Jupiter's Moons Lab

Galileo discovered the four largest moons of Jupiter in 1610, and they are often referred to as the Galilean Moons. He was using a simple telescope and a keen mind. It is a testimony to his observational prowess that out of all the stars and bright objects he could see in the sky, he noticed that Jupiter and these four dimmer lights, which he assumed were stars, were stretched out along a straight line. When he looked again he saw that the positions had changed from one night to the next, which is not what stars do. After repeated observations he determined that they were moons orbiting around Jupiter.

I. Find the Moons

There are 10 images on the next page of Jupiter and the four Galilean moons. The images were all taken one hour apart. Carefully study the images and identify the path that each moon takes**. Label them 1, 2, 3 and 4 in each image**. Which direction is each moon moving (closer to or farther from Jupiter)? **After examining all of the images, draw an arrow next to each moon in the first image indicating in which direction it is moving** (closer to or farther from Jupiter)

(a) Fill in the table below with the distance in mm from Jupiter for each moon. Be consistent! Make a mark at the center of Jupiter and measure the straight-line distance from here to each moon.

	Moon 1	Moon 2	Moon 3	Moon 4
Hour 1				
Hour 2				
Hour 3				
Hour 4				
Hour 5				
Hour 6				
Hour 7				
Hour 8				
Hour 9				
Hour 10				

(b) Investigate the numbers in Table 1 by subtracting the distances in consecutive images for each of the moons and filling them in below.

	Moon 1	Moon 2	Moon 3	Moon 4
Hours 1-2				
Hours 2-3				
Hours 3-4				
Hours 4-5				
Hours 5-6				
Hours 6-7				
Hours 7-8				
Hours 8-9				
Hours 9-10				

(c) Do the moons move the same distance each time? Why or why not? Use specific numbers from your data to explain how you came to this conclusion.

(d) Two of the moons disappear over the course of this 10 hour span and one of them reappears in the last image. Where are they when you can't see them directly? Sketch in their location as best you can in the images where you can't see them directly (make a mark and label it or draw an arrow).

(e) Which moon(s) appear to be traveling the fastest? slowest? On what did you base this conclusion? Do you have any data to support it?

(f) Do you think your conclusion depends on the portion of the orbit you are examining? In other words, if you were observing the moons orbiting Jupiter a few hours, days or months later, would you always reach the same conclusion about which are moving the fastest and which the slowest? Explain your reasoning. (*Hint: Examine the pattern in speed – at which point in their orbits are the moons moving the fastest? Slowest? By how much does there apparent speed vary? Is this a real difference in speed or an observational effect?)*

IV: Interpreting Your Data

The four moons Galileo discovered in 1610 are named Io, Europa, Ganymede, and Callisto. This table below shows the period and orbital radius for each moon. The period is the time for one complete revolution around Jupiter.

One more piece of information: the further the orbit from Jupiter, the slower the speed of the moon. This is because Jupiter's gravity weakens with distance.

Moon	Period (days)	Orbital Radius (km)
Io	1.8	421,600
Europa	3.5	670,900
Ganymede	7.2	1,070,000
Callisto	16.7	1,883,000

(a) Using this data, match each of your moons (1-4) with one of these. For each, explain how you reached your conclusion.

Io:

Europa:

Ganymede:

Callisto:

The Mass of Jupiter

By analyzing images of Jupiter and its moons, you can determine values for the variables D and T in the equation below and solve for the mass of Jupiter, M_J.

$$M_J = \frac{4\pi^2 D^3}{GT^2}$$

In this equation, D is the radius of the orbit of one of Jupiter's moons and T is the time it takes the moon to complete one orbit (the orbital period). G, the constant of universal gravitation, has a currently accepted value of: G = 6.67 x 10-11 m^3/kg-sec^2. Note that this equation looks a lot like Kepler's Third Law, but is modified to incorporate Newton's universal gravitation constant, which makes it apply to any central body that is being orbited by a much less massive object (not just the sun); e.g., The Hubble Space Telescope orbiting the Earth, a moon around a planet, one of the planets around the sun, or the sun around the center of our Milky Way galaxy. In all these cases the mass of the orbiting body is insignificant compared to the mass of the central body, and as you can see, its mass is not even included in the equation. If the mass of the orbiting body were significant, they would be orbiting around a common center, and a different equation would be needed.

As a practice problem, use the equation above to find the mass of the Earth in kilograms given the following observational data. The period of the Moon around the Earth is 27.3 days and the mean radius of its orbit is 384,000 km. Use meters for the units of D and seconds for T. **Check the answer with your instructor to make sure you have the method down before you move on.**

Determining the mass of Jupiter

a) You need the distance data you collected earlier. Make sure that all of your distances are in millimeters.

b) Edit Table 1 by making the distances for the moons to the left of Jupiter in the image negative (-) and the distances to the right of Jupiter positive (+).

(c) For all four moons in all the images, plot the distance from the center of Jupiter versus the time the image was taken on graph paper (recall that they were taken at 1 hour intervals). Use the full width of your graph paper for the x axis (distance from Jupiter), but use only one or two boxes per hour on the y axis for time so that you leave at least half of the sheet blank above the top of the y axis. Plot your data for the distances to all of the moons from Table 1 on this graph, but with a different color or symbol for each moon. Make a legend to show which colors/symbols represent which moons.

(d) To determine the period of each moon, you need to extrapolate from your data by sketching what you think the graph would look like if you had data for more hours. This is why you left the top of your sheet blank. Sketch in your best guess for the future orbit of each moon as a dashed line.

(e) Do any of the moons complete a full orbit in your projection? What does a full orbit look like? A half orbit? A quarter orbit? Make a small "dummy" graph of distance from planet vs. time below and mark full, half and quarter orbits on it. Then, explain how this is related to the data in your Table 2. **Verify that you have this correct with your instructor before moving on.**

(f) Use your extrapolations to estimate the time for each moon to complete one full orbit (the **period** of the moon). Hint: does it make a half orbit, quarter orbit or less during the 10hr interval?

Moon 1:

Moon 2:

Moon 3:

Moon 4:

(g) Now use your projections to estimate the maximum distance that each moon will get from Jupiter in mm before turning around and going back toward Jupiter. Fill these in in Table 3 below.

(h) In order to convert this “turnaround distance” to a real physical distance, you need a reference object. Luckily, Jupiter is the perfect candidate. It has a real diameter of 1.43×10^5km. Measure its diameter on your images and use that conversion factor to translate your mm distances into real physical distances. Fill in the table below with the values you calculate. Use the space below to show your work for at least one of these conversions.

Moon	“turnaround distance” (in mm)	Real distance from Jupiter (in km)
Moon 1		
Moon 2		
Moon 3		
Moon 4		

(i) Explain why this “turnaround distance” gives us the radius of each moon’s orbit around Jupiter. You may wish to draw a picture to support your claim. *Hint: think about the geometry of the orbits. Are we watching them orbit from the top or the side? What about an orbit changes as you change your viewing angle?*

(j) Estimate how much error there is in your values for the period and the distance respectively and explain how you made your error estimate.

(k) You now have the period and radius for each of the four moons. Use the values for the period *each moon individually* to determine the mass of Jupiter from the equation for M_J. Use meters for the units of D and seconds for T. Show your work for at least one of these calculations in the space below and then fill in the table

Moon	Mass of Jupiter
Moon 1	
Moon 2	
Moon 3	
Moon 4	

(l) Calculate the average Mass of Jupiter according to your four estimates

(m) Look up the currently accepted value for the mass of Jupiter. Determine the percent difference between the accepted value and your calculated (experimental) values using the following equation:

$$\% \text{ Difference } = \frac{\text{accepted value - calculated value}}{\text{accepted value}}$$

Moon 1:

Moon 2:

Moon 3:

Moon 4:

Average:

(n) Which of these gave you the most accurate estimate for the mass of Jupiter and why?

(o) Were these error estimates close to the error you estimated in (j)? Why or why not?

Wrap Up:

Design an experiment that would allow you to obtain a more accurate value for the mass of Jupiter. Be specific.