Jupiter and Its Moons

Name:                                      Date:

Project Goals

1) to measure the orbital properties of Jupiter's moons.
2) to use your measurements and Kepler's third law to determine the mass of Jupiter.

Materials Required

- calculator
- PC and download computer software (see instructions below)

Background Information

In this project, you are going to repeat Galileo's observations of four moons orbiting Jupiter. With additional information not available in Galileo's time, you will be able to determine the mass of Jupiter based on your observations.

When one body such as a moon orbits around a parent body that is much more massive, Kepler's third law may be expressed as

\[ P^2 = \frac{4\pi^2}{GM} a^3 \]

M is the mass of the parent body (kilograms)
P is the amount of time it takes the moon to make one full orbit (seconds)
a is the semi-major axis (radius) of the moon's elliptical orbit (meters)

G is the gravitational constant, \(6.67 \times 10^{-11}\) Nm\(^2\)/kg\(^2\)

The Galilean Satellites program simulates the operation of an automatically controlled telescope with a CCD camera that sends a video image to a computer screen. On the screen, you will view the Jovian system edge-on. All the moons orbit Jupiter in roughly the same plane, so when viewed edge-on, the moons fall in a row. For each moon, you will obtain measurements of a and P, and use them in the law above to solve for M, the mass of Jupiter. Of course the answer should be the same regardless of which moon you use for the calculation. By calculating the mass based on the motions of all four moons,
though, you significantly reduce your chances of making a gross error. The names of the four moons, in order of increasing distance from Jupiter, are Io, Europa, Ganymede and Callisto (I Eat Green Carrots).

The Observations

- Go to the website [http://www.gettysburg.edu/academics/physics/clea/CLEAhome.html](http://www.gettysburg.edu/academics/physics/clea/CLEAhome.html). Click on the green "Software" in the upper left corner. Then click on the project "Revolution of the Moons of Jupiter." Download "JupLab.EXE" or "Mac Software" if you have a Mac. Double click on "JupLab.EXE" icon to install the software.

- Look on the computer for the folder called "CLEA" and the sub-folder called 'Juplab.' Double click the icon "Clea_jup.exe" to start the program. Click on "File" in the upper left corner and log in. You should now see a picture of Jupiter. Click on "File" again and choose "Run" to start.

- Next, select the date and time when your observing begins. When you are done, click the "ok" button. Under File-Pref-Timing, choose intervals of 12 hours for your observations. You will do a total of 16 observations (nine "days" worth of observations--two observations each day).

- After you have entered this information into the computer, it will display the main telescope screen.

    **WAIT:** do not click the button marked "next observation" just yet!

    Familiarize yourself with the telescope console. The large round object you see is Jupiter. The small dots are the moons. The current telescope magnification is displayed on the screen. You can change this by clicking on any one of the buttons in the lower middle section of the screen (try it now). Time and date are also displayed for you.

- How do you tell which moon is which? Position the cursor over a moon, and click and hold the mouse button. The name of the moon will appear as well as its projected distance from Jupiter's center expressed in units of Jupiter's diameter (Dj). If the moon is east of Jupiter, you will see "E," if it is west, you will see "W." To measure a moon, identify it and then switch to the highest power magnification that leaves the moon on the screen. It is important to use the highest magnification possible for the best accuracy. Sometimes a moon is behind Jupiter, so it can't be seen at all. When that happens, record the distance for that moon as zero. If you encounter "cloudy skies," just skip to the next observation. You will have a small gap in your data, but that's ok.

- Begin the date collection process by recording the position of EACH moon in the table on the next page. When you are done with the first date, click the button labeled "Next." Repeat your measurements for the new positions of the moons. For example, your data might look like this:

<p>| | | | | | |
|   |   |   |   |   |   |
|---|---|---|---|---|---|
| 1 | 04/12/96 | 8:00 | 2.33E | 7.00W | 10.22W | 11.12E |</p>
<table>
<thead>
<tr>
<th>Number</th>
<th>Date</th>
<th>Time (12 hour interval)</th>
<th>Io</th>
<th>Europa</th>
<th>Ganymede</th>
<th>Callisto</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Analysis**

Next you will determine the radius (a) and period (P) of each moon's orbit by plotting the Jupiter-moon separation (what you just measured) as a function of time. The period is the time it takes for any one moon to complete one full orbit. Thus the time between two maxima on such a plot is P. The time between subsequent crossings at 0 separation is equal to half the period (because this is the time it takes to get from the front of Jupiter to the back of Jupiter). If we assume the orbits of the moons are nearly circular, then the $maximum$ separation we observe between a moon and Jupiter is also equal to the radius (a) of that moon's orbit. For circular orbits, radius = the semi-major axis.
• Enter the data for each moon on the graphs provided. Along the horizontal scale are day numbers starting on the left (table column 1). The vertical scale is marked in units of D_J. Positions to the left (east) of Jupiter are considered negative, to the right (west) positive.

• For each moon, connect the points on the graph with a smooth curve (a sine curve). Mark all maxima and minima on each curve with an "X." They need not fall on one of the grid lines. The curve should be centered on separation zero. The maxima and minima should have the same values, except for the sign.

• Determine ‘P’ and ‘a’ from your figures for each moon. The units are days for ‘P,’ and D_J for ‘a’. Enter the results in columns 2 and 4 of the table below.

<table>
<thead>
<tr>
<th>Moon</th>
<th>P (days)</th>
<th>P (seconds)</th>
<th>a (D_J)</th>
<th>a (meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Io</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Europa</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ganymede</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Callisto</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

• Before using Kepler’s law to determine the mass of Jupiter, you need to convert these numbers into units of seconds for P and meters for a. There are 86,400 seconds in a day. Jupiter’s diameter is 1.44x10^6m. Use the space below for your conversion calculations and enter the results in the table above.

• At last, it is time to find the mass of Jupiter. Use Kepler’s 3rd law as given in the introduction to this exercise to calculate the mass in each of the four cases. Show your work and answers on the next page.
From Io: \[ M_I = \text{______________} \text{kg} \]
From Europa: \[ M_E = \text{______________} \text{kg} \]
From Ganymede: \[ M_G = \text{______________} \text{kg} \]
From Callisto: \[ M_C = \text{______________} \text{kg} \]

Hint: If one of the values is very different from the other three, look for a source of error. Perhaps the data are not adequate for a better result, in which case leave the value as you obtained it.

- Calculate the average of these four masses below:

\[ \text{Average } M_J = \text{______________} \text{kg} \]

Jupiter's mass is actually \(1.9 \times 10^{27} \text{ kg}\). How does your value compare? Describe the biggest source of error in your measurement:

_________________________________________________________________________________
_________________________________________________________________________________
_________________________________________________________________________________
_________________________________________________________________________________
p (period) = ___________ days  a (semi-major axis) = _______________ J.D.

p (period) = ___________ years  a (semi-major axis) = _______________ A.U.

p (period) = ___________ days  a (semi-major axis) = _______________ J.D.

p (period) = ___________ years  a (semi-major axis) = _______________ A.U.
Moon III Ganymede

- Position (J.D.)
  - East
  - West
- Time (days)

\[ p \text{ (period)} = \underline{\text{________ days}} \quad a \text{ (semi-major axis)} = \underline{\text{________ J.D.}} \]

\[ p \text{ (period)} = \underline{\text{________ years}} \quad a \text{ (semi-major axis)} = \underline{\text{________ A.U.}} \]

Moon IV Callisto

- Position (J.D.)
  - East
  - West
- Time (days)

\[ p \text{ (period)} = \underline{\text{________ days}} \quad a \text{ (semi-major axis)} = \underline{\text{________ J.D.}} \]

\[ p \text{ (period)} = \underline{\text{________ years}} \quad a \text{ (semi-major axis)} = \underline{\text{________ A.U.}} \]