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Trippensee® Planetariums

Worlds in Motion

Teaching Manual for SOL-100 and SOL-300

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Function of Science

We are so accustomed to thinking of the earth and the universe in our kind of scientific ideas that any other form seems childish and even unintelligent. But transport yourself backward in time some 2,000 years ago and place yourself in someone else's scientific shoes. How childish would it then seem to imagine the earth as flat and floating in a great sea of water? How childish would it then seem to picture the stars as fixed on a big sphere and rotating about the earth? Would you have been ashamed 2,000 years ago to admit you did not understand the motions of the planets or how they differed from the stars on the inside of the celestial sphere? When you put yourself in another time you are amazed at how **much** they knew rather than how **little.**

As you study the story of science, you will probably be impressed with the number of times our explanations of things and their behavior have changed in a few short centuries. You will find people believing the truth one century, denying it the next, and then **rediscovering** it a century later. Before you criticize science harshly for this behavior, remember that **one of the basic functions of science is to replace old theories with new.** Sometimes the new theories are not correct, but the fact that we are free to develop new theories means that we will sooner or later arrive at that position which is most true.

Geocentric Universe of the Greeks

One of the longest lasting explanations of the earth and universe was developed by Claudius Ptolemy who studied in Alexandria, Egypt between 85 A.D. and 165 A.D. Ptolemy developed an explanation for the motions that man saw about him everywhere in his wonderful universe. This explanation was honored as truth for 1,200 years and was called the "Ptolemaic System."

The Earth is Round

The first thing Ptolemy explained was the earth itself. Ptolemy, like other scientists before him, used eclipses to help determine the shape of the earth. He theorized that if the earth were really flat, a popular notion of his day, then an eclipse ought to be seen by all the people of the earth at the same time. Since the records clearly indicated that this was not so, Ptolemy claimed the earth to be spherical or round in shape.

The Geocentric Earth

At the same time, however, Ptolemy was committing an error in reasoning that was to prove a difficult hurdle for scientists who would follow. He placed the earth at the center of the universe (a geocentric system) and had everything revolve about it. The earth, according to ptolemy, had no local motion; it neither rotated on an axis nor revolved around the sun. This method of proof was simple observation. If the earth were not stationary in space, birds would be left behind in their flight and rockets would fall sideways rather than down.

Ptolemy knew that during the course of one night the planets moved westward; but, as prior observers had noticed, during the course of a week, these planets moved eastward as measured against a background of fixed stars. Fascinated with "motor" explanations, he pictured a motor rotating the celestial sphere once every 24 hours. The planet motion was eastward about the earth according to this "motor" theory, because it was geared slower than the machinery operating the celestial sphere.

Ptolemy theorized that Mercury and Venus were inferior planets lying between the earth and sun. Since neither Mercury nor Venus can ever be seen far from the position of the sun, a maximum of 48° for Venus, it was assumed by Ptolemy that the earth, Mercury, Venus, and the sun were all connected by some central axis. Two thousand years ago this was the most logical explanation available.

Observations had taught men another interesting fact about the planets and their motions as viewed against a "fixed" background of stars. Although the motion of the planets was generally eastward, there were

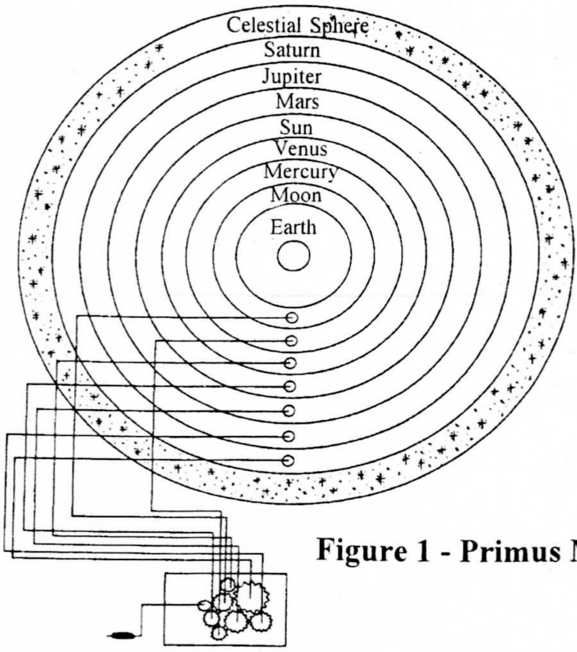

Figure 1 - Primus Mobile

Figure 1 - **Primus Mobile.** Ptolemaic idea of the known universe showing the machine relations of objects in motion. Notice that the earth is the only body not controlled by gears and motion arms.

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Fig 2

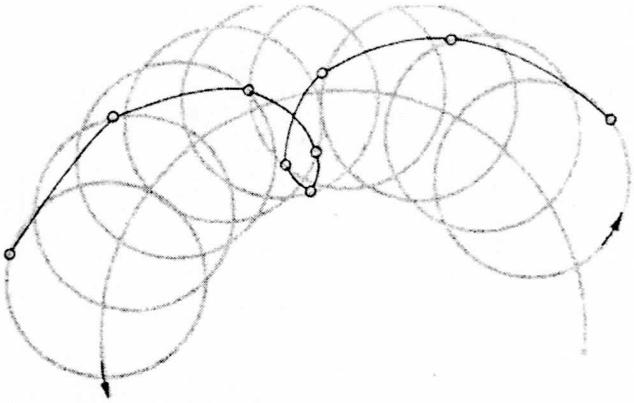

Figure 2 - **Deferents and Epicycles.** The large circle on which the planet revolves is called the deferent. Also to be seen here are the smaller circles or epicycles that Ptolemy used to describe retrograde motion and the dimming and brightening of the planet's light.

many occasions when the planets, particularly Jupiter and Saturn, moved backward or westward among the stars. This regression of the planets presented a real challenge to Ptolemy, who, in designing a machine to explain the motions of things in space, had to take every motion into consideration.

Deferents and Epicycles

According to the final diagrams of the universal machine, the moon, the interior planets, the sun and the stars had single circular rails on which to revolve about the earth. These circular rails were called **deferents.** The **retrograde** (regression or westward motion of the outer or superior planets) could only be explained by building a series of smaller circles on the deferents. These smaller circles were called **epicycles**. Each epicycle contained two objects: the planet seen in the evening sky and another unseen point called the **fictitious planet.**

When the real planet Mars, Jupiter, or Saturn moved to the top of the epicycle, its eastward motion quickened. When the real planet moved inside the deferent, the bottom of the epicycle, the planet slowed down its visible motion and appeared to move westward (in retrograde motion) as viewed from the earth.

Not only did the construction of deferents and epicycles solve the problem of the motion of the planets, it also provided the solution for another observed phenomenon as well. It has been observed that planets changed in brightness as they were observed over a period of time. The Ptolemaic theory explained this by saying that when the planet was at the top of the epicycle, outside the deferent, it was further from the earth and consequently its brilliance would be diminished. On the other hand, when the planet reached its bottom position on the epicycle, it would be closer to the earth and consequently appear to be brighter.

Perhaps you can now see why the work of Claudius Ptolemy enjoyed such long-lasting popularity. Each step in his theory accounted perfectly, or almost so, for every motion that many could observe in the morning and evening sky. It is understandable also that when Ptolemy's book, Mathematical Systems of Astronomy, was translated by the Arabs, it was referred to as the Almagest, or the great system. The fact that Arab astronomers added cogs and wheels to the Ptolemaic machine, eventually winding up with over eighty circles to explain the motions of their universe, does not detract from the simple fact that his position in scientific history, the work he produced to explained observed phenomena of the sky, was the greatest.

Fig 3

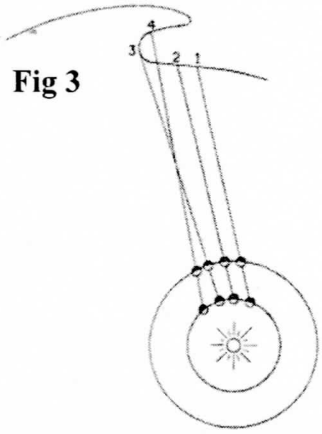

Figure 3 - **Path of Jupiter in Retrograde.** This shows four observational sightings of Jupiter as made by someone on earth. Position 3 shows the beginning of the retrograde. It is more pronounced in position 4 as the earth has moved farther in its orbit around the sun. This is a typical retrograde motion of a superior planet as observed on an inferior planet.

Copernicus

At the beginning of the 16th century, a Polish astronomer named Nikalaus Kopernik (Copernicus) published a book called De Revolionibus Orbium Coelestium. The book revolutionized the world of science in that it assumed just the opposite position that had been taken by Ptolemy. Instead of placing the earth at the center of the universe and allowing everything to move about it Copernicus placed the sun at the center and allowed the earth and the other five known planets to revolve about it. The introduction of this new theory moved us from a geocentric system - **earth centered** - to a heliocentric system - **sun-centered.**

It is easy to forget the battles fought in order to accept this theory as fact. People objected to the Copernican theory on the grounds that is was antireligious. Many felt it was against religion to allow the earth to orbit about the sun. Still others refused to accept the new theory because they could not understand how such great speed could keep from tearing the earth to pieces.

The new theory did not answer all the observed facts, however. If the planets really moved in a circle about the sun, their observed speeds should be constant at all times as measured against a background of stars. Simple observation proved that this was not so. There were times when the planets appeared to speed up in their courses and other times when they slowed.

The first visible support for the basic theory of Copernicus came from Italy in 1609. An astronomer named Galileo Galilei was using a telescope for the first time when, in scanning the planet Jupiter, he discovered four bright objects revolving about it. These he correctly assumed to be moons, and since they obviously were going about Jupiter rather than the earth, it proved to him that the earth was not, as Ptolemy had said, the center of everything.

Tycho Brahe

Tycho Brahe, a Danish nobleman interested in astronomy since the age of 14, believed that at least some of the planets revolved around the sun, particularly the inferior planets of Mercury and Venus. He knew that if Venus and Mercury revolved as Copernicus said then they ought to show phases like the moon. Since they did not appear to do so, his findings did not change the scientific thinking of his time. Although Brahe believed these planets revolved around the sun, he still believed the sun in turn went around the earth.

Galileo, Telescope Maker

In 1610-1611 Galileo Galilei, while studying the planet Venus through his telescope, discovered that the planet did go through phases like the moon. These phases go unnoticed to the naked eye, but in they are distinguished through the telescope.

Johannes Kepler, Astronomer/ Mathematician

The final work in establishing the current view of the solar system was done by Johannes Kepler, a student of Brahe's. In 1609, at the age of 45, after many years of research and experiments, Kepler published the **first two laws of planetary motion**. These laws not only established Copernicus' heliocentric system as fact but also provided answers to questions that troubled people about their observations of sky and space.

Kepler's First Law

The first law describes the shape of the orbital path of a planet about the sun. Instead of a circle, Kepler substituted an ellipse. He found that planets described this kind of path with the sun acting as one of the foci of the ellipse.

Kepler's Second Law

The second law is often referred to as the law of equal areas. As Kepler stated, "The radius vector of each planet passes over equal areas in equal intervals of time."

As seen in *Figure 5*, a planet will sometimes be closer to the sun than at other times. When it is closer, or **perihelion**, it will travel faster thereby covering a short but wide part of the ellipse. When the planet is farthest from the sun, or **aphelion**, it will move more slowly. Our own planet earth, for example, travels at 18.3 miles per second at aphelion and 18.9 miles per second at perihelion. Although this does not seem to be a great difference when expressed this way, a little arithmetic will show you that our earth is actually travelling over 2,000 miles per hour faster when we are closer to the sun than it is when we are farthest from it. If you think of the two shaded areas as being pieces of pie, you will see that both are exactly equal in the amount of pie they contain. This is in keeping with Kepler's second law of equal areas.

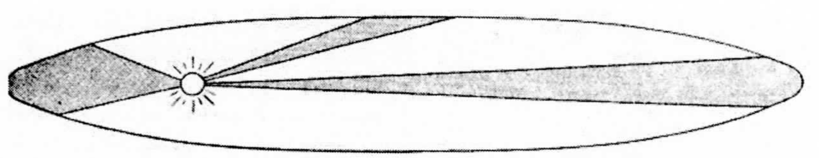

Figure 5 - Kepler's First and Second Laws. The solid line represents a highly exaggerated ellipse (Kepler's first law). The shaded sections represent the area swept out by a planet in an equal amount of time (Kepler's second law). Both aphelion and perihelion positions represent an equal area. Only the shapes of the shaded areas are decidedly different as the angle converges on the sun at one focus of the eclipse.

Kepler's Third Law

Kepler's third law was published several years after the first two. It is called the **harmonic** law and is usually expressed mathematically as:

$$A1^3 : A2^3 :: P1^2 : P2^2 \quad \text{or}$$

$$\frac{p^2}{p^2} = \frac{R^3}{r^3}$$

Expressed in words, the square of the time of a planet's revolution is proportional to the cube of its average distance from the sun. Expressed as symbols, letters **A** or **R** equal the average distance from the sun, with **A** and **R** standing for *area* and *radius* respectively. The letter **P** in both instances stands for the *period* or time of the planet's revolution.

The third law is an important formula because it means that, by knowing only the radius of one planet, we can calculate the orbital radius of every other planet. It also enables us to understand how rapidly a particular planet moves in its orbit.

Not only did these laws answer the question about variation of speed in the planet motion about the sun, they also answered the old problem of retrograde motion in a simple and logical fashion. The epicycles of Ptolemy were no longer needed. Since the earth moves faster than Mars, Jupiter, or Saturn, our rapid motion would make them appear to move backward even though their real course remained unchanged. When you pass a slower vehicle on a highway, there is a point in passing when the slower vehicle seems to stand still, then move backward, and then, after the faster vehicle is going the opposite way, the other object seems to be moving unusually fast.

The planets

From the very beginning of time man had known of the existence of five planets other than his own earth. He had watched their motions, and he had ascribed to them the power of the gods that ruled over him his daily life. Even as late as the 17th century, when the telescope was invented and when Kepler published his 3 famous laws of motion, these 6 objects (including the earth), represented the limits of man's solar system.

Uranus

In the year 1781 an English astronomer and telescope builder named *William Herschel* added to our knowledge of the solar system by discovering the seventh planet - the first one to be discovered in historical times. He promptly named the planet Georgium Sidus in honor of King George III of England.

Later, the planet was to be re-named *Uranus* by *Bode* of the Berlin Observatory.

"Bode's Law"

The astronomer Bode is remembered principally because in 1772 he had published a "law" relating to planet positions within the solar system. In actuality Bode did not discover it, nor is it a law. It is an exercise in arithmetic that happens to apply with some degree of accuracy.

If you take a series of numbers: 0, 3, 6, 12, 24 etc. and add 4 to each number and divide by 10, you arrive at a fairly good approximation as to the location of the planets measured in astronomical units or AU's. One astronomical unit equals 92,956,000 miles, the mean distance from the earth to the sun.

The system works well in theory until the planet Mars, where Bode's "law" suggests another planet should exist between Mars and Jupiter. Since none exists, many scientists doubt the usefulness of these figures.

If you carry the figures out to the correct place, Pluto's distance should be 77.2 AU's from the sun. Since this is clearly in error, the figures for Neptune are usually ascribed to Pluto as shown in the *Table 1*.

Table 1

Bodes' Law		Actual	
Mercury	0.4	Mercury	0.39
Venus	0.7	Venus	0.72
Earth	1.0	Earth	1.00
Mars	1.6	Mars	1.52
Asteroids	2.8	Asteroids	2.8
Jupiter	5.2	Jupiter	5.20
Saturn	10.0	Saturn	9.54
Uranus	19.6	Uranus	19.19
Neptune	--	Neptune	30.07
Pluto	38.8	Pluto	39.46

Asteroids

On the first day of the 19th century the Sicilian astronomer Piazzi noticed something unusual at the distance of Bode's unknown planet. He thought he had discovered the mystery planet and named it Ceres after the mother goddess of Sicily. Later observations proved Ceres was not a planet but a minor planetoid with a diameter of some 480 miles. In the years following, so many thousands of these fragments were found that astronomers engaged in space research consider them to be nuisance objects.

Neptune

The eighth planet of the solar system was predicted before it was found. You have seen how astronomers predict the paths planets will follow and the speed at which they move. Suppose you were able to predict the path and velocity of a planet only to find it did not act as expected. Either your facts were wrong or there were additional facts not taken into consideration.

Astronomers observing the path of Uranus were disappointed with their predictions. Before 1822 the planet moved faster than expected, while after 1822 it seemed to slow. Rather than scrap the work of Kepler and Newton, scientists began looking for an undiscovered force that would explain Uranus' behavior. This outside force on another object is called **perturbation.**

Two mathematicians - Adams, an Englishman and Leverrier, a Frenchman -began to work on the problem independently. Both came to the conclusion that there must be another planet, as yet undiscovered, disturbing the path of Uranus. Adams had difficulty getting an astronomer to verify his prediction. Leverrier met with better luck, and in 1846 the German astronomer, Galle, discovered Neptune almost exactly where Leverrier had predicted it would be.

Fig. 6

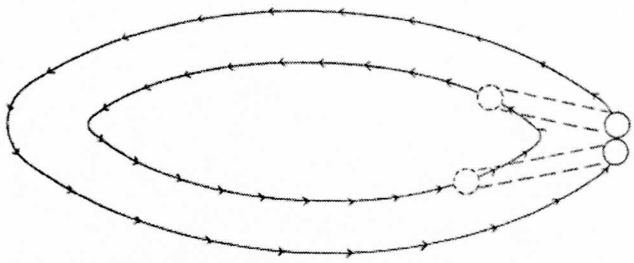

Figure 6 - **Perturbation.** The inner planet in order represents the planet Uranus. The outer planet represents Neptune. The dash lines between the inner and outer orbits show lines of force existing before 1822 and after 1822.

Pluto

Lowell questioned whether Uranus' great perturbation was caused by a planet Neptune's size. In the early 1900's, he and his associates at the Flagstaff Observatory began an intensive search for planet X.

About 25 years later, Clyde Tombough, a young astronomer, came across a suspicious object in photographs taken of the stars in the constellation of Gemini. The announcement of the discovery was made on March 13, 1930, the day of Lowell's birthday celebration.

A contest conducted to select the name for the new planet was won by an 11-year-old English girl. "Pluto" combines Lowell's initials with the name of the ancient god of eternal darkness. A good choice for a planet that lies some 3,664 million miles from its source of light and heat!

Morning/ Evening "Stars"

We know much about the planets and how people over centuries developed the idea of the solar or sun system. The struggle for truth was not an easy one. The story of the science of astronomy shows that "common sense" based on simple observations is not always considered truth.

One of the most easily misunderstood observations involves the planets and their relationships with the earth and sun. There was a time, not many centuries ago, when man believed he could see more planets in the evening sky than there actually are. For example, when the Greeks saw the planet Mercury in the sky before the sun rose in the morning, they called it "Apollo". Likewise, the planet Venus was called "Phosphorus" in the early morning sky but "Hesperus" in the evening sky.

Why? How can the same planet be seen in both morning and evening?

Imagine you are out of doors and facing directly south with a great hoop running over your head from due south to due north. This line, called your **local meridian,** will be helpful in the study of astronomy. Since you are imagining it above you, consider it an **upper meridian.**

Now imagine your hoop passes underneath you all the way around the earth. This line is your **lower meridian.** (This kind of scientific thinking helps explain such concepts as time and planet positions).

Now imagine that we can hold the earth stationary, thereby keeping the sun on your noon line (local meridian). In addition, allow the two inferior planets, Mercury and Venus, to follow their natural course and see what positions they might assume.

Fig 7 - Planetary Data Chart

	Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune	Pluto
Astrological Symbol	☿	♀	⊕	♂	♃	♄	♅	♆	♇
Distance from sun in AU's	0.387	.723	1.000	1.524	5.203	9.55	19.191	30.071	39.457
Distance from sun million miles	36	67	93	142	483	886	1,783	2,794	3,664
Revolution period of planet	88d	225d	365d	687d	11.86d	29.46y	84.02y	164.8y	284.4y
Rotation period of	59+5d	243	23h56m	24h37m	9h50m	10h14m	10h49m	15h40m	?
Diameter in miles	3,008	7,600	7,918	4,215	865,800	71,500	29,400	28,000	?
Mass in terms of earth's mass	0.053	0.815	1.0	0.107	318.0	95.2	14.3	17.6	?
Density in terms of water	5.3	5.0	5.5	4.0	1.3	0.7	1.6	2.3	?
Inclination to ecliptic plane	7°.0	3°.4	0°.0	1°.8	1°.3	2°.5	0°.8	1°.8	17°.1
Termperature	+640°F -450°F	800°F	var	var	-220°F	-243°F	-300°F	-330°F	-348°F

Superior and Inferior Conjunction

When either Mercury or Venus is directly between you and the sun, the planet is at a position of **inferior conjunction.** When it has reached its furthest angle from the sun, it is at **greatest elongation.** This is particularly important with tiny Mercury which is seen only when it has reached its greatest eastern or western elongation, some point between the 18° and 28° maximum positions. Note also that either of the two inferior planets may stand on your meridian line if that line is extended from the sun to the earth. When a planet is in a straight line with, but on the other side of, the sun from you, it is at **superior conjunction.**

Those planets that lie beyond the earth in our solar system can never, of course, assume a position of **inferior conjunction.** They can, and often do, however, assume positions of **superior conjunction.**

The outer or superior planets can assume other positions in the solar system which the inferior members of the solar family cannot assume.

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Fig 8

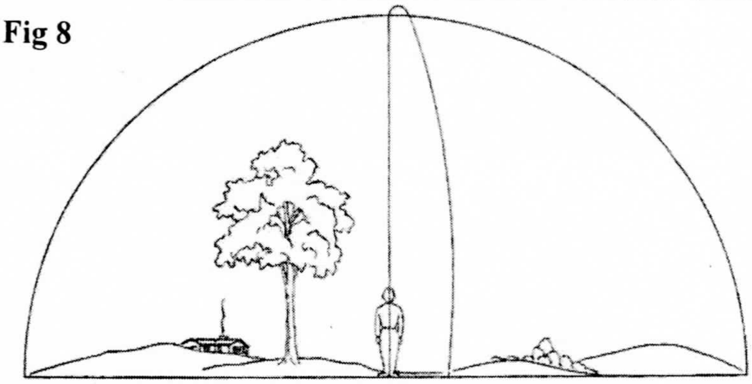

Figure 8 - Meridian Lines. The upper meridian line is indicated. The lower meridian line is not indicated, but it extends below the observer and connects to the two ends of the upper meridian line.

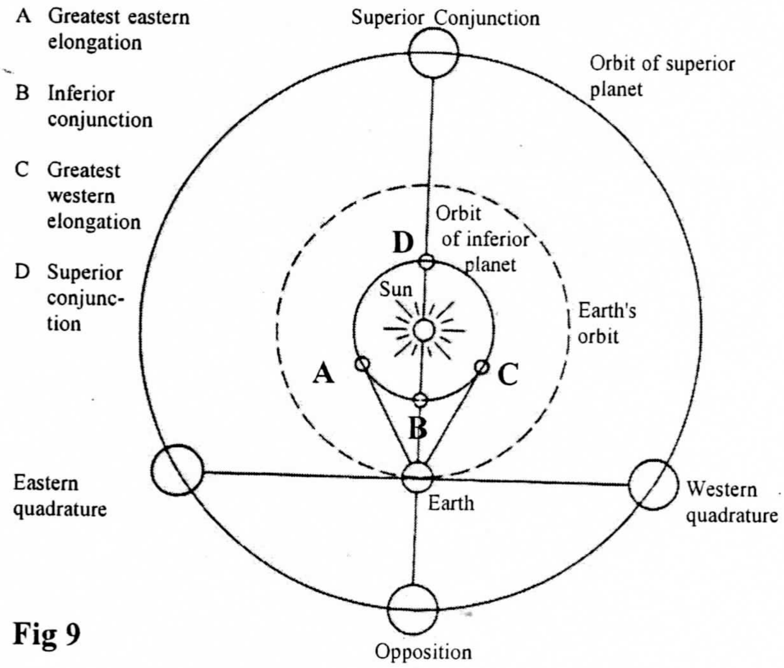

Fig 9

Figure 9 - **Conjunction and Quadrature.** This diagram illustrates the astronomical terms used to describe the relative locations of the planets with respect to the earth.

Quadrature

Notice that in this drawing three new positions have been added. The position left of the earth is called **eastern quadrature** and the position to the right is **western quadrature.** A superior planet may, as you can see by this diagram, stand behind the earth on the line drawn from the earth through the sun. This places the planet on the lower meridian at midnight, a point referred to in astronomy as **opposition.**

If you know that a planet is at either superior or inferior conjunction, you will know you cannot see it because it will be in the middle of the sky at the same time as the sun. If, on the other hand, a planet is said to be in opposition, you will need to look for it at midnight if you wish to see it on your imaginary meridian line.

Assume you read in the paper that Mercury has reached its greatest eastern angle of elongation. You know automatically that you will look for it in the western sky shortly after sunset.

Since a planet that is at conjunction is on our meridian at noon, and one that is at opposition is on our meridian at midnight, and since quadrature represents a halfway point between these two extremes, it is logical to assume that quadrature point represents a six o'clock position. Whether a planet that is at quadrature is a 6 AM or 6 PM planet depends once again on which side of the sun it is located.

Trippensee® Solar System Models

Science First® produces 2 hand-operated Trippensee® planetarium models specifically designed for school use. They are characterized by simple design, easy maintenance, attractiveness and ability to withstand years of hard use.

The **SOL-100 Copernican System** Model is a hand operated model of the complete solar system with the heliocentric (sun-centered) design of Copernicus.

The **SOL-300 Ptolemaic System** Model is a hand operated model of the geocentric solar system described by Ptolemy and others. Besides its historical use, it serves as a convenient model for demonstrating the movements of planets, the sun and the moon. It serves as a constant reminder of what these heavenly bodies look like when viewed with the unaided human eye. After all, without a telescope, Saturn has no rings and appears to be similar to Jupiter and Venus in size and color.

Why use models?

Models have always been a successful device used by scientists and engineers to understand and explain many complex or difficult ideas, concepts, or theories. The Trippensee® solar system models can be used in this manner.

These models allow you to "see" and "feel" what the solar system looks like and appears to look like. Many people have trouble comprehending spacial relations. Without such models, they would be lost trying to visualize the physical relationships between the planets and the sun and the various motions of the planets.

Scale of the Solar System

A. For this class activity, a compass and highway map are needed. Locate the site of your school or some other landmark. By setting the compass point on this site, the planetary orbits can be drawn to scale. The scale of miles is given somewhere on the highway maps.

- The **sun** globe would be 600 feet in diameter;
- **Mercury** - 2 feet in diameter, 4-3/4 miles away;
- **Venus** - 5-1/3 feet in diameter, 9 miles away;
- **Earth** - 5-1/2 feet in diameter, 12-1/4 miles away;
- **Mars** - 3 feet in diameter, 18-1/2 miles away;
- **Asteroids** - tiny globes ranging from under a millimeter to three inches in diameter, an average distance of 30 miles;
- **Jupiter** - 60 feet in diameter, 64 miles away;
- **Saturn** - 52 feet in diameter, 117 miles away;
- **Uranus** - 20 feet in diameter, 234 miles away;
- **Neptune** - 19 feet in diameter, 367 miles away;
- **Pluto** - 2-1/2 feet in diameter, 485 miles away;

B. The following scale would be in proportion to the 6" sun globe on the Trippensee® Copernican Solar System Model SOL-100.

- **Mercury** - 7 yards away;
- **Venus** - 13 yards away;
- **Earth** - 18 yards away;
- **Mars** - 27 yards away;

Note that none of these planets would be larger than a pin head.

- The orbit of the asteroids would be 50 yards away and they would be too small to see on this scale.
- The great planets Jupiter, Saturn, Uranus and Neptune are the size of small peas and are 93, 171, 344, and 539 yards away, respectively.
- Pluto is a speck of silver 707 yards away.

Since it is not practical to build a model the length of 7 football fields, models such as this are useful for the classroom.

C. For a solar system model suitable for a classroom, the following scale may be used:

- **Mercury** - 5" from a point which we will call the sun
- **Venus** - 8-1/2" from the sun
- **Earth** - 12" from the sun
- **Mars** - 18" from the sun
- **Asteroids** - 2'9" to 2'10" from the sun
- **Jupiter** - 5 feet from the sun
- **Saturn** - 9-1/2 feet from the sun
- **Uranus** - 19 feet from the sun
- **Neptune** - 30 feet from the sun
- **Pluto** - 40 feet from the sun

It would be impossible to see most of the planets on the same scale if you were to look at them from across the room.

- You may use your own scale for making a series of circles which can be taped to the wall in the above orbits. Use the data in this book to make an appropriate scale.

Trippensee® Copernican System

This is a highly simplified model of the solar system as we know it. Not only does it demonstrate the knowledge gathered by pioneers such as Galileo, it also clearly demonstrates much of the knowledge gathered in the first half of the 20th century.

As we have already seen, the planets of our solar system travel about the sun in ellipses rather than circles. The eccentricity of an ellipse - approximately 3,000,000 miles in the case of our own earth - may sound tremendously large when we speak of a planet orbit, but to a space voyager far enough away to see all the planets at once, the earth would appear to move in a circle about its star. When you use a model of the solar system to explain motions and relationships, you must adopt a space-eye view. When the orbits are reduced to correspond with this point of view, the ellipses will appear as circles.

At the same time there is a problem with the plane of the planetary orbits. Any model, unless specially complex, will show all planets moving in the same plane. Actually this is not the case - the orbital planes of all the planets except Pluto and some asteroids lie within 7° of the ecliptic. Remember, however, that the Copernican model examines the entire solar system at once and therefore even large distances seem relatively small. For all practical purposes, the earth and its sister planets appear to be moving along a completely flat plane.

Trippensee® Ptolemaic System

This model is designed to demonstrate the basic concepts of the solar system as described by Ptolemy.

Since Ptolemy was convinced that the earth occupied the center of all things, the model has been constructed so that the earth no only occupies a central position in the model but also dominates the other bodies by being larger than all the others, including the sun. Even this representation, however, is not as extreme as the ideal held by Heraclitus of Ephesus, about 500 B.C., who believed the sun to be only one foot wide and recreated new every morning.

The constellations of the Zodiac can be traced back as far as the written history of man himself. Although the ancients had no understanding of such complex terms as "obliquity of the ecliptic", and although they were completely unaware that the polar axis of their own planet was inclined at 23-1/2° to the perpendicular of its own plane, they were aware of the sun's rise and fall against a fixed background of stars. The Ptolemaic model has been designed so that the earthbound observer might be able to see how this seasonal phenomenon occurs.

You will also notice that the deferent arms holding Mercury, Venus and the sun are held together by a slip ring. This grouping represents the central axis that Ptolemy believed connected the two inferior planets to the sun. Because of space

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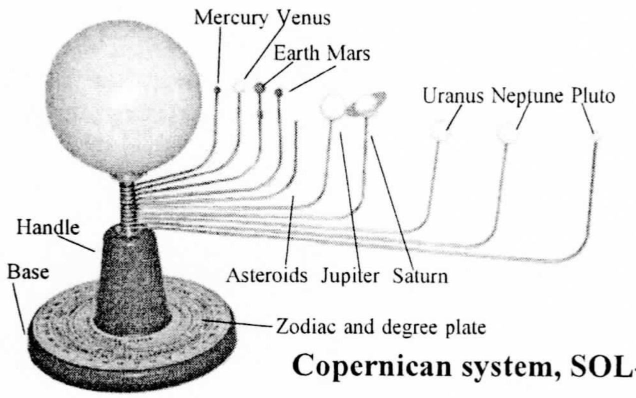
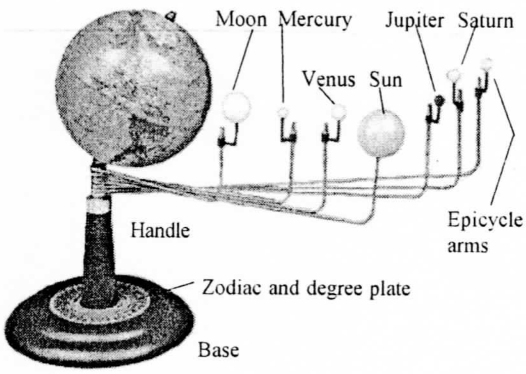


Copernican system, SOL-100

Ptolemaic system, SOL-300

This unique model dramatically demonstrates the planetary motions involving deferents and epicycles described by Ptolemy. It explains **apparent** motions of the planets more clearly than the Copernican Model.



limitations, the epicycles are not as large as Ptolemy conceived them to be, but they do allow you to demonstrate the particular planetary motion that appears to be only a swinging motion between us and the sun.

Again there is a problem with the plane of planetary orbits as indicated by the moon in this model. The moon is usually much higher (or lower) than the plane of the ecliptic and does not cause one solar eclipse and one lunar every lunar month.

Since the sun is continually on the ecliptic, and since the moon crosses the ecliptic twice a month, it would appear that we might expect one solar and one lunar eclipse every month. The fact that keeps this from occurring at this frequency is that ours is a solar system in constant motion. Both sun and moon must be close to a node, a crossing of the equator, at the same time. A **solar eclipse** always occurs if the sun is within less than 15°21' of a node at the line of the new moon, and a **lunar eclipse** always occurs if the moon is less than 9°31' of a node at the time of full moon. The actual maximum number of eclipses which can occur in one year is seven. This would include four solar and three lunar or five solar and two lunar eclipses.

Reading the Zodiac Plates

When attempting to read the location of a planet in space, the actual reading is done on the **ecliptic.** The ecliptic is an imaginary line drawn through the background of stars. This imaginary line is generated by the sun as the earth moves about it.

There are two view points to be considered. In the heliocentric (Copernican) models the planet locations are given on the ecliptic as viewed from the sun. Even though their speed may vary a little, the planets move regularly through the sky (Appendix I). The date is read under the earth wire arm. The sign of the Zodiac in which the sun is rising and setting is 180° away from the calendar date, that is, the sign is where the sun appears on the ecliptic as viewed from the earth.

The constellations of the Zodiac no longer appear where the signs of the Zodiac are, because of their precession. The Zodiac signs are used on the Zodiac plates as they were originally set up over 2,000 years ago. The signs of the Zodiac are points on the ecliptic, not the location of the constellations of the same name.

(Hold the Copernican model in one hand and move the earth about the sun. Note that when viewed from the morning earth, the sun appears to move on a line about the room. This line is called the ecliptic.)

The data for locating the planets on the Copernican model is given in Appendix I and III. Follow the movement of all the planets for a year or two to see how the planets move.

The Trippensee® Ptolemaic System is much easier to read, as only one view point, that of the earth, need be considered. All data is read under the appropriate wire arm. Notice that the sun's location on the ecliptic, the sign of the Zodiac, and the date are all read under the sun's wire arm.

Remember, **real** planetary locations are the sun's view on a Copernican (heliocentric) system. **Apparent** planetary motions are an earth observer's view (geocentric) as on the Trippensee® Ptolemaic system model.

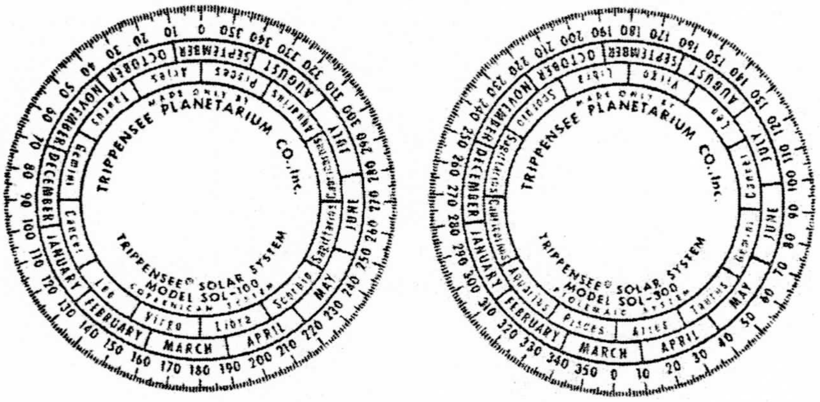
Care of your Trippensee® Solar System Models

Our models are designed to give many years of trouble-free service. However, any mechanical device can eventually give difficulty in operation.

If the stainless steel wire arms become difficult to move, a light application of machine oil should enable them to move much easier.

The models are designed to be held in one hand and the wire arms moved with the other hand. If the handle wants to turn when the wires are moved, then the nut at the bottom should be tightened so that the handle does not move while the wire arms are being moved.

Fig 10



Zodiac and degree plane of SOL-100 Zodiac and degree plane of SOL-300

Fig 11

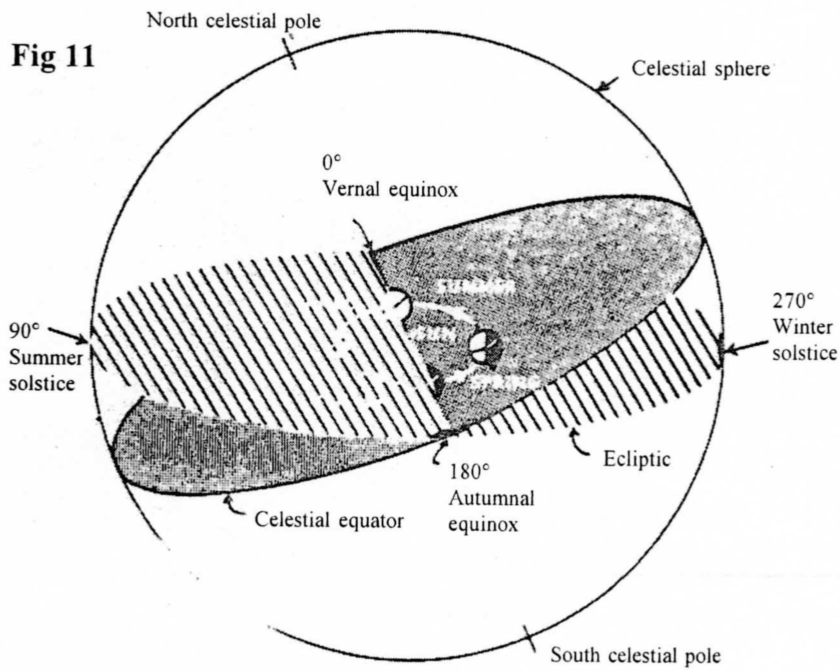


Figure 11 - Ecliptic and celestial equator with degrees. The earth revolves around the sun in an orbit which is almost circular. The path the sun appears to follow through the background of "fixed" stars during one revolution is called the ecliptic. It is represented as a great circle located on the celestial sphere. The earth's equator projected out to the celestial sphere becomes a great circle called the celestial sphere. The points of intersection of the ecliptic and celestial equator are called the vernal and autumnal equinoxes located on 0° and 218° respectively. The location in space of the planets is determined from the degree markings of the ecliptic.

If the wires become loose on the steel standard, the nut which holds them may be tightened. There is a wave washer between the top washer and the nut which supplies the tension for keeping the stainless steel wire arms taut. If this nut should work loose, it is a simple matter to tighten it down again.

The plastic balls are fused to the stainless steel wire arms. If any should be lost, they can be replaced. The ring of Saturn is also available. When inquiring about replacement balls, refer to part numbers and pricing are list on page 12 - **Remember that on the Copernican system the wire for the asteroid orbit contains no ball.**

How to use SOL-100 and SOL-300 solar system models

These models will help explain many complex concepts related to the motion of planetary bodies. They allow you to control time, since it will be you who will move the planets a predetermined distance in their orbits about the sun. You will also be able to demonstrate eclipses, changing seasons of the earth, retrograde motion, planetary changes in the sky outdoors, and problems of motion that confront our scientists as they prepare to visit our interesting neighbors in the solar system.

a. Planetary Locations

Information regarding the location in the sky of any of the planets can be obtained from The American Ephemeris and Nautical Almanac. The data for the planetary motions is given as the "Heliocentric Position for 0^h Ephemeris Time" and the locations are given in **degrees of longitude,** which correspond to the degrees on the Zodiac plate for Trippensee® Copernican system model SOL-100. This information has been summarized in *Appendix I.*

When using the Ptolemaic system, the above data does not apply. Remember that the Ptolemaic system **does not show** real motions and real locations but **apparent** motions and locations. These planetary locations are also found in The American Ephemeris and Nautical Almanac under the date for each planet titled "O^h Ephemeris Time" under the column **Apparent Right Ascension;** this data can be given in eight degrees or hours. The person using The Ephemeris to determine Apparent Right Ascension will find the translation of time into degrees considerably simplified by using the table, also included in The Ephemeris, under the heading "Conversion of Time to Arc."

By comparing the revolution period of each planet (note the planetary tables in *Table II*, below), we can make mathematical comparisons of the earth's motion to that of other planets. In other words, one complete revolution of the earth equals 4.1 revolutions of Mercury, 1.6 revolutions of Venus, 0.53 revolutions of Mars etc.

Arbitrarily select a six-month period in which to show the relative motion of each of the planets. If you are using the Copernican model, you will move the earth arm so that its reading becomes 0° instead of the original 180°. The same concept may be emphasized by using the Ptolemaic Model by moving the sun arm rather than the earth arm.

The only planet to complete a total revolution during a six-month period is Mercury. It will complete slightly more than two revolutions. Be certain that Mercury, as well as the other planets, is moved in a counterclockwise direction around the sun (as viewed from the top of the model).

Correct settings for the planets can be made for any date, past or future, by consulting The American Ephemeris and Nautical Almanac. The settings are listed under the longitude column of heliocentric positions.

b. Morning and Evening Star Demonstrations

Whenever an inferior planet appears to the west of the sun (when looking at the sun from the earth), it will appear as a "morning star", unless it is obscured by the sun. From the Earth, the only inferior planets are Venus and Mercury. An inferior planet is seen as an evening star when it is in the east. The evening stars appear shortly after the sun sets and generally remain visible for 2 or 3 hours.

Both evening and morning stars can be demonstrated on all the Trippensee® solar system models. Just set Venus or Mercury west of the earth when looking a the sun or set them to the east so they may appear as evening stars.

The person using the model should review the material included in sections "Morning and Evening Stars" and "Superior and Inferior Conjunction." This information will permit the planets to be set to any desired position corresponding to earth observations of day or night. These observations of earth-planet-sun relationships should clear up any misunderstanding as to how the same planet can, on different occasions, appear to be both morning and evening objects.

c. Planes of the celestial Equator and Ecliptic

The ecliptic is a circle generated by the apparent motions of the sun as it moves through the sky during the course of the year. All the planets appear to move within 7° of this generated circle. Consequently, all the references to planetary motion are made from the ecliptic. Since any circle can form planes, we can use this plane as a reference guide throughout the entire universe.

The equator of the earth is a circle and can be projected in space to create the celestial equator. The position of the stars in the sky is usually calculated along this imaginary line. In the spring, when the sun first starts to cross one of the two intersections of these planes, the first day of spring occurs. Similarly, when the sun recrosses the intersection in September, the autumnal equinox occurs.

Since most people prefer to measure positions in space with a system common to both distance and time, they refer to an equatorial system - that system that uses the earth's equator extended into space. In this way, it is possible to divide the circle into 24 hours with each hour having 60 minutes and each minute 60 seconds. Degrees are easily converted into hours by dividing the degrees by the number 15.

Table II- Positions of planets on equinoxes in 2002

Position of Planets on March 21, 2002

Planet	Longitude	Distance/AU Sun
Mercury	304.8°	0.43
Venus	38.8°	0.72
Earth	180°	1.0
Mars	70.3°	1.52
Jupiter	107.0°	5.20
Saturn	75.2°	9.05
Uranus	326.0°	20.00
Neptune	308.0°	30.15
Pluto	246.6°	30.11

Position of Planets on September 22, 2002

Planet	Longitude	Distance/AU Sun
Mercury	344.7°	0.37
Venus	336.7°	0.73
Earth	0°	1.0
Mars	156.8°	1.67
Jupiter	122.3°	5.27
Saturn	82.1°	9.03
Uranus	328.0°	20.02
Neptune	309.1°	30.15
Pluto	247.7°	30.15

d. The Selection of Zodiacal Signs

It is well known that the constellations of the Zodiac do not appear where they once did thousands of years ago. In fact, the constellations of the Zodiac have moved eastward about 30° in the last 2,000 years. In *Figure 11*, the ecliptic is shown divided into 360°. One-twelfth of

360° is 30°. About 2,000 years ago, the constellation Aries was found in that part of the sky, which is indicated on the ecliptic from 0° to 30°.

The constellation Taurus was found in the space from 30° to 60°. Gemini, Cancer, Leo, Virgo, Libra, Scorpio, Sagittarius, Capricornus, Aquarius and Pisces follow at 30° intervals. These areas represent regions of space which today are called the signs of the Zodiac. The constellation Aries is no longer found between 0° - 30° but occupies a space approximately 30° - 60°. Likewise, all other constellations have moved about 30° in the last 2,000 years. Since this is all very confusing and can easily lead to errors, it is much simpler to refer to a location along the plane of the ecliptic in degrees. These are called **celestial longitude.**

e. The Asteroid Orbit

The SOL-100 has a stainless steel wire arm to indicate the orbits of the vast majority of the asteroids. Many thousands of these tiny rocks revolve around the earth between Mars and Jupiter. The wire arm is used to indicate their orbit, rather than trying to show each individually.

The asteroids or planetoids were discovered on January 1, 1801 by the Sicilian astronomer, Piazzi. The object he discovered was the largest of the asteroids - Ceres, a single piece of solar system material with a diameter of 480 miles.

Since then, thousands of these objects have been discovered on astronomical photographs. Obviously, these pieces of material do not occupy a single position within the solar system as the planets do. Rather, they are spread somewhat uniformly around the sun. The wire arm indicates the orbit of these pieces of material rather than to try to show each of them individually.

As shown by the model, the orbit of these minor planets lies between Mars and Jupiter. Mars would probably have little effect on the grouping of the asteroids since Mars is only about half the size of the earth, but scientists theorize that the great gravitational pull of Jupiter may alter the arrangements of the asteroids, leaving gaps in the belt itself. These probably empty areas are called **Kirkwood gaps.**

f. Eclipses

Both Ptolemaic and Copernican models explain why lunar and solar eclipses occur. The complete solar eclipse is more easily observed with the Ptolemaic than with the Copernican because of the moon's position in the orrery. By placing the moon directly between the sun and earth, you can see how the light from the sun can be obscured by the moon as it moves between us and the sun. The same effect can be achieved with the Copernican system by substituting the planet Venus for the moon.

g. Retrograde Motion

This backward motion of some of the planets was discussed earlier and illustrated in *Figure 3.* Since retrograde motion is only an apparent motion, not a real one, it can be best illustrated on the Ptolemaic System.

Ptolemy's concept of the epicycle was so successful simply because he did not know, and could not know, that he had confused the real and apparent motion of the planets.

h. Motions of the Moon

A simple yet difficult concept to explain is how the moon manages to rotate and revolve and yet keeps the same side facing the earth at all times. Astronomers tell us that both motions take place in exactly the same amount of time, and yet, only the moon's revolution about our planet is obvious. The Ptolemaic model is constructed so that the moon can be rotated about a center axis. This rotation is helpful in making this astronomical principle understood.

Mark the side of the moon facing the earth lightly with colored chalk. Ask students to form a ring around the model to observe it. Since the students are outside the model, this means they are no longer earthbound. They can watch the moon's motion as if they were half million miles away.

Move the moon slowly around the earth, being careful to keep the chalked side toward the earth.

Give the students the opportunity to discuss how much of the moon's surface they have seen. Each student, after one complete revolution, will have seen the entire surface of the moon. This raises the interesting question as to how much of the moon people on earth could expect to see if it **did not** rotate on its axis.

Repeat the experiment with the moon held stationary on its support arm. Students watching the demonstration will easily understand that if the moon **did not** rotate at the same rate it revolved, we would be able to see all of its surface during the course of one lunar month.

Observations of the motion of the noon line will allow you to understand why it is afternoon in New York while people in California have just finished breakfast. Since evening would also come earlier for those on the east coast than for those on the west coast, students in Florida could be studying evening stars and planets while astronomers in Seattle could be counting sunspot numbers.

j. When to use Copernican and Ptolemaic systems

The Trippensee® Copernican system is used to show the solar system as it really is. The heliocentric view shows the **real** positions and motions of the planets as viewed from the sun. Data is given in *Appendix I.*

People do not, however, view the planets, moon and stars from the sun.

We are on the third planet - quite different. When locating a heavenly object in the sky, we need to know its **apparent** location and motion. Which brings us back to Ptolemy.

The Ptolemaic system illustrates the apparent motions better than the heliocentric models.

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k. Demonstration of planetary nomenclature

While this model has many advantages, chief among them is the fact that it lends itself to an almost infinite number of planetary configurations. You can see for yourself what astronomical terms mean as they apply to our solar system. Once the model has been set for the correct date, you can also determine what planets we will find in the evening sky and what planets we will not be able to see at all because of sunlight.

Photographs of the Copernican model can illustrate several distinct planetary positions. The student should learn to recognize these positions easily. [The figure below shows the heliocentric view of planets, sun and moon on - what date]. When viewed from the earth, Mars is near superior conjunction. Jupiter and Venus at eastern quadrature, Saturn and Uranus at western quadrature, and Neptune and Pluto have just been in opposition.

i. The sun and time of day

We know the sun is no fiery chariot crossing the sky behind invisible horses. These myths of sky and space have been dead for centuries. There are even those who realize that the rotation of our planet causes the sun to appear to move westward at approximately 15° per hour. But how many understand the simple but important role the rotation of the earth plays in ordering our lives through a process called **time?**

The Ptolemaic model is designed so that rotation of the earth can be demonstrated. The student can learn how time is measured by establishing a line relationship between the earth and the sun. This relationship can be shown by holding a pencil or piece of wire stationary against the sun. Then, very slowly, rotate the earth counterclockwise on its axis. The pencil or wire represents the most direct rays of the sun as they fall on the earth; that is, they represent the noon line.

A class project could include a wraparound mural, about one foot high, on which various constellations of stars are painted. By placing this around the solar system, you can show planetary position. You can also demonstrate in what constellation a particular planet is found.

Once a constellation mural has been created to be used in conjunction with the Trippensee® solar system models, it will be possible to combine the many demonstrations with observational astronomy in which all students can participate.

Select a conspicuous planet or planets. Arrange the planets of the model so that they appear to stand in front of the appropriate constellation. Over a period of several weeks, observe the planets and chart any changes. These changes can then be made on the solar system model.

If the charted motion of the planet is eastward, you will know that you are following the real counterclockwise motion of the planets about the sun. If, on the other hand, the planet seems to be moving westward, you will know that you are observing a planet in retrograde. This observation can be used to review and reinforce the material covered in this booklet.

k. Demonstration of seasons

Everyone in the north temperate zone has experienced cold, blustery winters and hot, sticky summers. Obviously the sun does not increase and decrease its heat to mesh with the dates on our calendar. To understand the reasons for the seasons, we must look to a world in motion.

Ptolemy had no idea that the world was not perpendicular to the almost flat plane in which the planets move. Modern astronomy, however, shows that the polar axis of the earth's equator is inclined 23-1/2° to the plane of the ecliptic. This simple fact is the reason for our seasons.

You will notice that in the fall and spring the light of the sun falls equally on the northern and southern hemispheres. In the northern hemisphere's winter, the sunlight is falling more directly on the southern hemisphere, and in the northern hemisphere's summer, the sunlight falls more directly on the northern hemisphere and less directly on the southern hemisphere.

The Copernican model of the solar system shows the earth's polar axis clearly. By revolving the earth slowly about the sun, the change of seasons due to the difference in the angle of the sunlight falling on the earth can be easily understood. Stop at either polar extreme or at either equinox period in order to demonstrate the changes taking place.

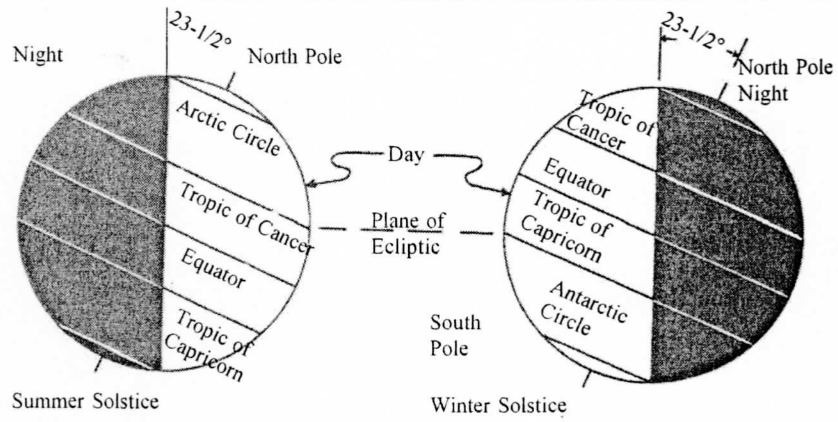

Figure 12 - **Seasonal Changes.** As the earth orbits about the sun, it is lighted evenly. The angle of the polar axis of the earth provides us with days of various lengths and thus with our temperature extremes.

Glossary

Albedo - The percentage of light reflected from the planet

Apparent motion - Any motion not based on real causes.

Aphelion - The point of an object's orbit farthest from the sun.

Antarctic circle - An imaginary circle 23.5° north of the south pole.

Arctic circle - An imaginary circle 23.5° south of the north pole.

Area - Used to describe a specified amount of distance within a determined plane.

Asteroids - "Star like", name applied to the minor planets.

A.U. - Astronomical unit, a distance of 92,956 miles.

Autumnal equinox - Point where the sun crosses below the celestial equator.

Axis - A real or imaginary straight line relationship.

Celestial equator - The equator of the earth extended to infinity.

Celestial longitude - An imaginary line perpendicular to the ecliptic.

Celestial pole - Imaginary north-south axis of earth extended into space.

Coma - The gaseous envelope of the nucleus in a comet.

Conjunction, inferior - Between earth and sun on direct axis.

Conjunction, superior - Opposite the sun on an earth-sun axis.

Constellations - Imaginary figures composed of stars.

Copernican - Adjective indicating influence of Nikalaus Kopernik.

Corona - Crown halo of the sun.

Deferent - Major circle of revolution in the Ptolemaic planetary system.

Eclipse - A complete or partial blockage of light, applied to sun or moon.

Ellipse - The path of a point that moves so that the sum of its distances from two fixed points is constant.

Elongation - The distance of a planet from the sun measured in degrees.

Epicycle - Circles designed by Ptolemy to explain planetary motions.

Foci - Two fixed points used in determining an ellipse.

Geocentric - Earth centered.

Heliocentric - Sun centered, as a solar system.

Hour angles of right ascension - Perpendicular measurement from the celestial equator.

Hyperbola - A curve formed by the section of a cone cut by a plane that makes a greater angle with the base than the side of the cone makes.

Inferior - Term applied to Venus and Mercury, lying between earth and sun.

Kirkwood gaps - Possible vacancies in the asteroid belt due to the gravitational attraction of Jupiter.

Meridian, lower - An imaginary north-south line running below the observer on the other side of the earth.

Meridian, upper - An imaginary north-south line running above the observer and bisecting the sky into two parts.

Oblateness - A polar flatness more pronounced with rapidly rotating objects.

Orbit - The path of any object around a primary object.

Parabola - Curve formed by the intersection of a cone with a plane parallel.

Perihelion - Point of an object closest to the sun.

Period - The time taken to complete any cyclical action.

Perturbation - An irregularity in the motion or orbit of a heavenly body.

Phases - Stages of variation in illumination.

Planetoids - Planet like; name given to small objects between Mars and Jupiter.

Ptolemaic - The adjective applied to the ideas of Claudius Ptolemy.

Quadrature - The relative position of two heavenly bodies when 90° distant from each other.

Regression - Movement backward, westward with the planets.

Retrograde - Movement backward.

Revolution - The movement of an object around another body.

Rotation - The turning of an object on a central axis.

Spherical - Globular in shape.

Solstice, summer - The position when the sun appears to reach its highest position.

Solstice, winter - The position when the sun appears to reach its lowest position.

Superior - Term used to designate objects farther from the sun than the earth.

Transit - The passage of any object across any given meridian.

Tropic of Cancer - Position 23-1/2° north latitude.

Tropic of Capricorn - Position 23-1/2° south latitude.

Velocity - Rate of motion in a particular direction.

Vernal equinox - The position where the sun makes its upward passage across the celestial equator.

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Appendix I

Average daily, monthly, yearly planetary motions
Heliocentric System

Planet	Average Daily Motion	Average Monthly Motion	Average Yearly Motion
Mercury	4.1°	123°	4 revolutions + 36°
Venus	1.6°	43°	1 revolution + 216°
Earth	1.0°	30°	360°
Mars	0.53°	15.8°	190°
Jupiter		2.5°	30.1°
Saturn		1.0°	12.2°
Uranus		0.4°	4.3°
Neptune			2.2°
Pluto			1.45°

SOL-300	**Parts List, Ptolemaic Solar System***	
017838	Earth Wire	
006625	Earth Globe	
001130	Base	
033252	Zodiac	
017955	Moon Wire	
017920	Mars Wire	
017985	Jupiter Wire	
017900	Saturn Wire	
033112	Jupiter Ball	
033112	Saturn Ball	*Same as Jupiter*
033112	Venus Ball	*Same as Jupiter*
000362	Mars Ball	
015325	Sun Ball	
000387	Mercury Ball	
000410	Moon Ball	
017840	Epicycle Casting	
011950	Nylon Retainer, pair *For epicycle casting, set of 2*	
033862	Mercury, Venus, Sun wire together	

* Big earth, small planets

SOL-100	**Parts List, Copernican Solar System**
000355	Mercury Ball
000382	Venus Ball
000352	Earth Ball
000362	Mars Ball
000410	Jupiter Ball
032154	Saturn Ball
033112	Uranus/Neptune Ball
000387	Pluto/ Moon Ball
017975	Pluto Wire
017970	Neptune Wire
017995	Uranus Wire
017985	Saturn Wire
017940	Jupiter Wire
017930	Asteroid Wire
017945	Mars Wire
017935	Earth Wire
018000	Venus Wire
017855	Mercury Wire
033254	Zodiac
017854	Main Shaft
001130	Base
017205	Wire Guide
033850	Sun Globe ass'y

Appendix II

SOL-100 Ephemeris 2003-2010
Planetary Heliocentric Longitude as of January 1 (Degrees)

Planet	2003	2004	2005	2006	2007	2008	2009	2010
Mercury	50.9	125.7	193.5	236.7	269.3	308.5	11.3	84.8
Venus	138.3	2.4	230.2	93.7	318.8	184.3	49.3	275.3
Earth	100.8	100.5	101.3	101.0	100.7	100.5	101.2	101.0
Jupiter	130.5	159.1	186.8	214.2	242.3	271.5	302.3	334.4
Saturn	85.8	99.4	113.0	126.4	139.7	152.8	165.7	178.3
Uranus	329.1	333.0	336.9	340.8	344.7	348.6	352.5	356.4
Neptune	309.7	311.9	314.1	316.3	318.5	320.7	322.8	325.0
Pluto	248.3	250.4	252.6	254.7	256.8	258.9	261.1	263.2

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