## LAB - KEPLER'S LAWS

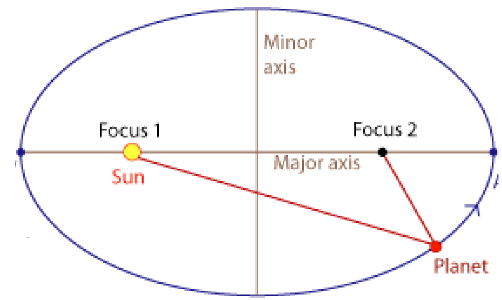
name: ________________________________

### Part I: Orbits of Planets and Satellites

**QUESTION -** What is the shape of the orbits of planets and satellites in the solar system?

**MATERIALS**

- piece of cardboard or foam
- sheet of blank paper
- two push pins
- metric ruler
- sharp colored pencils
- four small pieces of tape
- string loop 10-14 cm




**PROCEDURE: Each pair of students will have a diagram & will attach diagram to the end of one the lab!**

1. Draw a line across the center of the paper, along the length of the paper. This line represents the **major axis**.
2. Mark the center of the line, draw, and label it "**Sun**".
3. Choose a colored pencil for the different orbiting objects.
4. Using the loop you will draw a circle by placing a **push pin** at the **Sun** location. Then put the loop of string around the pin. Pull the loop taut with your pencil. (Your lab partner should HOLD the push pin in place by lightly pressing down on it.)
5. Swing the pencil in a circular fashion around the Sun, while keeping the string taut. **Label: CIRCLE**.
6. Measure both the farthest and closest distance from the sun to the circle to the nearest mm and record.
7. Average the closest and farthest distances and use this as the **circle's radius** in step 8.
8. Now starting with the **Earth**, calculate the distance between the foci, **d,** using the equation below. The **eccentricity**, **e**, for each object is on the data table**.** You will need to enter the **radius of your circle** into the equation! Show Earth example below.

$$d = \frac{2\mathbf{e}(\text{circle's radius})}{(e + 1)}$$

[4]

9. Choose a different colored pencil for the Earth. Place a **second pin** at the calculated distance, **d,** from the **Sun pin** on the **major axis**. Remember that the Sun pin stays for all trials!
10. Place the **loop** of string **around both pins** then repeat steps 5 & 6 for each of the listed objects.

**DATA TABLE / CALCULATIONS [-2/blank or math error]**

| Object | Known Eccentricity (e) | Calculated Distance (d) [cm] | Farthest dist. from Sun [cm] | Closest dist. to Sun [cm] | Experimental Eccentricity (e') | % Error |
|---|---|---|---|---|---|---|
| **Circle** | 0 | 0 | | | 0 | 0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Earth** | 0.017 | | | | | |
| **Pluto** | 0.25 | | | | | |
| **Comet** | 0.70 | | | | | |

**ANALYZE**

**11.** Calculate the **experimental eccentricity**, **e'**, for each of the objects and record your data in the data table. Use the following equation:

$$e' = \frac{(\textit{farthest distance} - \textit{closest distance})}{(\textit{farthest distance} + \textit{closest distance})} =$$

[4]

**12.** **Error Analysis**: Calculate the percent error of the experimental eccentricities. Record in the data table.

$$\%\ error = \frac{|e - e'|}{e} x\, 100\,\% =$$

[4]

**13.** **Analyze**: Why is the shape of the orbit with e = 0 a circle? [2]

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**14.** **Compare**: How does Earth's orbit compare to a circle? [2]

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**15.** **Observe**: Which of the orbits truly looks elliptical? CIRCLE / EARTH / PLUTO / COMET [2]

**CONCLUDE AND APPLY**

**16.** Does the orbit model you constructed obey Kepler's first law? Explain.

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**17.** Kepler studied the orbit data of Mars (e = 0.093) and concluded that planets move about the Sun in elliptical orbits. What would Kepler have concluded if he had been on Mars and studied Earth's orbit?

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**18.** Where does a planet travel fastest: at aphelion, farthest from Sun, or perihelion, closest from Sun? Why?

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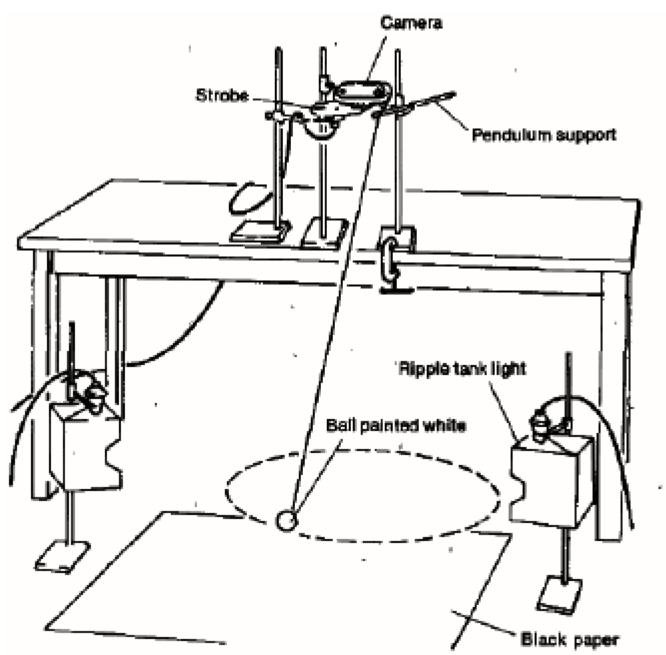
_______________________________________________ [4]

**Part 2 - KEPLER'S LAW OF EQUAL AREAS**

**INTRODUCTION:** Johannes Kepler discovered that the planets follow elliptical paths around the sun. He also discovered that an imaginary line from the sun to a planet sweeps out equal areas in equal time intervals. The photographs in Figure 14-2 were made by illuminating a white pendulum bob and photographing it in its rest position. The bob was then made to swing so that it follows an elliptical path. By means of a motorized stroboscope, the bob was then photographed in several positions all on the same film exposure that was used to photograph the rest position of the bob. The motion of the bob closely duplicates the motion of a planet as it orbits the sun.




***F*igure 14-1.** The photographs In Figure 14-2 were taken with apparatus similar to this. A white ball Is suspended above a dark background. The central position of the ball is recorded on the film. On the same film exposure, the swinging ball is photographed using the stroboscope to obtain exposures at frequent intervals along the path of the ball, It is important to close the camera shutter after the ball has completed one revolution. A second method of obtaining the same effect is to use a strobe light as a source of Illumination as the photograph is taken.  Below is a negative of the photo.

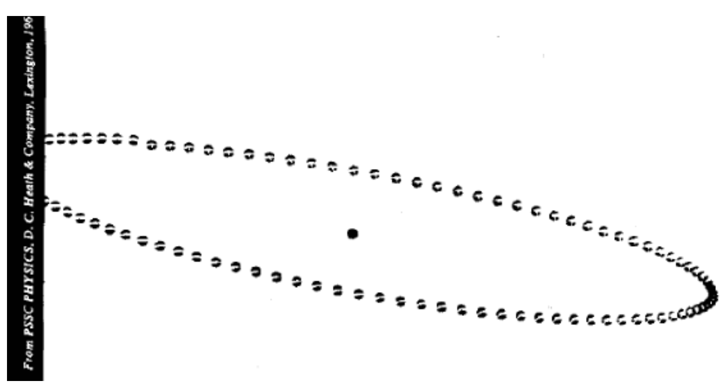



**Figure 14-2**. (a) The elliptical path of a suspended ball. Each position is separated from the next by exactly the same time interval.

**Objectives:** During this investigation you will study Kepler's law of equal areas and note that such laws are not confined to special cases, but are true for all circular or elliptical motion.

**PROCEDURE:** Working with your lab partner.

19. Examine the photographs in Figure 14-2b, enlarged on the last page. Assume that the intervals between consecutive images of the bob are equal. The bob therefore moved from any position shown to its next position in equal time intervals. To determine the area swept out by an imaginary line from the bob to the central image in equal times we will draw triangles on the image.
20. Place a dot over the center of the central image (**O**). Locate the **centers** of the **images** marked **A**, **B**, **C**, and **D**. Place a **dot** over the **centers** of each of these images.
21. Construct two triangles (**AOB** and **COD**) using the five points marked on the paper. With a ruler, carefully measure the **bases**, the **longest side**, and the **height**, the **perpendicular distance from the longest side to the opposite corner**, of each triangle. Record 1. Calculate the **area** of each.
22. Repeat Steps 2 end 3 using different positions of the images. You will be determining the **area** of **2 time intervals** as was done for **AOB** & **COD**. Do not try to use the extreme right of the photographs where the images run together.

**DATA AND CALCULATIONS**

| Data | | |
|---|---|---|
| **Triangle** | **Base (cm)** | **Height (cm)** |
| **AOB** | | |
| **COD** | | |
| | | |
| | | |
| | | |

| **Calculations** |
|---|
| **Area = $^1/_2$bh (cm$^2$)** |
| |
| |
| |
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| |

**INTERPRETATION**

23. Were the areas of the triangles in close agreement? How do you account for slight differences?

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[4]

24. When the bob follows an elliptical path, it is sometimes closer to the central position than it is at other times. If an imaginary line from the bob to the central image sweeps out equal areas in equal times, what can you conclude about the speed of the bob when it is closer to the central image as compared with the speed of the bob when it is farther away from the central image?

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[4]

25. The earth follows an elliptical path around the sun. In the Northern Hemisphere the Earth is closer to the Sun by

about $6.4 \times 10^6$ km in the winter than it is in the summer. Compare the speed of the Earth along its orbit in the winter with the speed of the Earth along its orbit in the summer.

[4]

**Part 3 Kepler's 3rd Law Problems**

**26.** Callisto's Distance from Jupiter Galileo measured the orbital sizes of Jupiter's moons using the diameter of Jupiter as a unit of measure. He found that Io, the closest moon to Jupiter, had a period of 1.8 days and was 4.2 units from the center of Jupiter. Callisto, the fourth moon from Jupiter, had a period of 16.7 days. Using the same units that Galileo used, predict Callisto's distance from Jupiter.

**27.** If Ganymede, one of Jupiter's moons, has an orbital period of 7.15 days, how many units are there in its orbital radius? Use the information given in Problem 1.

**28.** An asteroid revolves around the Sun with a mean orbital radius twice that of Earth's. Predict the period of the asteroid in Earth years.

**29.** It is found that, on average, Mars is 1.52 times as far from the Sun as Earth is. Predict the time required for Mars to orbit the Sun in Earth days.

**30.** The Moon has a period of 27.3 days and a mean distance of $3.90 \times 10^5$ km from the center of Earth. What is the distance of a satellite that takes 5 days to orbit the earth?

**31.** Use Kepler's laws to find the period of a satellite in orbit $6.70 \times 10^3$ km from the center of Earth.

**32.** Using the data in the previous problem for the period and radius of revolution of the Moon, predict what the mean distance from Earth's center would be for an artificial satellite that has a period of exactly 1.00 day.

[1] 18.5 units; [2] 10.5 units; [3] 2.83 years; [4] 684 days; [5] $1.26 \times 10^5$ km; [6] 0.06 days; [7] $4.19 \times 10^4$ km

## Enlarged 14-B