Name ____ Date _________________

Partners ____

Kepler and Mars: Lab #13

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Objective: to understand how Johannes Kepler measured the orbit of Mars, and what it meant to the development of physics

Equipment: ruler, protractor, polar graph paper, scissors, masking tape, pencil, red pencil

Background: Copernicus had correctly deduced that the planets such as Mars went around the sun rather than going around the Earth. This meant that the true orbital period of Mars was 686.98 days (roughly 1 year 10.5 months). For this lab we will use 687 days. If we could observe Mars from two different places in the Earth's orbit separated by 687 days then we would be seeing Mars at the SAME point in its orbit.

Kepler searched through the 20 years of observations done by Tycho Brahe to find pairs of dates separated by 687 days on which Tycho had seen and recorded the direction toward Mars in his notebook. He made a scale model of the inner solar system on a piece of paper, with the sun at the center. For each observation date he put a dot for the Earth's position in its orbit, then a line from the Earth in the direction towards Mars as observed. Where the lines crossed, there must be Mars. He made the assumption that the Earth’s orbit was a perfect circle.

We will do as he did and repeat this construction several times, each time finding one position of Mars as it travels through space. Eventually we will fit a curve to these hard-won points. Precision is important in this activity, so measure everything carefully.

Procedure:

1. Label the center of the graph paper "Sun."

2. The Earth's orbit will be approximated by the circle with radius 15 units. Trace around it lightly. Note that there are marks every 5 degrees around the circles.
Draw heavily the line from the sun to "180 degrees." Where this line crosses the Earth's orbit put a dot and label it March 21. This is because we have traditionally defined 0 degrees longitude as the direction we look to see the sun from Earth on March 21, the Vernal Equinox.
Label the 0 degrees “longitude.”

3. We will make the approximation that all the months have the same length, 30 degrees.
Going counterclockwise, procede 10 degrees beyond the Vernal Equinox dot to 190 degrees. Put a light mark there and label it April 1.
Go 30 degrees further and lightly mark May 1.
Continue around the Earth's orbit lightly marking the first day of each month.

4. Now you are ready to plot the observations of Mars given in the data table.
Each pair of observations (A and B, C and D, etc) contains data which is separated by 687 days, so they are observations of Mars at one place in its orbit as seen from two different places in the Earth's orbit.

For A put a dot on the Earth's orbit at March 21. (You should already know where this is!)
Carefully position the protractor there such that its 0 degree line is parallel to the main 0 degree line. Draw a line from the Earth toward 118.8 degrees longitude (measured counterclockwise) and extend the line to the edge of the graph paper circles.

For B put a dot on the Earth's orbit at February 5.
Carefully position the protractor there such that its 0 degree line is parallel to the main 0 degree line. (This is the hard part.)
Draw a line from the Earth toward 168.9 degrees longitude (measured counterclockwise) and extend the line to the edge of the graph paper circles.

These two lines should cross. Put a red dot there and label it "Mars 1".

5. Using the lines on the graph paper carefully measure the distance from the Sun to Mars 1 and record this as R in the data table.

6. Continue for each observation date pair.
Mark the crossing points "Mars 2" etc.

7. Calculate the average R value.
In terms of the Earth's orbital radius (1 AU) the value is ______________ AU.
The accepted value is 1.524 AU,
Your percent error is ___________________

8. Cut out a paper circle of this “average R” in radius.

9. Lightly tape this “average circle” to a window.
Move your orbit of Mars around over it to get a match.
Carefully mark on your orbit paper the center of the "average circle" and label this "center."

10. Measure the distance between this center and the Sun's position. (It will be a small distance.)
Now you can calculate the eccentricity of Mars' orbit by

$$\text{Eccentricity} = e = \frac{\text{center to Sun distance}}{\text{average R}} =$$

The accepted value is e = .093.
Your percent error is ___________________

11. Draw a red line from the Sun to the center and extend it all the way across the orbit of Mars. Label Mars' perihelion point (the closest point on the orbit to the Sun) and its aphelion point (the farthest point on the orbit from the Sun).
Label this line the "major axis."
The longitude of the perihelion point is __________________ degrees.
The accepted value is 335.7 degrees.
Your percent error is ___________________ out of 180 degrees.

12. Discuss sources of error in this lab exercise.

13. Kepler’s analysis of Tycho Brahe’s observational data showed:

How did this change the course of physics?

14. Future work:

Data Table

Event	Date	Longitude, degrees	Latitude, degrees	R
A	March 21, 1931	118.8	3.2 N	***
B	February 5, 1933	168.9	4.6 N	
C	April 20, 1933	151.6	2.6 N	***
D	March 8, 1935	204.5	3.2 N	
E	May 26, 1935	186.7	0.7 N	***
F	April 12, 1937	245.6	0.7 N	
G	September 16, 1939	297.4	4.7 S	***
H	August 4, 1941	16.4	4.7 S	
I	November 22, 1941	12.0	0.6 S	***
J	October 11, 1943	80.2	0.5 S	
K	January 21, 1944	65.7	3.0 N	***
L	December 9, 1945	123.1	3.3 N	
M	March 19, 1946	107.7	3.4 N	***
N	February 3, 1948	153.3	4.6 N	
O	April 4, 1948	138.4	3.2 N	***
P	February 21, 1950	190.6	3.7 N	

Average R ________________