purpose: To quantitatively see how the cratering rates on Mercury and Mars have changed with time.

A. Mercury

The Kuiper region of Mercury is one of the most heavily cratered regions of the solar system. The region takes its name from the small crater Kuiper located in the lower third of the map. Although this crater is small, it has an enormous ray system extending from it (speckled shaded region on map). These rays consist of fine dust ejected outward from the crater at the time of its formation, and their presence indicates that the crater is newly formed. Continual micro-meteroid bombardment of the surface of Mercury erodes the rays, so that they will eventually fade from view in a few hundred million years.

The craters on this map, as well as the other maps, have been color coded to indicate their degree of erosion and hence their relative age. By comparison with Lunar craters scientists have inferred that the blue craters were formed about 4.5 to 4 billion years ago, that the green craters were formed about 3.5 to 2.5 billion years ago, and that the yellow craters were formed sometime during the last 1 billion years. By counting the number of craters of each color type in this $4 \times 10^6$ square km region you can roughly determine how the rate of cratering has varied since the formation of the solar system some 5 billion years ago.
Steps:

1. It will speed things up if each person in the group is responsible for a section of the map. You may want to further subdivide your section into longitudinal (or latitudinal) strips in order to improve the accuracy of your count.

2. Count the number of yellow, green, and blue craters. Note that some small blue craters lie within the ejecta blanket of a few of the large blue craters. These small craters should also be counted.

3. Total up the number of yellow, green and blue craters for the entire map.

4. Draw a bar chart (histogram) of the number of craters versus color (time) in the space provided below.
5. Answer the following questions:

a. What evidence can you find on the map that shows that the yellow craters are younger than the green craters and the green craters are younger than the blue ones? Give location (and names if given on map) of your example and state why you chose it.

b. Why are there more old craters (blue) than young ones (green and yellow)?
B. Mars

The Syrtis Major region of Mars shows a great variety of surface features which are peculiar to Mars, and you should take a moment to read the legend on the back of the map to help you find some of these features. (The sub-paragraphs labeled "interpretation" are particularly useful in this respect).

Steps:

(1 - 4) Repeat steps (1) through (4) above. Use the space below for the bar chart.
5. Answer the following questions:

a. You will have noticed after completing your bar chart for this region that there are fewer old craters (blue) than there are middle-aged craters (green). This result is opposite to that which you obtained for Mercury. What reasons can you think of that might explain this (give as many as possible)? Where relevant or possible, cite examples on the maps to support your arguments.

b. Give locations of features on Mars, which do not exist on Mercury.
II. SCALING LAW FOR IMPACT ENERGY

Purpose: To obtain a quantitative relation between the energy of an impact projectile and the diameter of the crater it causes.

In this part we will carry out a simple cratering experiment to determine how the size of an impact crater varies with the energy of the impacting object. We will do this by dropping a series of steel balls of different sizes into a box of sand, which has been coated with a layer of paint. This layer makes it possible to measure the size of a crater formed by an impact. These measurements can then be used to obtain a scaling law, which will allow us to estimate the impact energy required to form the Copernicus crater on the Moon. This value can in turn be used to estimate the size of the impacting asteroid if some assumptions are made about the density and velocity of the asteroid.

Steps:

1. Find the diameter in kilometers of Copernicus on the lunar map. Note the extensive ray system (speckled shading) surrounding Copernicus which indicates that it is a relatively new crater.

2. Gently put your box on the floor if it is not already there.

3. Drop the smallest steel ball (21 gm) into the box from a height of 2 meters using the 2 meter cord (included with your set-up) to measure the height.

4. Measure the diameter in centimeters of the crater that is formed. If you are lucky you may also have a system of "rays" surrounding your crater. (This depends critically on the thickness of the paint layer). If a crater does not form, then your paint layer is too thick, and you should ask the lab instructor to re-work your sand layer and apply a thinner coat of paint.

5. Repeat steps 3 and 4 for the other two steel balls (67g and 224g).
6. Put your diameters in the following chart.

<table>
<thead>
<tr>
<th>Mass (gm)</th>
<th>Energy E (erg)</th>
<th>Diameter D (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>4.3 x 10^6</td>
<td></td>
</tr>
<tr>
<td>62</td>
<td>12.8 x 10^6</td>
<td></td>
</tr>
<tr>
<td>224</td>
<td>44.0 x 10^6</td>
<td></td>
</tr>
</tbody>
</table>

7. Plot energy versus diameter on the supplied log-log paper (5 x 2 cycles).

8. Draw a line that best fits the data.

9. Measure the slope, s, of the line with a ruler as shown in the diagram:

10. Find the y-intercept of the line (that is, the value of the energy E at D = 1 cm). Call this A.

11. The straight line in your log-log plot corresponds to the equation

   \[ \log E = \log A + s \log D \]

   or taking the anti-log

   \[ E = AD^s. \]

   *This is the key equation for the next step.*

12. Now use the above equation to compute the energy needed to form the crater Copernicus by inserting the actual diameter D of Copernicus (in cm!) and the values of A and s that you determined from your experiment. If you wish, you can convert ergs to megatons of TNT by dividing your answer by 4.2 x 10^{22}.  


13. Assuming that the impacting asteroid is a sphere, its diameter $D$ can be expressed as

$$D = \left(\frac{12}{\rho}\right)^{1/3} (E/\rho)^{1/3} u^{-2/3}$$

where $\rho$ is its density and $u$ is its velocity. For Apollo asteroids impacting on the Earth or the Moon the impact velocity $u$ is typically between 20 to 40 km/s. Over 80% of the asteroids are made up of stony material, which has a density of about 2 gm/cm$^3$ (the remaining 20% are composed of iron alloys with a density of about 5 gm/cm$^3$). Assuming $u = 30$ km/sec and $\rho = 2$ gm/cm$^3$ we get for the asteroid diameter

$$D = 6.0 \times 10^{-7} E^{1/3}$$

where $E$ is in ergs and $d$ is in meters. Using the value of $E$ determined in step 12, estimate the diameter $d$ of the asteroid, which created Copernicus.

14. Impact scaling laws, like the one you determined in Step 11, have been extensively investigated since the 1950's. In p. 103 of his book "Cosmic Impact" John Davis summarizes the results of these investigations for the Earth in a scaling-law of the same type you used in Step 11. However, in his equation $A = 1.3 \times 10^5$ ergs and $s = 3.5$. (Note that if $D$ is expressed in km and $E$ in megatons then one has simply $E = D^s$.) With Davis's values of $A$ and $s$ the energy required to make the Copernicus crater is about $4.0 \times 10^{29}$ ergs (10 million megatons), and the size of the impacting asteroid is approximately 4.5 kilometers. What reasons can you think of which might explain why your results are different?