Group Activity: The Moon**

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Part 1: In this activity you will investigate the times between new and full moons (and full and new moons) over the course of a year. You will find data about the times of new and full moon for the year your group has been assigned. You will then make calculations and changes in your Excel spreadsheet to enable you to make a plot of the duration of the synodic months throughout your year.

1) Find the dates and times for new and full moon for the year your group was assigned by going to astropixels.com/ephemeris/moon/moon20xx.html, where 20xx is the year you were assigned (such as 2005).
2) Group new moon data together and full moon data together as you record the information. In Excel record the month and day in separate columns, with number designations (January is 1, *etc*.) Record the time of new or full moon in 24-hour format in a third column. You should have twelve or thirteen entries each for new and full moon.
3) Determine the number of the day of the year (1-365 or 366) in Excel for all your new and full moons in a fourth column. The Date function can be helpful. (Search for it under help and use the cell addresses for your month, day and year.)
4) Convert the times to fractions of a day. (Format cells will do this for you if you choose the General or Number tab. Please copy your times to a new column before converting to days so I can see the original, unconverted times.)
5) Add the fractions of a day to the day of the year minus one to find the decimal form of the date & time of each new and full moon. (You need to subtract one, because on January 1 zero full days have elapsed so far.)
6) The goal is to create a plot containing the length of the waxing (and waning) phases versus when those durations occurred (which is the midpoint dates & times between new and full (and full and new) respectively). Create a column for the "Duration of waxing phase," which is just the date & time of full moon minus the date & time of (previous) new moon.
7) Similarly, create a column for the "duration of the waning phase," which is the date & time of new moon minus the date & time of (previous) full moon.
8) For your horizontal entries on the plot you will need the midpoint dates & times for these waxing and waning durations. Find these midpoints in a new column by averaging the date & time values for new and full moon that you subtracted in steps 6 and 7 when finding the durations of the waxing and waning phases. The midpoint values will run from 0 to 365 or 366.
9) Insert a scatter plot showing both waxing duration versus its midpoint date & time and waning duration versus its midpoint date & time (both on one plot). Give the two curves appropriate series names, label your two axes (including the appropriate units) and give your graph a title that includes the year.

Ask at least four significant questions about the graph and try to answer your questions, if you have sufficient background at this point in the semester.

Part 2: Answer the following questions and perform the requested calculations based on your data and plot.

Terms you will need: *perigee* (point in moon's orbit where it is closest to Earth), *apogee* (point in moon's orbit where it is furthest from Earth), *line of apsides* (line from perigee to apogee)

Think of this activity as a Kepler tutorial. You need to think about Kepler's Laws and what they *really* mean in order to answer many of these questions.

1) Based on your data, what do you calculate the length of a synodic month to be to a tenth of a day? Give specifics that explain your evidence and reasoning.
2) Why do the lengths of the waxing and waning phases change throughout the year? What is (are) the underlying cause(s)?
3) Below is a sketch (not to scale) of the moon's orbit. The line between points B and D is known as the *line of apsides*. What would Kepler call this line?

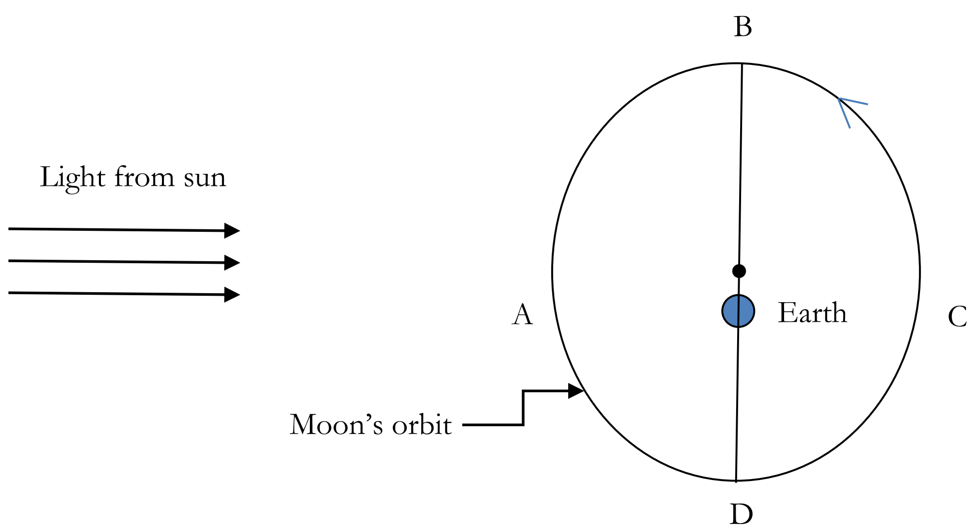

Figure 1

4) What is the phase of the moon when it is at points A, B, C, and D?
5) For the situation in the Figure 1, which portion of the month is longer and which is shorter? How do you know?
6) On another day of the year the light from the sun might be striking Earth from below in the figure (going past position D on its way to Earth). What would the phase of the moon be at points A, B, C, and D on that day? About how many days apart would the case described in this question be from the case given in Figure 1? Explain.
7) At approximately what day of the year was the *first quarter* moon at apogee? Explain.
8) At approximately what day of the year was the *third quarter* moon at apogee? Explain.
9) On approximately which day of the year was the line of apsides oriented as shown in Figure 1, given that location of the sun?

10) The dot just above Earth represents the center of the moon's orbit. Draw a line from point A to point C passing through Earth. Draw a line just above and parallel to this line that passes through the center point.
11) Lightly shade the region between the two lines within the ellipse in Figure 1. We will approximate this shaded area as a rectangle. (Bonus: Why is this assumption a far better approximation than this drawing would suggest?)
12) Mathematical definitions and formulas you will need, as related to Figure 1: Label as *a* the distance from point B to the center. Label as *b* the distance along the second line you drew from the ellipse to the center. Label as *c* the distance from Earth to the center. The total area of the ellipse is equal to πab. Also, $a^2 = b^2 + c^2$. The ratio c/a is equal to the eccentricity of the ellipse, e.
13) Using steps (11) and (12) the following relationship can be derived, between the area above the line through Earth (the *upper area*) and the area below the line through Earth (the *lower area*):

$$\frac{upper\ area}{lower\ area} = \frac{\pi ab+4bc}{\pi ab-4bc} = \frac{\pi+4e}{\pi-4e}$$

If your group can show why this relationship is true (derive it from information in (11) and (12), you can earn extra credit.

14) Why would the ratios in the equation in (13) also equal $\frac{duration\ of\ waning\ moon}{duration\ of\ waxing\ moon}$?
Remember that Figure 1 is related to your answer to question (6).
15) What is the value of the ratio in question (14) for your data/plot/year? Explain what data you use.
16) Use the information in (13) through (15) to calculate the eccentricity (e) of the moon's orbit. Show your work/calculations. (You only need the last expression in (13) for your calculation.)
17) Find (Google) the actual value of the moon's orbital eccentricity and compare with your value. Why might they differ?
18) Now step back and think about the entire project. You found and plotted the *times* of various phases of the moon. But you were able to use information gathered from the *times* to find out the eccentricity of the moon's orbit, which is related to the *position* of the moon. How can that be? What was the key that allowed you to connect these two aspects (time and position) of the moon in its orbit?

Extra credit: Use steps (11) and (12) to derive the equation in (13).

**This activity is based on "Introducing the Moon's Orbital Eccentricity" by Benjamin Oostra published in *The Physics Teacher* Vol 52, 460.