Chapter 1

The Transit of Venus

How far is it from the Earth to the Sun?
This has been a question posed by philosophers and scientists since the time of the ancient Greeks. It plays an important role in today’s exploration of the solar system. The distance from the Earth to the Sun is called an astronomical unit (AU). The planet Jupiter, for instance, is 5.46 AU from the sun (five and a half times the distance from the Earth to the Sun). But, how long is an AU?

In 1716, a British astronomer, Edmund Halley (Figure 1.1), described a way this could be measured. Astronomers had used Newton’s laws of motion to calculate the orbits of the known planets and shown that every 113 years, the relative positions of the planet Venus and the Earth would put Venus between the Earth and the Sun. With the best of telescopes, astronomers could determine the time it took for the black dot that was Venus to cross the face of the Sun. This time would differ depending upon where you were on the Earth. So, Halley pointed out, if we could measure that time from two different places on the Earth that are very far apart, we could use those two different times, the relative distance of the orbits of Earth and Venus, and a complicated series of calculations to determine the distance from the
Earth to the Sun. Reference [1] describes how one could estimate the AU from two such points on Earth, assuming only the knowledge of high school geometry.

When Venus crosses the face of the Sun, it does it twice, 8 years between each transit. The next expected transits of Venus would occur in 1761 and 1769.

Halley died in 1742, but his proposal lived on. As the year 1761 approached, groups of natural philosophers prepared for the event in Russia, Austria, Norway, France, and England. They prepared small lightweight telescopes that could be carried easily. They planned to use the telescopes to cast images onto paper, where they could watch the passage of the black dot of Venus crossing

FIGURE 1.1 Edmund Halley (1656–1742) who proposed that the distance from the Earth to the Sun could be determined by timing the transit of Venus from two widely separated places on the Earth. (Courtesy of istock.com.)
the face of the Sun. (It is impossible to stare directly at the Sun through a telescope without damaging the eye.)

In 1761, most of the Earth had been identified and mapped but much of it was in wilderness. Since the distance between two places in civilized Europe was too short for Halley’s proposal, adventurers set off for destinations from Siberia to India and Sumatra. More than a dozen adventurers participated in the transits of 1761 and 1769, but, as we shall see, not all were successful. At that time, science had not advanced to the point where some scientists studied astronomy, others chemistry, some others physics, and so on. They were all called “natural philosophers,” and one might travel to a distant land and come back describing the plant and animal life, the type of people, the geography, and the appearance of the heavens. So, these adventurers set off to do more than time the transit of Venus. They planned to provide detailed observations of the places they visited.

How did they pay for this? Now, in the twenty-first century, scientific endeavors are financed by charitable foundations or governments, but this type of support has only been widely available since the end of World War II in 1945. In the eighteenth century, the scientists were either independently wealthy or were supported by wealthy patrons. Jean-Baptiste Chappe d’Auteroche and Guillaume le Gentil were minor noblemen in France. Christian Mayer and Andras Lexell were bankrolled by the Russian Empress Catherine the Great. Charles Mason and Jeremiah Dixon set out for Sumatra with funds raised by subscription in England.

Nor was there any kind of a central scientific archive. There were academies of science supported by the rulers of France, Russia, and Sweden. But, by far the most influential scientific body was the Royal Society of London. Correspondents from all over Europe sent letters to be read at Royal Society meetings. For instance, Anton Leeuwenhoek, the inventor of the microscope, sent detailed drawings of tiny things invisible to the naked eye from his home in the Netherlands. Adventurers sent letters describing their observations in far off newly discovered lands. The Reverend Thomas Bayes
submitted his mathematical musings. The Royal Society decided to coordinate these various sightings of the transit of Venus and gather them together after the 1769 transit to determine the distance from the Earth to the Sun.

After the transit of 1761, the observations began to arrive. An even more concerted effort was made to time the transit in 1769, with adventurers traveling to St. Petersburg, Canada, Baja California, Tahiti (the famous Captain Cook was involved in this one), Norway, Philadelphia, and Manila.

These adventures were not without their dangers. In 1756, war broke out between England and France and their allies. In the United States, this is remembered as the French and Indian War, where George Washington learned how to make war. It was called the Seven Years War in Europe and lasted until 1763. For the 1761 transit, many of the adventurers carried letters from both English and French diplomats that would supposedly get them through battle lines. However, these letters were not always adequate.

When Charles Mason and Jeremiah Dixon set out from England for the 1761 transit, their ship was attacked by a French warship, killing 10 of the sailors and forcing their crippled vessel back into port. Guillaume le Gentil was traveling in the Indian Ocean when he learned that the British had taken the French colony of Pondicherry in India, where he had intended to take his measurements. The ship turned around and headed back to Mauritius, but le Gentil was at sea on a tossing ship on the day of the transit and did not have a stable platform to make his measurements. The observations for the 1769 transit were taken in a more peaceful world and were more complete.

Of all the adventurers, Guillaume le Gentil was singularly unlucky. He missed the 1761 transit because he was on board a ship in the Indian Ocean. He stayed around for the 1769 transit and decided to view it from the Philippines. The Spanish authorities in Manila suspected him and did not understand his mission, but he was able to set up his instrument and showed Spanish officials and their wives the wonders of the heavens in the clear
night sky. Le Gentil spent 3 years in Manila preparing for the 1769 transit, but the French Academy of Science contacted him in 1768 and urged him to return to Pondicherry, which had just been recaptured by the French, in India.

The night before the transit, the sky was clear at Pondicherry, but the day of the transit, the weather got worse and worse, with clouds piling up and blocking any view of the Sun. (It was a clear day, perfect for viewing the Sun, in Manila.) He returned to France to find that, when he had not been heard from for so long, he had been declared dead. His wife remarried, and his relatives split up his fortune. But, all was not lost for le Gentil. He wrote the story of his adventures, and this memoir became a bestseller in Europe. In 1992, the Canadian writer, Maureen Hunter, turned le Gentil’s travails into a play, and, in 2007, she wrote the libretto for an opera—both named “The Transit of Venus.” The complete story of the adventurers who went out to time the transits can be found in References [2–4].

In the months that followed the 1769 transit, the final observations of these adventurers were sent to the Royal Society of London. The Royal Society appointed a committee to examine the numbers and use them to compute the distance from the Earth to the Sun. The chairman of that committee was Lord Henry Cavendish (Figure 1.2). The Cavendish family was involved in scientific ventures for at least two generations, but Henry Cavendish was the most distinguished, having made major contributions to astronomy, chemistry, biology, and physics. Henry Cavendish had investigated the nature of hydrogen, measured the density of the Earth, showed the nature of fermentation, and had played a major role in the movement to make science dependent upon very careful measurements. Remember, the “natural philosophers” of that time were not walled off into separate disciplines, so a genius like Henry Cavendish could make contributions to many fields.

The Cavendish committee kept careful minutes of their meetings, and those minutes and the original data they received are in the archives of the Royal Society. How were they to proceed?
(In 1977, Stephen Stigler used those records and applied modern computer-intensive statistical methods to see if he could improve on the conclusions of the Cavendish committee but more of that in Chapter 10.)

Edmund Halley had proposed that, if the transit of Venus were to be observed at two points on the Earth, the difference in timing and the distance from one point to the other could be used to compute the distance from the Earth to the Sun. Depending upon how many of the observations they found that met their standards, the Cavendish committee could have had as many as 45 pairs of observations available, although the accuracy would be greatest if the two comparable measurements were made from places on either side of the equator. Which pairs of observations should be used?
Until the rise of statistical models in the twentieth century, scientists would consider a collection of observations or experimental results like these and carefully choose the “best” ones or one. For instance, in the 1870s Albert Michelson attempted to measure the speed of light at the Naval Observatory in Washington, DC. His idea was to send a thin beam of white light down two different pathways of mirrors. He could adjust the mirror positions on one path until he had dark rings of interference on the screen where he projected both beams at the end. The difference in length of the two paths could be used to measure the speed of light.

To do this, Michelson needed a steady source of pure white light. None of the artificial light sources available at that time produced the type of beam he needed. However, there was a crack in the wall of the observatory. For a brief period during the day, the Sun shone directly through that crack. Thus, he had a brief moment each day to take his measurements. Although he recorded all his runs, he used only a small subset of these for his final analysis. This was because he trusted his experimental experience and sense to tell him which of the runs was “correct.”

(Nowadays, when most science is sponsored by government or foundation grants, it is considered a scientific fraud to select the “correct” values from a set of observations or experiments. The reputable scientist is expected to display all the data. This book will show why and how this came about.)

And so, in the spirit of eighteenth- and nineteenth-century science, the Cavendish committee examined the data that had been collected, searching for the ones that were “correct.”

1.1 ERRORS

The first problem they ran into was called the “black dot” problem. It turned out that the adventurers could not observe exactly when the black dot of Venus crossed onto the disk of the Sun and when it left. Instead, they saw the black dot stretched and enlarged as it approached the limb of the Sun’s disk and then suddenly appeared within the disk, without their being able to observe the
exact moment of crossing. A similar problem occurred as the black dot emerged from the Sun’s disk. The calculations Halley had proposed assumed that the time of crossing could be determined down to the second.

This is a problem that occurs in almost all scientific observations. The most careful measurements produce different numbers when the observations are run more than once. This failure to be able to replicate exact measurements descends all the way down to atomic physics, where current theory holds that the position or spin or whatever we wish to measure on an individual particle is fundamentally random.

In this book, we will call these kinds of differences in measurement “errors.” Section II of this book will show how modern statistical methods deal with “errors.”

1.2 BLUNDERS

But, the Cavendish committee had to contend with more than just random error. One of the adventurer’s numbers did not match anything else in their data. When they made his time of transit part of the equations, the result was dramatically different from their other calculations. They eventually concluded that he had gotten the longitude of his position wrong. It was, in fact, very difficult to measure the longitude of one’s position on the Earth during the eighteenth century. The latitude is easily determined by the height of the Sun from the horizon at noon, but the longitude has to be determined by knowing the exact time of the observation at the place where you are and also at some fixed spot on the Earth (like the Greenwich meridian).

The failure to have the correct longitude was not an “error” like the black dot problem. In the 1920s, the statistician William Sealy Gosset made a distinction between “errors” and “blunders.” Errors were the differences in measurement that are inherent in the act of measuring. Blunders are something else.

I was once involved in an investigation of recorded temperatures in a large fermentation reactor that was supposed to be kept
at a constant temperature. Once an hour, to determine the current temperature, the operators had to pull a small bucket of material out of the reactor, measure its temperature, and adjust the cold water flow into the reactor accordingly. We examined the records of 1 week, where, at the beginning of a new shift, the temperature suddenly dropped and had to be adjusted back, and, at the beginning of the next shift, the temperature suddenly rose and had to be adjusted down. Someone was sent to observe what was happening on those two shifts.

Drawing a bucket of material from a reactor was a dirty job. The worker had to climb up metal stairs, reach around in a small space, and open the spigot. So, that job was usually given to the least senior man on the shift. It turned out that the man who drew the sample on the first shift had just been hired, handed the bucket and the thermometer and told to get the temperature of the fermentation tank. He was observed to climb up to the spigot, draw the sample of material, take the thermometer, shake it hard up and down, plunge it into the bucket, wait a few seconds, then take the thermometer out and carry it over to the light to read it.

The only thermometers he had experience with were the clinical fever thermometers that might have been used at his home. In a clinical thermometer, a small kink in the mercury column keeps the mercury at the maximum value it reached unless the thermometer is shaken down. He did not realize that his thermometer registered whatever was the ambient temperature, so his “measurement” of the temperature of the reactor was, in fact, a measurement of the ambient air around the reactor. In the words of Gosset, all of his measurements were “blunders.”

Section III of this book deals with how blunders are identified and handled in statistical analyses.

1.3 LIES

One of the adventurers bothered the Cavendish committee. He was a man who had been known to exaggerate some of his “findings” in previous adventures. Could his data be trusted?
Scientific activities have been bedeviled by instances of fraud since the beginning of the modern age. In spite of the honest attempt by most explorers and scientists to uncover the true nature of the world, there are isolated examples of something else.

For an early example, consider the voyage of discovery of Sebastian Cabot in 1508. Cabot left Bristol, England, with two ships and three hundred men, financed by the king, Henry VII. He sailed across the North Atlantic, discovered Newfoundland and traveled into Hudson Bay, which he thought was the beginning of a northwest passage around the Americas to the Orient. But, his men revolted at traveling further, and he returned home. At least, that’s the story he supposedly told of his voyage. But, there is no contemporary record of that voyage, and all the evidence that we have for it are the statements of those who heard it from Sebastian. On the strength of his tales, Sebastian Cabot was named Master Mariner by the King of Spain and given the authority to oversee all future voyages of discovery from Spain to the New World [5].

Though we have no confirmatory knowledge of his 1508 voyage, we know from contemporary critics that he was a blowhard and told different versions of the voyage to different people. We know that he led one Spanish expedition to South America in 1526, which he botched through his inept seamanship and his provocative treatment of the Indians, who ambushed and killed most of his men.

Fortunately, the Sebastian Cabots of science are few, but they are there, publishing data from experiments that were never run, displaying doctored photographs to “prove” their conjectures, and describing in painstaking detail the results of observations on pairs of twins who never existed.

At one time, the most a scientist gained from his or her studies was prestige. And, there were still some who falsified data to get that prestige. But, since the end of World War II, science has become a more lucrative “business.” A successful scientist can expect to have her or his work supported by the government or by grants from private foundations. The lure of money and prestige sometimes proves
too much for a less than honest scientist. How can you know when data have been cooked or falsified? Section IV of this book shows how statistical methods have been used to identify the liars.

So, after all of this, how far is it from the Earth to the Sun? Current estimates put the length of an AU at 92,955,807 miles. The estimate of the Cavendish committee was off by only 4%—not bad for an eighteenth-century committee that had to overcome the “black dot” problem to find the correct answer without the aid of modern statistical methods.

1.4 SUMMARY

In the eighteenth century, the Royal Society of London collected observations from adventurers who went to different places in the world in order to time the transit of Venus across the Sun, which occurred in 1761 and 1769. A committee was formed to examine these reports and use them to determine the distance from the Earth to the Sun. In the process, they had to contend with small uncertainties that resulted from the inability to determine the exact time of transit. These are called “errors” in modern statistical terms. One of the adventurers apparently did not determine his longitude correctly. In statistics, this is called a “blunder.” One of the adventurers had been caught lying before. This raises the problem of detecting falsified data.

REFERENCES

For a method of estimating the Astronomical Unit from the transit times of Venus


For the history of the transit of Venus expeditions, 1761, 1769


For the story of Sebastian Cabot