Laboratory 5: Moons of Jupiter (CLEA)

Experiments are to be completed on the provided laboratory sheets below; any supporting material (eg. graphs) should be attached. Make sure your name and your partners name(s) are clearly indicated on the front page of your lab. **Neatness and clarity count!** Use complete sentences in answering all questions, explain your answers when asked clearly, and if you use an equation to do a calculation, *write the equation down* first, then put in numbers and solve. **Show all your work!**

Labs must be written *in pen* and are due a week after the lab.

APPARATUS

CLEA's Revolution of Jupiter's Moons software (in B315/113), calculator, graph paper (provided).

OBJECTIVE

1. To determine the mass of Jupiter from observations of the orbital motion of its moons.

THEORY

1). The four largest moons which orbit Jupiter were first seen by Galileo Gallilei in 1609; they are often referred to as the *Galilean moons* in his honour. Observations of their motion were tangible evidence for Copernicus' *heliocentric* model of the solar system. The moons are, in *increasing* distance from Jupiter: *Io, Europa, Ganymede,* and *Callisto* ("I Eat Good Carrots").

2). CLEA's Revolution of Jupiter's Moons software allows us to view the motion of Jupiter's moons at set intervals over some period of time. The moons move in (nearly) circular orbits about Jupiter, but as viewed from the Earth they appear to move "back and forth" along the horizontal plane about Jupiter's equator (see Figure 1. As the Moon orbits from A-to-B-to-C, it appears from Earth to move left-to-right in front of Jupiter as shown in the figure. Note that the moon is hidden from Earth's view by Jupiter at position *D*). Clicking on a moon in the program yields the horizontal position of that moon in units of Jupiter Diameters (J.D.). A position of 0 corresponds to the center of Jupiter and the letters 'E' and 'W' refer to positions to the *left* or *right* of the zero position.

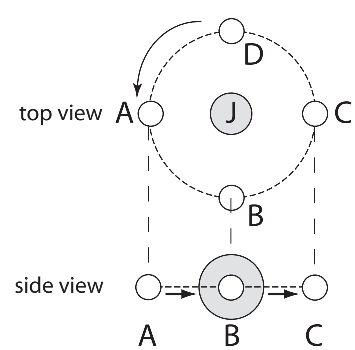

Figure 1: Jupiter's moons actual positions vs view from the Earth.

3). If appropriate time intervals are used between viewings, recording the position of any of the moons as a function of time results in a *periodic* (sine) curve. The **period** T (time between one peak and the next) corresponds to the orbital period of the moon; the **amplitude** a (height of the peaks above zero) corresponds to the radius (semi-major axis) of the moon's orbit (see Figure 2). This information, along with Kepler's Third Law, may be used to determine the mass of Jupiter.

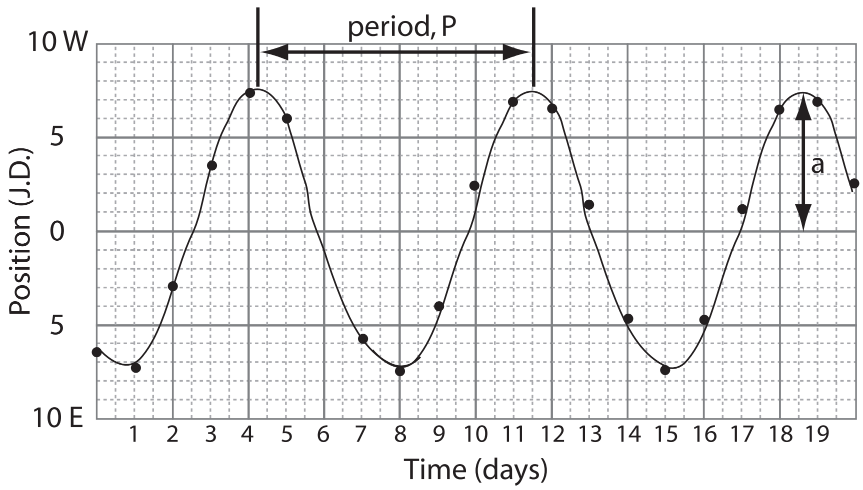

Figure 2: Sample plot of orbital motion of one of Jupiter's moons as a function of time.

4). Originally derived to describe the motion of the planets about the Sun, Kepler's Third Law

$$M = \frac{a^3}{P^2} \tag{1}$$

applies equally well to the motion of moons about a planet. If P is the *orbital period* of a moon (in Earth years), and a is the *length of the semi-major axis or the average radius* of the orbit of a moon (in units of AU), then M is the *mass* of the planet (in units of solar masses).

5). To compare a measurement with an *expected* value, use *percent deviation*:

$$\text{Percent Deviation} = \frac{(experimental - expected)}{expected} \times 100\%$$

(Example) *We measure a value to be 9.0 units and compare it to the known, expected value of 10.0:*

$$\text{Percent Deviation} = \frac{(experimental - expected)}{expected} \times 100 = \frac{(9.0 - 10.0)}{10.0} \times 100 = -10\%$$

The measured value is ten percent below the expected value.

Mark this lab:	☐ individually ☐ as a group	NAME: PARTNER:

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1. Form groups of two (2). The overall strategy for this lab is:

   1. Use the CLEA software to observe the *position* of **one** of the four Galilean moons
   2. Plot position as a function of time and graph the resulting (sine) curve
   3. Determine the period P and semi-major axis a of the orbit from the graph
   4. Convert P and a into units of years and AU
   5. Use Kepler's Third Law to calculate the mass of Jupiter

2. Start CLEA's *The Revolution of the Moons of Jupiter* software (*yellow* icon). **If a blank dialog box appears**, select *Cancel*; the program should start up normally. Select **Log In** under the File menu and press return (don't enter anything). Select **Run** under the File menu. **Use your birthday for the start date; leave start time as 0:00:00 UT**. Click okay. Each group member **MUST** do a **different moon** and **a separate set of observations and graph**; for group submissions, select ONE of the runs/graphs to be graded. The **time between observations** is set by selecting **Timing...** under the File menu & setting the observation step based on the moon being observed: **Io: 6 hours, Europa: 12 hours, Ganymede: 24 hours, Callisto: 48 hours**.

3. [***1 mark***] **Take twenty (20) time steps (observations) and fill in the table at the end of the lab**. **NOTE: record all data *before* pressing "Next" - there is NO 'back' button**. Record the position by clicking ON your chosen moon; *BOTH its name & position should appear on the bottom right of the screen.* **Record the bottom X position** (*include 'E' or 'W'*) in Jupiter diameters (J.D.) **and the date & time in the provided table** (see example below). Some observations may be 'cloudy' or your moon may be hidden behind Jupiter; put a line through that observation and continue to the next; a few 'missed' observations should not impact your results.

Moon: Europa			
Date (dd/mm/yy)	Time (UT)	Day	Position (J.D., E/W)
10/07/68	0:00:00	1	0.15 E
10/07/68	12:00:00	1.5	3.56 W
11/07/68	0:00:00	2	- cloudy -
11/07/68	12:00:00	2.5	1.95 E
⋮	⋮	⋮	⋮

4. [***6 marks***] **Use the supplied graph paper to plot position versus time**. For the vertical axis (position), choose upward as "W" and downward as "E", with zero in the middle; the units are J.D. The axis limits are: **Io: 5E - 5W, Europa: 5E - 5W, Ganymede: 10E - 10W, Callisto: 20E - 20W**. For the horizontal axis (time), use units of days (eg. 6 hours = 0.25 days), and pick a reasonable scale. In pencil draw a SMOOTH, SYMMETRIC curve passing through your data points (DO NOT simply connect the dots!). **Label your graph FULLY**, including a title, axes, & units. **Label the period, P, and semi-major axis, a.** See Figure 2 as an example.

5. [***4 marks***] **Determine the period** P **(in days) and the semi-major axis** a **(in J.D.) from your graph** (as shown in Figure 2). **Convert** P **to years. Convert** a **to km and AU.** Show all calculations fully. Note: 1 J.D. = 142,984 km = 0.00096 AU.

6. [***1.5 marks***] **Compare** P **with its (cited) expected value** using % deviation.

7. [***1.5 marks***] **Compare** a **with its (cited) expected value** using % deviation.

8. [*4 marks*] **Use Kepler's Third Law to find Jupiter's mass (in solar masses); convert to kg and to 'Earth masses'. Compare Jupiter's mass in kg with its (cited) expected value** using % deviation. Note: 1 solar mass = 1.99×10^{30} kg; Earth's mass = 5.98×10^{24} kg.

9. [*2 marks*] **Would a moon beyond *Callisto* have a longer or shorter period? Explain.**