Chapter 1

The Origin of the Seasons

1.1 Introduction

The origin of the science of Astronomy owes much to the need of ancient peoples to have a practical system that allowed them to predict the seasons. It is critical to plant your crops at the right time of the year—too early and the seeds may not germinate because it is too cold, or there is insufficient moisture. Plant too late and it may become too hot and dry for a sensitive seedling to survive. In ancient Egypt, they needed to wait for the Nile to flood. The Nile river would flood every July, once the rains began to fall in Central Africa.

Thus, the need to keep track of the annual cycle arose with the development of agriculture, and this required an understanding of the motion of objects in the sky. The first devices used to keep track of the seasons were large stone structures (such as Stonehenge) that used the positions of the rising Sun or Moon to forecast the coming seasons. The first recognizable calendars that we know about were developed in Egypt, and appear to date from about 4,200 BC. Of course, all a calendar does is let you know what time of year it was, it does not provide you with an understanding of *why* the seasons occur! The ancient people had a variety of models for why seasons occurred, but thought that everything, including the Sun and stars, orbited around the Earth. Today, you will learn the real reason *why* there are seasons.

- *Goals:* To learn why the Earth has seasons.

- *Materials:* a meter stick, a mounted styrofoam globe, an elevation angle apparatus, string, a halogen lamp, and a few other items

1.2 The Seasons

Before we begin today's lab, let us first talk about the seasons. In New Mexico we have rather mild Winters, and hot Summers. In the northern parts of the United States, however, the winters are much colder. In Hawaii, there is very little difference between Winter and Summer. As you are also aware, during the Winter there are fewer hours of daylight than in the Summer. In Table 1.1 we have listed seasonal data for various locations around the world. Included in this table are the average January and July maximum temperatures, the latitude of each city, and the length of the daylight hours in January and July. We will use this table in Exercise #2.

Table 1.1: **Season Data for Select Cities**

City	Latitude (Degrees)	January Ave. Max. Temp.	July Ave. Max. Temp.	January Daylight Hours	July Daylight Hours
Fairbanks, AK	64.8N	-2	72	3.7	21.8
Minneapolis, MN	45.0N	22	83	9.0	15.7
Las Cruces, NM	32.5N	57	96	10.1	14.2
Honolulu, HI	21.3N	80	88	11.3	13.6
Quito, Ecuador	0.0	77	77	12.0	12.0
Apia, Samoa	13.8S	80	78	11.1	12.7
Sydney, Australia	33.9S	78	61	14.3	10.3
Ushuaia, Argentina	54.6S	57	39	17.3	7.4

In Table 1.1, the "N" following the latitude means the city is in the northern hemisphere of the Earth (as is all of the United States and Europe) and thus *North* of the equator. An "S" following the latitude means that it is in the southern hemisphere, *South* of the Earth's equator. What do you think the latitude of Quito, Ecuador (0.0^o) means? Yes, it is right on the equator. Remember, latitude runs from 0.0^o at the equator to $\pm 90^o$ at the poles. If north of the equator, we say the latitude is XX degrees north (or sometimes "+XX degrees"), and if south of the equator we say XX degrees south (or "$-$XX degrees"). We will use these terms shortly.

Now, if you were to walk into the Mesilla Valley Mall and ask a random stranger "why do we have seasons"? The most common answer you would get is "because we are closer to the Sun during Summer, and further from the Sun in Winter". This answer suggests that the general public (and most of your classmates) correctly understand that the Earth orbits the Sun in such a way that at some times of the year it is closer to the Sun than at other times of the year. As you have (or will) learn in your lecture class, the orbits of all planets around the Sun are ellipses. As shown in Figure 1.1 an ellipse is sort of like a circle that has been squashed in one direction. For most of the planets, however, the orbits are only very slightly elliptical, and closely approximate circles. But let us explore this idea that the distance from the Sun causes the seasons.

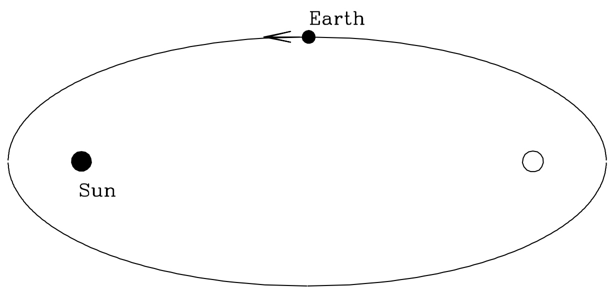

Figure 1.1: An ellipse with the two "foci" identified. The Sun sits at one focus, while the other focus is empty. The Earth follows an elliptical orbit around the Sun, but not nearly as exagerrated as that shown here!

Exercise #1. In Figure 1.1, we show the locations of the two "foci" of an ellipse (foci is the plural form of focus). We will ignore the mathematical details of what foci are for now, and simply note that the Sun sits at one focus, while the other focus is empty (see the Kepler Law lab for more information if you are interested). A planet orbits around the Sun in an elliptical orbit. So, there are times when the Earth is closest to the Sun ("perihelion"), and times when it is furthest ("aphelion"). When closest to the Sun, at perihelion, the distance from the Earth to the Sun is 147,056,800 km ("147 million kilometers"). At aphelion, the distance from the Earth to the Sun is 152,143,200 km (152 million km).

With the meter stick handy, we are going to examine these distances. Obviously, our classroom is not big enough to use kilometers or even meters so, like a road map, we will have to use a reduced scale: 1 cm = 1 million km. Now, stick a piece of tape on the table and put a mark on it to set the starting point (the location of the Sun!). Carefully measure out the two distances (along the same direction) and stick down two more pieces of tape, one at the perihelion distance, one at the aphelion distance (put small dots/marks on the tape so you can easily see them).

1) Do you think this change in distance is big enough to cause the seasons? Explain your logic. (3pts)

2) Take the ratio of the aphelion to perihelion distances: ____________. (1pt)

Given that *we know* objects appear bigger when we are closer to them, let's take a look at the two pictures of the Sun you were given as part of the materials for this lab. One image was taken on January 23rd, 1992, and one was taken on the 21st of July 1992 (as the "date stamps" on the images show). Using a ruler, *carefully* measure the diameter of the Sun in each image:

Sun diameter in January image = ____________ mm.

Sun diameter in July image = ____________ mm.

3) Take the ratio of bigger diameter / smaller diameter, this = ____________. (1pt)

4) How does this ratio compare to the ratio you calculated in question #2? (2pts)

5) So, if an object appears bigger when we get closer to it, when is the Earth closest to the Sun? (2pts)

6) At that time of year, what season is it in Las Cruces? What do you conclude about the statement "the seasons are caused by the changing distance between the Earth and the Sun"? (4pts)

Exercise #2. Characterizing the nature of the seasons at different locations. For this exercise, we are going to be exclusively using the data contained in Table 1.1. First, let's look at Las Cruces. Note that here in Las Cruces, our latitude is +32.5°. That is we are about one third of the way from the equator to the pole. In January our average high temperature is 57°F, and in July it is 96°F. It is hotter in Summer than Winter (duh!). Note that there are about 10 hours of daylight in January, and about 14 hours of daylight in July. Thus, for Las Cruces, the Sun is "up" longer in July than in January.

7) Is the same thing true for all cities with northern latitudes: Yes or No ? (1pt)

Ok, let's compare *Las Cruces with Fairbanks, Alaska.* Answer these questions by filling in the blanks:

8) Fairbanks is ________________________ the North Pole than Las Cruces. (1pt)

9) In January, there are more daylight hours in ________________________. (1pt)

10) In July, there are more daylight hours in ________________________. (1pt)

Now let's compare *Las Cruces with Sydney, Australia.* Answer these questions by filling in the blanks:

12) While the latitudes of Las Cruces and Sydney are similar, Las Cruces is ____________ of the Equator, and Sydney is ____________ of the Equator. (2pts)

13) In January, there are more daylight hours in ________________________. (1pt)

14) In July, there are more daylight hours in ________________________. (1pt)

15) **Summarizing:** During the Wintertime (January) in both Las Cruces and Fairbanks there are fewer daylight hours, *and* it is colder. During July, it is warmer in both Fairbanks and Las Cruces, *and* there are more daylight hours. Is this also true

for Sydney?: ____________. (1pt)

16) In fact, it is Wintertime in Sydney during ____________, and Summertime during ____________. (2pts)

17) From Table 1.1, I conclude that the seasons in the Northern hemisphere are exactly ______________ to those in the Southern hemisphere. (1 pt)

From Exercise #2 we learned a few simple truths, but ones that maybe you have never thought about. As you move away from the equator (either to the north or to the south) there are several general trends. The first is that as you go closer to the poles it is *generally* cooler at all times during the year. The second is that as you get closer to the poles, the amount of daylight during the Winter decreases, but the reverse is true in the Summer.

The first of these is not always true because the local climate can be moderated by the proximity to a large body of water, or depend on the elevation. For example, Sydney is milder than Las Cruces, even though they have similar latitudes: Sydney is on the eastern coast of Australia (South Pacific Ocean), and has a climate like that of San Diego, California (which has a similar latitude and is on the North Pacific Coast). Quito, Ecuador has a mild climate even though it sits right on the equator due to its high elevation–it is more than 9,000 feet above sea level, similar to Cloudcroft, New Mexico.

The second conclusion (amount of daylight) is always true—as you get closer and closer to the poles, the amount of daylight during the Winter decreases, while the amount of daylight during the Summer increases. In fact, for all latitudes north of 66.5^{o}, the Summer Sun is up all day (24 hrs of daylight, the so called "land of the midnight Sun") for at least one day each year, while in the Winter there are times when the Sun never rises! 66.5^{o} is a special latitude, and is given the name "Arctic Circle". Note that Fairbanks is very close to the Arctic Circle, and the Sun is up for just a few hours during the Winter, but is up for nearly 22 hours during the Summer! The same is true for the southern hemisphere: all latitudes south of -66.5^{o} experience days with 24 hours of daylight in the Summer, and 24 hours of darkness in the Winter. -66.5^{o} is called the "Antarctic Circle". But note that the seasons in the Southern Hemisphere are exactly opposite to those in the North. During Northern Winter, the North Pole experiences 24 hours of darkness, but the South Pole has 24 hours of daylight.

1.3 The Spinning, Revolving Earth

It is clear from the preceeding that your latitude determines both the annual variation in the amount of daylight, and the time of the year when you experience Spring, Summer, Autumn and Winter. To truly understand why this occurs requires us to construct a model. One of the key insights to the nature of the motion of the Earth is shown in the long exposure photographs of the nighttime sky on the next two pages.

What is going on in these photos? Obviously the easiest explanation is that the Earth is spinning, and as you keep your camera shutter open, the stars appear to move in "orbits" around the North Pole. You can duplicate this motion by sitting in a chair that is spinning—the objects in the room appear to move in circles around you. The further they are from the "axis of rotation", the bigger arcs they make, and the faster they move. An object straight above you, exactly on the axis of rotation of the chair, does not move. As apparent in Figure 1.3, the "North Star" Polaris is not perfectly on the axis of rotation at the North Celestial Pole, but it is very close (the fact that there is a bright star near the pole is just random chance). Polaris has been used as a navigational aid for centuries, as it allows you to determine the direction of North.

As the second photograph shows, the direction of the spin axis of the Earth does not change during the year—it stays pointed in the same direction *all* of the time! If the Earth's spin axis moved, the stars would not make perfect circular arcs, but would wander around in whatever pattern was being executed by the Earth's axis.

Now, as shown back in Figure 1.1, we said the Earth orbits ("revolves" around) the Sun on an ellipse. We could discuss the evidence for this, but to keep this lab brief, we will just assume this fact. So, now we have two motions: the spinning and revolving of the Earth. It is the combination of these that actually give rise to the seasons, as you will find out in the next exercise.

Exercise #3: In this part of the lab, we will be using the mounted styrofoam globe, a piece of string, a ruler, and the halogen desklamp. **Warning: while the globe used here is made of fairly inexpensive parts, it is very time consuming to make. Please be careful with your globe, as the styrofoam can be easily damaged.** Make sure that the piece of string you have is long enough to go slightly more than halfway around the globe at the equator–if your string is not that long, ask your TA for a longer piece of string. As you may have guessed, this styrofoam globe is a model of the Earth. The spin axis of the Earth is actually tilted with respect to the plane of its orbit by 23.5^{o}.

Set up the experiment in the following way. Place the halogen lamp at one end of the table (shining towards the closest wall so as to not affect your classmates), and set the globe at a distance of 1.5 meters from the lamp. After your TA has dimmed the classroom lights, turn on the halogen lamp to the highest setting (there is a dim, and a bright setting). Note these lamps get very hot, so be careful. For this lab, we will define the top of the globe as the Northern hemisphere, and the bottom as the Southern hemisphere.

For the first experiment, arrange the globe so the axis of the "Earth" is pointed at a right angle to the direction of the "Sun". Use your best judgement. Now adjust the height of the desklamp so that the light bulb in the lamp is at the same approximate height as the equator.

There are several colored lines on the globe that form circles which are concentric with the axis, and these correspond to certain latitudes. The red line is the equator, the black line is 45^o North, while the two blue lines are the Arctic (top) and Antarctic (bottom) circles.

Experiment #1: Note that there is an illuminated half of the globe, and a dark half of the globe. The line that separates the two is called the "terminator". It is the location of sunrise or sunset. Using the piece of string, we want to measure the length of each arc that is in "daylight", and the length that is in "night". This is kind of tricky, and requires a bit of judgement as to exactly where the terminator is located. So make sure you have a helper to help keep the string *exactly* on the line of constant latitude, and get the advice of your lab partners of where the terminator is (and it is probably best to do this more than once!). Fill in the following table (4pts):

Table 1.2: Position #1: Equinox Data Table

Latitude	**Length of Daylight Arc**	**Length of Nightime Arc**
Equator		
45^{o}N		
Arctic Circle		
Antarctic Circle		

As you know, the Earth rotates once every 24 hours (= 1 Day). Each of the lines of constant latitude represents a full circle that contains 360^o. But note that these circles get smaller in radius as you move away from the equator. The circumference of the Earth at the equator is 40,075 km (or 24,901 miles). At a latitude of 45^o, the circle of constant latitude has a circumference of 28,333 km. At the arctic circles, the circle has a circumference of only 15,979 km. This is simply due to our use of two coordinates (longitude and latitude) to define a location on a sphere.

Since the Earth is a solid body, all of the points on Earth rotate once every 24 hours. Therefore, the sum of the daytime and nighttime arcs you measured equals 24 hours! So, fill in the following table (2 pts):

Figure 1.2: Pointing a camera to the North Star (Polaris, the bright dot near the center) and exposing for about one hour, the stars appear to move in little arcs. The center of rotation is called the “North Celestial Pole”, and Polaris is very close to this position. The dotted/dashed trails in this photograph are the blinking lights of airplanes that passed through the sky during the exposure.

Figure 1.3: Here is a composite of many different exposures (each about in one hour in length) of the night sky over Vienna, Austria taken throughout the year (all four seasons). The images have been composited using a software package like Photoshop to demonstrate what would be possible if it stayed dark for 24 hrs, and you could actually obtain a 24 hour exposure (which can only be truly done north of the Arctic circle). Polaris is the "C"-shaped arc at the very center.

Table 1.3: Position #1: Length of Night and Day

Latitude	**Daylight Hours**	**Nighttime Hours**
Equator		
45°N		
Arctic Circle		
Antarctic Circle		

18) The caption for Table 1.2 was "Equinox data". The word Equinox means "equal nights", as the length of the nighttime is the same as the daytime. While your numbers in Table 1.3 may not be exactly perfect, what do you conclude about the length of the nights and days for *all* latitudes on Earth in this experiment? Is this result consistent with the term Equinox? (3pts)

Experiment #2: Now we are going to re-orient the globe so that the (top) polar axis points *exactly away* from the Sun and repeat the process of Experiment #1. Near the North Pole, there is a black line on the globe that allows you to precisely orient the globe: just make sure the shadow of the wooden axis falls on this line segment. With this alignment, the Earth's axis should point exactly away from the Sun (you can spin the globe slightly for better alignment). Fill in the following two tables (4 pts):

Table 1.4: Position #2: Solstice Data Table

Latitude	**Length of Daylight Arc**	**Length of Nightime Arc**
Equator		
45°N		
Arctic Circle		
Antarctic Circle		

Table 1.5: Position #2: Length of Night and Day

Latitude	**Daylight Hours**	**Nighttime Hours**
Equator		
45°N		
Arctic Circle		
Antarctic Circle		

19) Compare your results in Table 1.5 for +45° latitude with those for Minneapolis in Table 1.1. Since Minneapolis is at a latitude of +45°, what season does this orien-

tation of the globe correspond to? (2 pts)

20) What about near the poles? In this orientation what is the length of the nighttime at the North pole, and what is the length of the daytime at the South pole? Is this consistent with the trends in Table 1.1, such as what is happening at Fairbanks or in Ushuaia? (4 pts)

Experiment #3: Now we are going to approximate the Earth-Sun orientation six months after that in Experiment #2. To do this correctly, the globe and the lamp should now switch locations. Go ahead and do this if this lab is confusing you—or you can simply rotate the globe apparatus by 180^o so that the North polar axis is tilted exactly *towards* the Sun. Try to get a good alignment by looking at the shadow of the wooden axis on the globe. Since this is six months later, it easy to guess what season this is, but let's prove it! Complete the following two tables (4 pts):

Table 1.6: Position #3: Solstice Data Table

Latitude	**Length of Daylight Arc**	**Length of Nightime Arc**
Equator		
45^{o}N		
Arctic Circle		
Antarctic Circle		

Table 1.7: Position #3: Length of Night and Day

Latitude	**Daylight Hours**	**Nighttime Hours**
Equator		
45^{o}N		
Arctic Circle		
Antarctic Circle		

21) As in question #19, compare the results found here for the length of daytime and nighttime for the +45^o degree latitude with that for Minneapolis. What season does

this appear to be? (2 pts)

22) What about near the poles? In this orientation, how long is the daylight at the North pole, and what is the length of the nighttime at the South pole? Is this consistent with the trends in Table 1.1, such as what is happening at Fairbanks or in Ushuaia? (2 pts)

23) Using your results for all three positions (Experiments #1, #2, and #3) can you explain what is happening at the Equator? Does the data for Quito in Table 1.1 make sense? Why? Explain. (3 pts)

We now have discovered the driver for the seasons: the Earth spins on an axis that is inclined to the plane of its orbit (as shown in Figure 1.4). *But the spin axis always points to the same place in the sky* (towards Polaris). Thus, as the Earth orbits the Sun, the amount of sunlight seen at a particular latitude varies: the amount of daylight and nighttime hours change with the seasons. In Northern Hemisphere Summer (approximately June 21st) there are more daylight hours, in the Autumn ($\sim$ Sept. 23rd) and Spring ($\sim$ Mar. 21st) the days are equal to the nights. In the Winter (approximately Dec. 21st) the nights are long, and the days are short. We have also discovered that the seasons in the Northern and Southern hemispheres are exactly opposite. If it is Winter in Las Cruces, it is Summer in Sydney (and vice versa). This was clearly demonstrated in our experiments, and is shown in Figure 1.4.

The length of the daylight hours is one reason why it is hotter in Summer than in Winter: the longer the Sun is above the horizon the more it can heat the air, the land and the seas. But this is not the whole story. At the North Pole, where there is constant daylight during the Summer, the temperature barely rises above freezing! Why? We will discover the reason for this now.

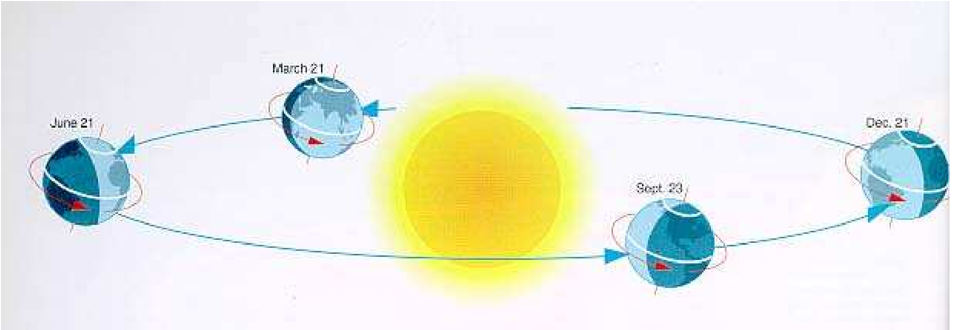

Figure 1.4: The Earth's spin axis always points to one spot in the sky, *and* it is tilted by 23.5° to its orbit. Thus, as the Earth orbits the Sun, the illumination changes with latitude: sometimes the North Pole is bathed in 24 hours of daylight, and sometimes in 24 hours of night. The exact opposite is occuring in the Southern Hemisphere.

1.4 Elevation Angle and the Concentration of Sunlight

We have found out part of the answer to why it is warmer in summer than in winter: the length of the day is longer in summer. But this is only part of the story–you would think that with days that are 22 hours long during the summer, it would be hot in Alaska and Canada during the summer, but it is not. The other affect caused by Earth's tilted spin axis is the changing height that the noontime Sun attains during the various seasons. Before we discuss why this happens (as it takes quite a lot of words to describe it correctly), we want to explore what happens when the Sun is higher in the sky. First, we need to define two new terms: "altitude", or "elevation angle". As shown in the diagram in Fig. 1.5.

The Sun is highest in the sky at noon everyday. But how high is it? This, of course, depends on both your latitude and the time of year. For Las Cruces, the Sun has an altitude of 81° on June 21^{st}. On both March 21^{st} and September 20^{th}, the altitude of the Sun at noon is 57.5°. On December 21^{st} its altitude is only 34°. Thus, the Sun is almost straight overhead at noon during near the Summer Solstice, but very low during the Winter Solstice. What difference can this possibly make? We now explore this using the other apparatus, the elevation angle device, that accompanies this lab (the one with the protractor and flashlight).

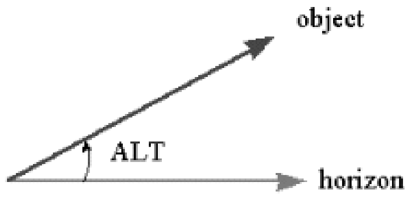

Figure 1.5: Altitude ("Alt") is simply the angle between the horizon, and an object in the sky. The smallest this angle can be is 0°, and the maximum altitude angle is 90°. Altitude is interchangebly known as elevation.

Exercise #4: Using the elevation angle apparatus, we now want to measure what happens when the Sun is at a higher or lower elevation angle. We mimic this by a flashlight mounted on an arm that allows you to move it to just about any elevation angle. It is difficult to exactly model the Sun using a flashlight, as the light source is not perfectly uniform. But here we do as well as we can. Play around with the device. Turn on the flashlight and move the arm to lower and higher angles. How does the illumination pattern change? Does the illuminated pattern appear to change in brightness as you change angles? Explain. (2 points)

Ok, now we are ready to begin. Take a blank sheet of white paper and tape it to the base so we have a more reflective surface. Now arrange the apparatus so the elevation angle is 90°. The illuminated spot should look circular. Measure the diameter of this circle using a ruler.

The diameter of the illuminated circle is __________________ cm.

Do you remember how to calculate the area of a circle? Does the formula πR^2 ring a bell?

The area of the circle of light at an elevation angle of $90°$ is ________________ cm^2. (1 pt)

Now, as you should have noticed at the beginning of this exercise, as you move the flashlight to lower and lower elevations, the circle changes to an ellipse. Now adjust the elevation angle to be $45°$. Ok, time to introduce you to two new terms: the major axis and minor axis of an ellipse. Both are shown in Fig. 1.6. The minor axis is the smallest diameter, while the major axis is the longest diameter of an ellipse.

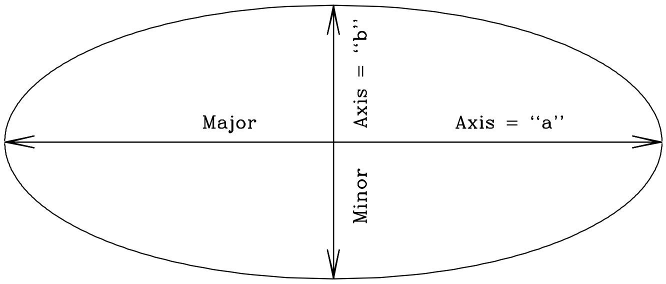

Figure 1.6: An ellipse with the major and minor axes defined.

Ok, now measure the lengths of the major ("a") and minor ("b") axes at $45°$:

The major axis has a length of $a =$ ____________ cm, while the minor axis has a

length of $b =$ ____________ cm.

The area of an ellipse is simply $\pi \times a \times b$. So, the area of

the ellipse at an elevation angle of $45°$ is: __________________ cm^2 (1 pt).

So, why are we making you measure these areas? Note that the black tube restricts the amount of light coming from the flashlight into a cylinder. Thus, there is only a certain amount of light allowed to come out and hit the paper. Let's say there are "one hundred units of light" emitted by the flashlight. Now let's convert this to how many units of light hit each square centimeter at angles of $90°$ and $45°$.

At $90°$, the amount of light per centimeter is 100 divided by the Area of circle

$=$ __________________ units of light per cm^2 (1 pt).

At $45°$, the amount of light per centimeter is 100 divided by the Area of the ellipse

= ____________________ units of light per cm^2 (1 pt).

Since light is a form of energy, at which elevation angle is there more energy per square centimeter? Since the Sun is our source of light, what happens when the Sun is higher in the sky? Is its energy more concentrated, or less concentrated? How about when it is low in the sky? Can you tell this by looking at how bright the ellipse appears versus the circle? (4 pts)

As we have noted, the Sun never is very high in the arctic regions of the Earth. In fact, at the poles, the highest elevation angle the Sun can have is 23.5°. Thus, the light from the Sun is spread out, and cannot heat the ground as much as it can at a point closer to the equator. That's why it is always colder at the Earth's poles than elsewhere on the planet.

You are now finished with the in-class portion of this lab. To understand why the Sun appears at different heights at different times of the year takes a little explanation (and the following can be read at home unless you want to discuss it with your TA). Let's go back and take a look at Fig. 1.3. Note that Polaris, the North Star, barely moves over the course of a night or over the year—it is always visible. If you had a telescope and could point it accurately, you could see Polaris during the daytime too. Polaris never sets for people in the Northern Hemisphere since it is located very close to the spin axis of the Earth. Note that as we move away from Polaris the circles traced by other stars get bigger and bigger. But all of the stars shown in this photo are *always* visible—they never set. We call these stars "circumpolar". For every latitude on Earth, there is a set of circumpolar stars (the number decreases as you head towards the equator).

Now let us add a new term to our vocabulary: the "Celestial Equator". The Celestial Equator is the projection of the Earth's Equator onto the sky. It is a great circle that spans the night sky that is directly overhead for people who live on the Equator. As you have now learned, the lengths of the days and nights at the equator are nearly always the same: 12 hours. But we have also learned that during the Equinoxes, the lengths of the days and the nights *everywhere* on Earth are also twelve hours. Why? Because during the equinoxes, the Sun is *on the Celestial Equator*. That means it is straight overhead (at noon) for people who live in Quito, Ecuador (and everywhere else on the equator). Any object that is on the Celestial Equator is visible for 12 hours per night from everywhere on Earth. To try to understand this, take a look at Fig. 1.7. In this figure is shown the celestial geometry explicitly showing that the Celestial Equator is simply the Earth's equator projected onto the sky (left hand diagram). But the Earth is large, and to us, it appears flat. Since the objects in the sky are very far away, we get a view like that shown in the right hand diagram: we see one hemisphere of the sky, and the stars, planets, Sun and Moon rise in the east, and set in the west. But note that the Celestial Equator exactly intersects East and West. Only objects located on the Celestial Equator rise exactly due East, and set exactly due West. All other objects rise in the northeast or southeast and set in the northwest or the southwest. Note that in this diagram (for a latitude of 40°) all stars that have latitudes (astronomers call them "Declinations", or "dec") above 50° never set–they are circumpolar.

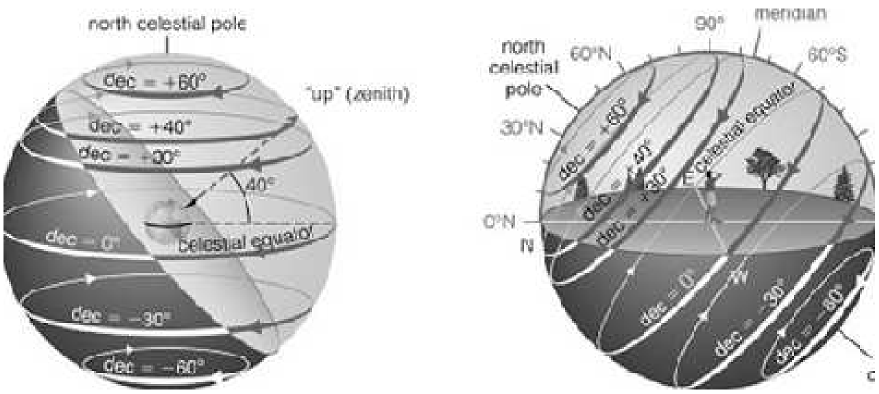

Figure 1.7: The Celestial Equator is the circle in the sky that is straight overhead ("the zenith") of the Earth's equator. In addition, there is a "North Celestial" pole that is the projection of the Earth's North Pole into space (that almost points to Polaris). But the Earth's spin axis is tilted by 23.5° to its orbit, and the Sun appears to move above and below the Celestial Equator over the course of a year.

What happens is that during the year, the Sun appears to move above and below the Celestial Equator. On, or about, March 21st the Sun is on the Celestial Equator, and each day after this it gets higher in the sky (for locations in the Northern Hemisphere) until June 21st. After which it retraces its steps until it reaches the Autumnal Equinox (September 20th), after which it is South of the Celestial Equator. It is lowest in the sky on December 21st. This is simply due to the fact that the Earth's axis is tilted with respect to its orbit, and this tilt does not change. You can see this geometry by going back to the illuminated globe model used in Exercise #3. If you stick a pin at some location on the globe away from the equator, turn on the halogen lamp, and slowly rotate the entire apparatus around (while keeping the pin facing the Sun) you will notice that the shadow of the pin will increase and decrease in size. This is due to the apparent change in the elevation angle of the "Sun".

1.5 Summary *(35 points)*

Summarize the important concepts covered in this lab. Questions you might want to answer include:

- Why does the Earth have seasons?
- What is the orgin of the term "Equinox"?
- What is the orgin of the term "Solstice"?
- Most people in the United States think the seasons are caused by the changing distance between the Earth and the Sun. Why do you think this is?
- What type of seasons would the Earth have if its spin axis was *exactly* perpendicular to its orbital plane? Make a diagram like Fig. 1.4.
- What type of seasons would the Earth have if its spin axis was *in* the plane of its orbit? (Note that this is similar to the situation for the planet Uranus.)
- What do you think would happen if the Earth's spin axis wobbled randomly around on a monthly basis? Describe how we might detect this.

1.6 Extra Credit

We have stated that the Earth's spin axis constantly points to a single spot in the sky. This is actually not true. Look up the phrase "precession" of the Earth's spin axis. Describe what is happening and the time scale of this motion. Describe what happens to the timing of the seasons due to this motion. Some scientists believe that precession might help cause ice ages. Describe why they believe this. (5 pts)

1.7 Possible Quiz Questions

- What does the term "latitude" mean?
- What is meant by the term "Equator"?

- What is an ellipse?
- What are meant by the terms perihelion and aphelion?
- If it is summer in Australia, what season is it in New Mexico?