The Distance of Venus from the Sun

by Jane Schmane and Robert Schmobert
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Abstract We determined the distance from the Sun to Venus by measuring the angle between the Sun and Venus when Venus was at maximum elongation. By lining up the shadow of a washer on a pin with another washer on a pin, and sighting Venus through a camera mounted onto a protractor, we measured the angle between Venus and the Sun for a period of 8 days in early May 2015. According to our data the moment of maximum elongation occurred at 6:20am on May 9, 2015 and Venus' distance from the Sun is about 1.1×10^7 m. This value is much smaller than the expected value of 1.08×10^8 m. We believe that this discrepancy is due to a large error in the value of the distance from the Sun to the Earth that we used in our calculation.

We affirm that we have carried out our academic endeavors with full academic honesty.

Introduction

Venus is one of just two planets in the Solar System that orbit interior to the Earth's orbit. The distance of Venus from the Sun, as first demonstrated by Copernicus (pp xxx, textbook name), can be determined by measuring the angle between Venus and the Sun and using simple trigonometry. In particular, when Venus is at the largest angle that it gets from the Sun, a position called "maximum elongation," then the orientation is like that depicted in Figure 1.

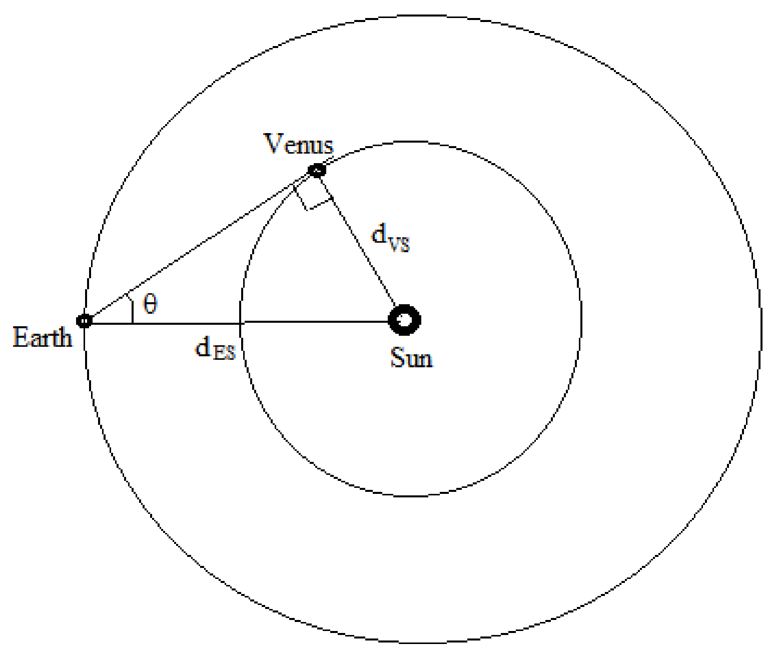

Figure 1: The relative orientations of the Earth, Venus, and the Sun when Venus is at its maximum angular separation, represented by θ, from the Sun, as viewed from the Earth.

As Figure 1 shows, the line of sight from Earth to Venus at this moment must be tangent to Venus' orbit, and therefore must be perpendicular to the radius of Venus' orbit. The triangle defined by the Earth, Venus, and the Sun at this time, then, is a right triangle with the right angle at Venus. By basic trigonometry, if we use θ to denote the angle between Venus and the Sun as viewed from the Earth, then

$$\sin\theta = d_{VS}/d_{ES}, \qquad (1)$$

where d_{VS} is the distance from Venus to the Sun and d_{ES} is the distance from the Earth to the Sun. The Earth-Sun distance was measured in a previous lab (Schmoe, *Ast50 Journal Vol 3*), and so we can, now, obtain the Venus-Sun distance by measuring the angle between Venus and the Sun at maximum elongation, which occurred on May 4.

Procedure:
The apparatus used for measuring the angle is shown in Figure 2.

Figure 2: The apparatus used to measure the angle between Venus and the Sun.

A metal plate had angle markings traced from a protractor and two small washers mounted on metal pins were attached on opposite sides of the plate. The plate was mounted to an adjustable tripod and a single-lens reflex camera was mounted onto the tripod and at the center of the plate. By altering the adjustments on the tripod we could arrange the plate so that the sunlight shined directly through both washers, which were aligned with the zero-angle markings. We then sighted Venus through the camera which had a small rod sticking out the back indicating the angle the camera was pointing.

In late afternoons from May 4 to May 12, we brought our angle-measuring apparatus to the field just east of the Nott, from where we could see both the Sun and Venus. We measured the angle five times over this eight-day period.

Results and Discussion:
The dates and our measured angles are listed in Table 1.

Table 1: Measured angles between Venus and the Sun for the 5 days of observations.

Date and Time	**Days since start**	**Observing Conditions**	**Angle** (degrees)
May 4, 4:00 pm	0.000	Clear	47.2
May 6, 4:10 pm	2.007	Clear	47.4
May 9, 5:30 pm	5.063	Partly cloudy	47.8
May 10, 3:00 pm	5.958	Clear	47.5
May 12, 3:30 pm	7.979	Partly cloudy	47.4

As shown in Figure 3, we plotted our measured angles on the y-axis and day on the x-axis. For the day number, we chose our first observation to be day 0, and converted the times of our observations to fractions of a day.

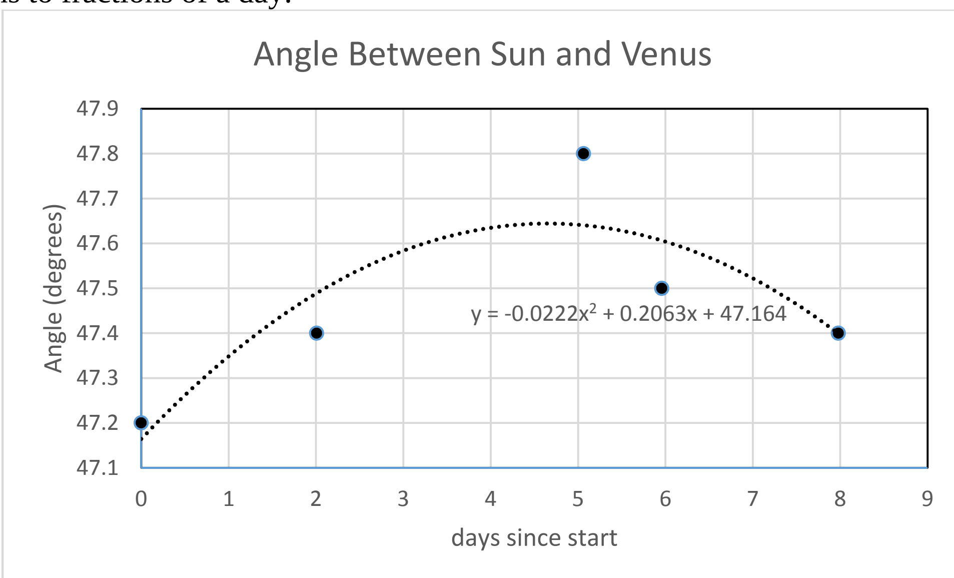

Figure 3: Graph of angle between Venus and the Sun vs. day.

One can see in Figure 3 that the angle between Venus and the Sun increased and then decreased, indicating that the time of maximum elongation did, in fact, occur during the time frame of our observations. By fitting a parabola to the data, as shown by the curve in Figure 3, we find the day and angle of maximum elongation. The peak of the curve of the fit parabola indicates that the time of maximum elongation was about 4.6 days after the first observation, i.e. at 6:20 am on May 9, and the angle was 47.65^{o}.

We can now find the distance from the Sun to Venus by inserting our inferred angle of Venus' maximum elongation into Equation 1. We also use the previously measured value of the distance of the Sun from Earth, which is 1.5×10^7 m (Schmoe, *Ast50 Journal, Vol 3*). Inserting this value in for d_{ES} and our inferred maximum angle for θ, we get that Venus' distance from the Sun is

$$d_{VS} = 1.1 \times 10^7 \text{ m.}$$

Our measured distance of Venus disagrees with the expected value, as given in the textbook, by a factor of 10! We recognize, though, that our calculation involved the previously measured distance of the Sun from the Earth, and so the accuracy of our result is also dependent on the access of this other measurement. As Schmoe explained in his report, their measurement was very sensitive to small errors and so the accuracy of their result was considered to be poor. We therefore infer that the large discrepancy of our result from the expected value is due to the inaccuracy of this previous measurement.

The effect of the error in the measurement of the distance of the Sun on our measurement of Venus' from the Sun demonstrates the interdependence of the accuracies of different measurements. The development of a successful, detailed model of the solar system, as well of any aspect of nature, therefore, requires that all measurements be made as carefully as possible.

This method of measuring the radius of Venus' orbit could also be applied, in principal, to Mercury's orbit as well. With the previous measurements of the size of the Earth, the size and distance of the Moon, and the size and distance of the Sun, we need only to develop a means of measuring the distance to the outer planets to have succeeded, as a class, in demonstrating how one can measure all distances and lengths of the major bodies in the Solar System.

In contemplating this lab, we find it profound that we were able to measure the distance between two bodies in space without leaving the Earth. Furthermore, we accomplished this amazing task with a simple, low-tech method and using the 11th-grade tools of trigonometry.