Figure 1. A gnomon, consisting of a vertical stick with a small sphere at the top. If we mark the center of the elliptical shadow of the sphere, we can get an accurate shadow length that corresponds to the elevation angle of the center of the Sun above the horizon. One can also use a vertical, pointed stick.

Determining Your Latitude with a Gnomon (due December 2)

1. Most everything you need to know about determining your latitude with a *gnomon* can be found at this website:

http://people.physics.tamu.edu/krisciunas/gnomon.html

It is recommended that you carry out this experiment with a partner.

2. Take a pointy stick/dowel rod and figure out a way to mount it vertically. This will be used to cast a shadow of the Sun.

3. Measure the height of the gnomon with a meter stick or a tape measure calibrated in millimeters. If your meter stick is calibrated in centimeters, you

will have to interpolate to get the gnomon height in millimeters. Estimate how accurately you can measure the height of your gnomon.

4. Find a *flat, level* surface where you will be able to see the Sun for about two hours each side of local noontime. This is one of the most critical parts of the experiment.

5. We assume you have a watch that reads hours, minutes, and seconds. Set your watch as accurately as possible to the Greenwich Mean Time via:

http://wwp.greenwichmeantime.com/

The key thing is the minutes and seconds. The hours basically tell you how many time zones you are west of England.

7. Lay out a poster board, large piece of cardboard, or large piece of paper on the flat, level surface.

8. Using duct tape or some other method, fix the posterboard and gnomon holder in place so that they won't move.

9. We change over to Central Standard Time on the morning of November 6th. After that, in College Station the Sun will be highest in the sky at roughly 12:25 PM. *This is basically what we mean by "local noontime"*, when the Sun is highest in the sky. Prior to that date we will be on Central Daylight Time, in which case local noontime will occur about 1:25 PM.

Starting 90 minutes to 2 hours before local noontime, make a mark on the posterboard with a pencil at the end of the dark part of the shadow of the gnomon. The shadow will have a dark part (*umbra*) and a lighter part (*penumbra*). Mark the end of shadow every 10 minutes, until 90 minutes to 2 hours after local noontime. Closer to noontime in College Station you could mark the shadow every 5 minutes. Write your time stamps, to the nearest second, on the posterboard and in your notebook. **Don't forget to write in your notebook the month, day, and year of your observations.**

10. Once you have observed the Sun's shadow for 3 to 4 hours centered on local noon, make sure you mark the position of the base of your gnomon on your poster board before untaping your whole experiment from the location where you took the data.

11. Using your meter stick or a tape measure calibrated in millimeters, measure the length of the shadow vs. time from the marks on the posterboard.

12. Make a graph of the length of the shadow vs. time. Draw a smooth curve through your data points. The appropriate curve should be a parabola.

13. Determine the minimum length of the shadow, in millimeters. Estimate the accuracy of the minimum shadow length.

14. The maximum elevation angle of the Sun above the horizon (h_{max}) is related to the gnomon height (g) and the minimum shadow length (L_{min}) as follows:

$$\tan(\mathrm{h_{max}}) \;=\; \frac{\mathrm{g}}{\mathrm{L_{min}}} \;\;.$$

You will need a calculator that can calculate the arctangent of some number in order to obtain h_{max} in degrees. What is the uncertainty of the tangent of h_{max}? What is the uncertainty of h_{max} itself?

15. Find the declination (δ) of the Sun from this website:

http://people.physics.tamu.edu/krisciunas/ra_dec_sun_2019.html

16. Your latitude (ϕ) will be related to the maximum elevation angle of the Sun and its declination as follows:

$$\phi \;=\; 90 \;-\; h_{max} \;+\; \delta \;\;.$$

17. If you used a vertical pointed stick instead of vertical stick with a small sphere at the top, there's one more correction that must be made to your

latitude. Imagine you were an ant and you were situated so that the tip of the gnomon lined up (according to your view) with the center of the disk of the Sun. Would you be in the dark part of the shadow? Actually, no. You could see the top half of the Sun. Thus, the dark part of the shadow of the gnomon actually tells us the elevation angle of the *top* edge of the Sun. To get our final value of the latitude we have to *add* the angular radius of the Sun, which is about 16 arcminutes, to our value from part 16.

18. We know the true latitude of College Station and most any place else on Earth (from a map, GoogleEarth, or other source). The difference between your value of the latitude and true value is called the *systematic error*. How big was your error? How does this compare to the best measurements that can be obtained using a wooden gnomon, roughly $10'$)?

19. According to your measurements, at what clock time did local "noon" occur? If it did not occur at exactly 1 PM Central Daylight Time on your watch, don't worry. Due to two factors (the tilt of the Earth's axis of rotation to the plane of its orbit and the ellipticity of the Earth's orbit) the clock time of local noon will vary $\pm$ 15 minutes or so over the course of the year. The average time of meridian transit of the Sun (over the course of a year) will be at 1 PM Daylight Time only if you are situated at a longitude such as 75, 90, 105, or 120 degrees. Since College Station is further west than 96 degrees, Central Standard Time is actually more than 24 minutes (= 6^o times 4 min/degree) ahead of our *mean solar time*.

To turn in:

A. Graph of your shadow length vs. time. You must label the axes, give your location, and give the date and year. (Do NOT make this graph with Excell on your computer. Odds are that your measurements were not obtained equally spaced in time, and depending on how you use the graphics in Excell it might not convert your label such as "12:20:35" into decimal hours.)

B. Determination of your latitude and its uncertainty.

C. Determination of the time of the Sun's meridian transit (time of local noon).

D. Discussion of the data acquisition and analysis.

E. Keep the piece of cardboard on which your shadow lengths were made, in case there is a question about your data. Don't throw it away until the semester is over.