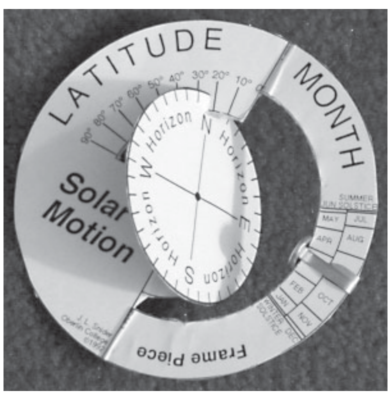
Solar Motion Demonstrator

From paper, glue, and a brass fastener you can build a remarkably powerful device which accurately models the apparent motion of the Sun, any time of year, from any place in the northern hemisphere of Earth. It's a simple, direct way to learn the pattern of the changing solar rising and setting points—just what the builders of Stonehenge, according to Gerald Hawkins, wanted to mark. You can go far beyond Stonehenge, however, and see how the Sun moves as seen from the Equator, the North Pole, or your own hometown.

Materials

- Solar Motion Frame and Horizon Disk cutout sheets (photocopy masters on page 32 and 33)
- Photocopy paper or heavy card stock sufficient for providing each student with one Solar Motion Frame and one Horizon Disk (using blue paper for the frame and green for the disk makes an attractive product)
- One long (1 inch) brass paper fastener (the type with spreadable flat prongs) for each student
- Manila file folders (one for every student)
- Rubber cement or glue stick (can be shared by 2 or more students)
- Scissors for every student. (If you will be cutting these out for the students, you may want to use a hobby knife or retractable-blade paper cutter which can cut more accurately)
- Optional: spray rubber cement instead of gluestick (available from art supply stores)
- Optional: newspapers if you are using spray glue, or will be cutting with a hobby knife



Before Class

It takes more time to read these instructions than to make a Solar Motion Demonstrator, so don't let the number of steps put you off.

If you want to save time and the gluing in this section, you can buy very low cost classroom kits, attractively printed on heavy color stock, with one finished device and all materials for 24 students, from:

The Science Source

P. O. Box 727

Waldoboro ME 04572

Phone: 207-832-6344

As you can see from the templates on pages 32 and 33, two pieces are needed for each device: the Solar Motion Frame and the Horizon Disk. These pieces must be mounted on a stiff backing. This can be achieved by gluing the Solar Motion Frame to a double thickness of manila file folder material, and by gluing the Horizon Disk to a single thickness of manila file folder.

As an alternative, you can copy the templates onto heavy card stock. The Solar Motion Frame then needs to be glued to only a single thickness of manila file folder, and the Horizon Disk does not need to be mounted at all.

1. Make enough copies of the Solar Motion Frame page and the Horizon Disk page so that each student will have one frame and one disk. If possible use blue paper. To make an even more attractive model, copy the frames on blue paper (to represent the sky) and the disks on green paper (to represent the Earth).

Note

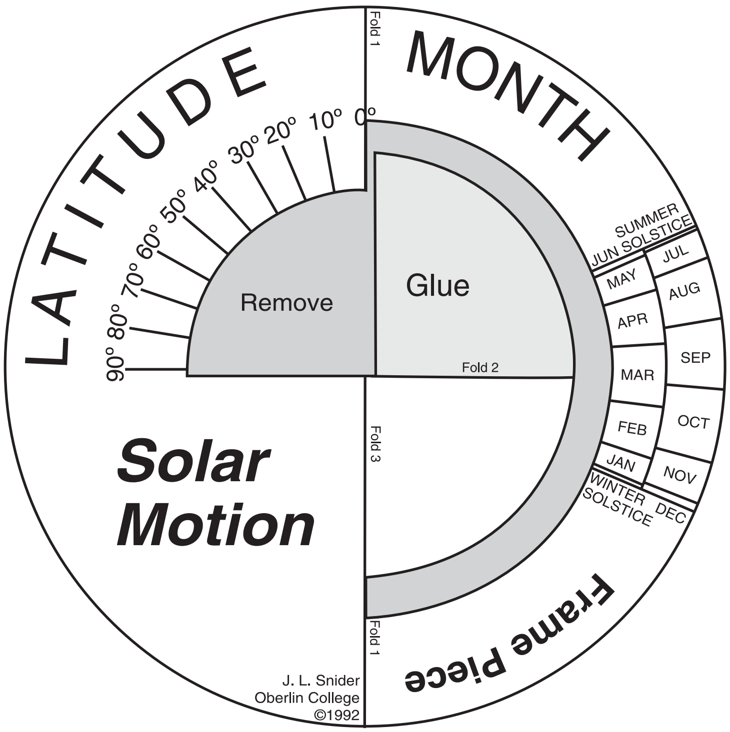
The Solar Motion Demonstrator was designed by Professor Joseph L. Snider of Oberlin College. The design and directions for use are copyrighted by Professor Snider. You may reproduce them as needed for your own classroom or planetarium (but not for commercial purposes).

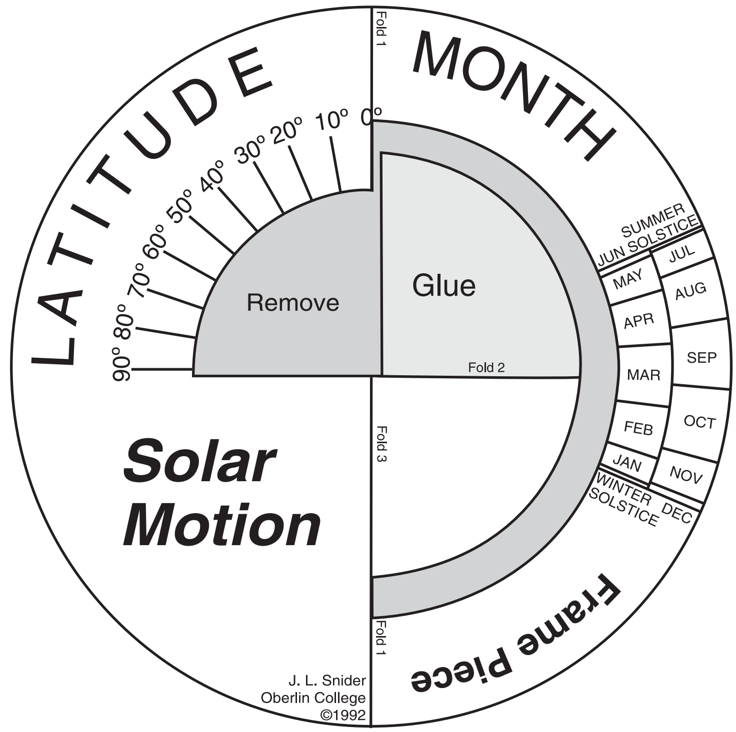
You can do the next three steps yourself to save time in class, or let your students do this themselves.

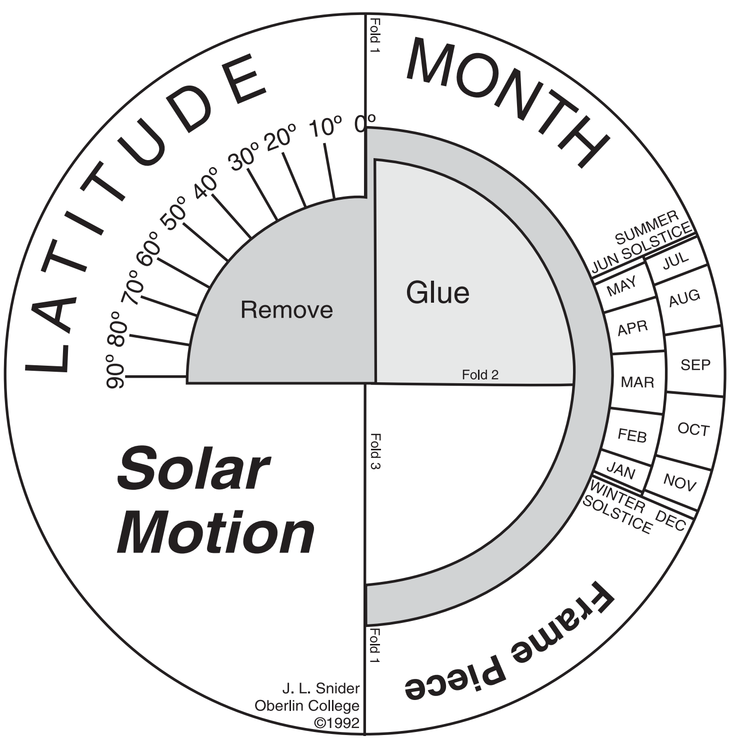
Spray-on rubber cement adhesive, available from art supply stores, is the fastest way to apply glue, but use this in a well-ventilated room, with lots of newspaper under your work to catch the excess spray. Brush-on rubber cement is cheaper but also requires a well-ventilated room. Glue sticks are an inexpensive, non-toxic, alternative.

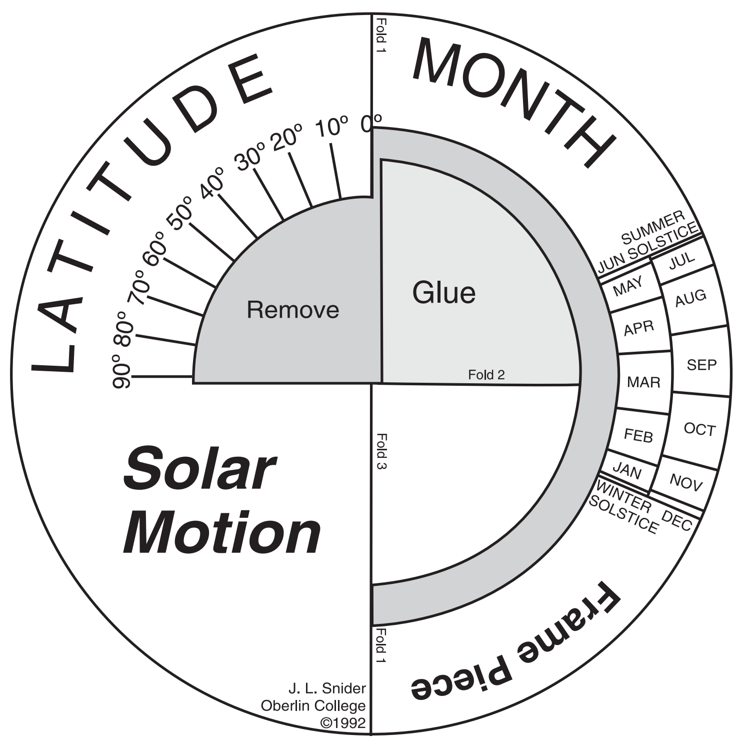
2. Glue the Horizon Disks to a single thickness of manila file folder stock.
3. Glue the Solar Motion Frames to a stiffer backing material, made by gluing two pieces of manila file folder material together.
4. Using scissors or a paper cutter, separate the Solar Motion Frames and the Horizon Disks, so that you can pass out one of each piece to each student. The final trimming and assembly should be done by the students.

Solar Motion Demonstrator Frame Piece: Master for Duplication

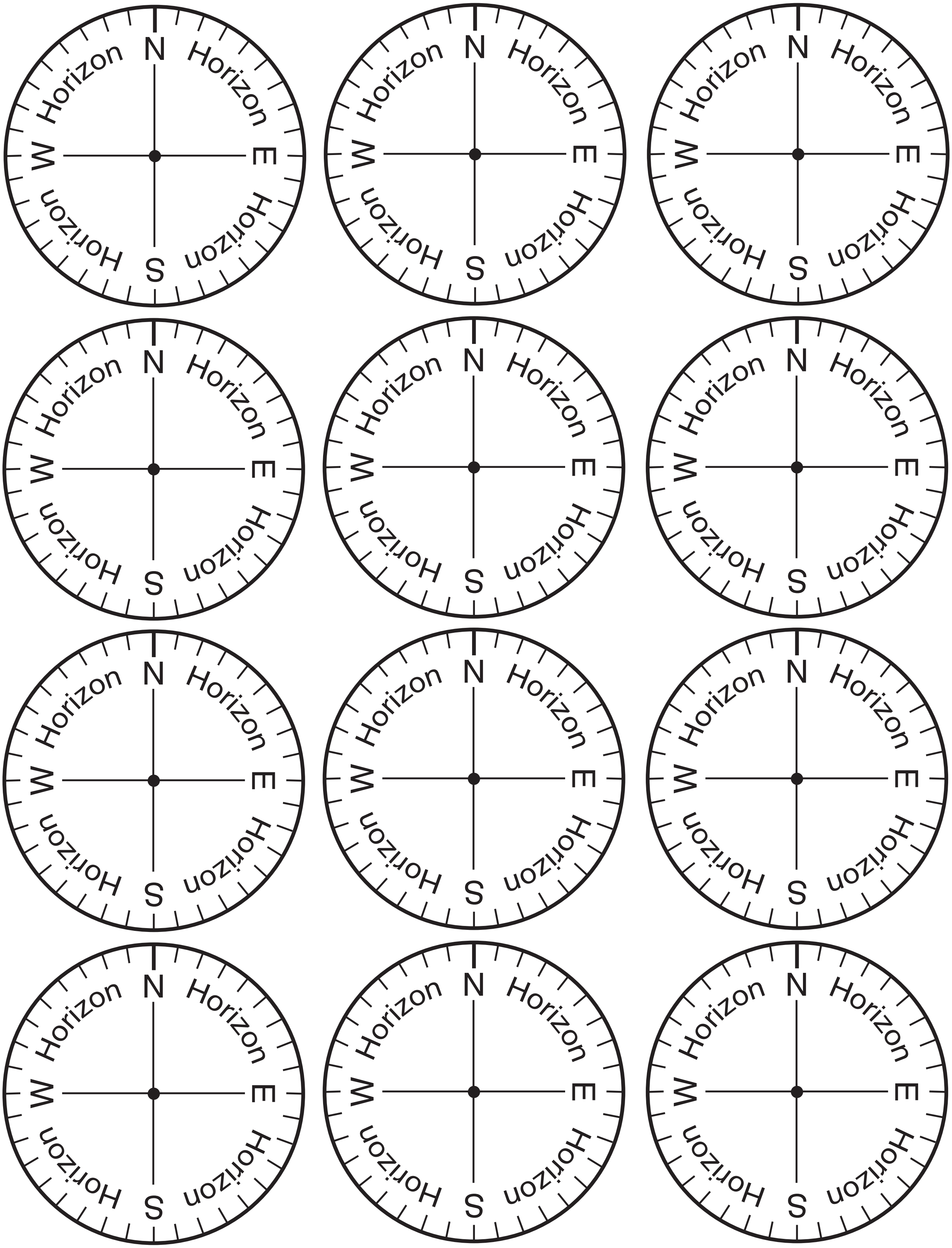








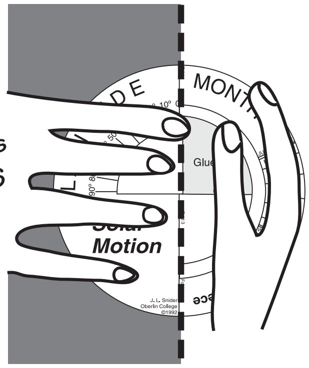
Solar Motion Demonstrator Horizon Piece: Master for Duplication



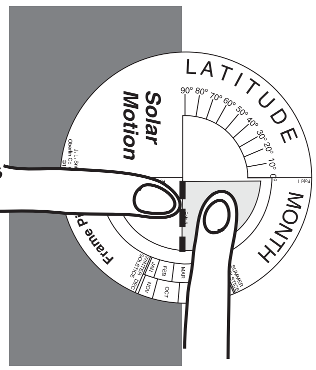
Solar Motion Demonstrator: In Class

Part 1: Making the Solar Motion Demonstrator

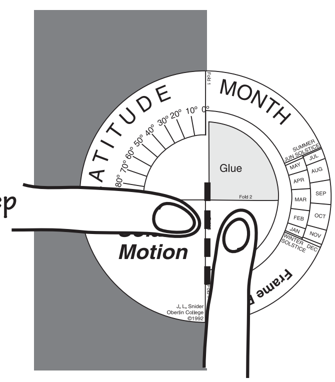
Steps 4 & 6

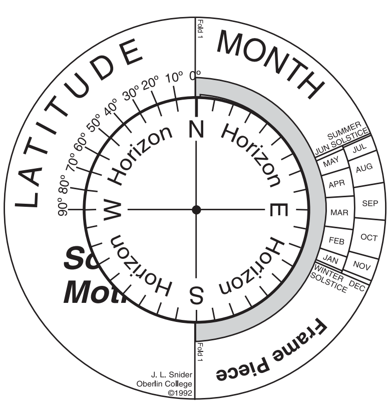


Steps 5 & 7



Step 8





Step 11

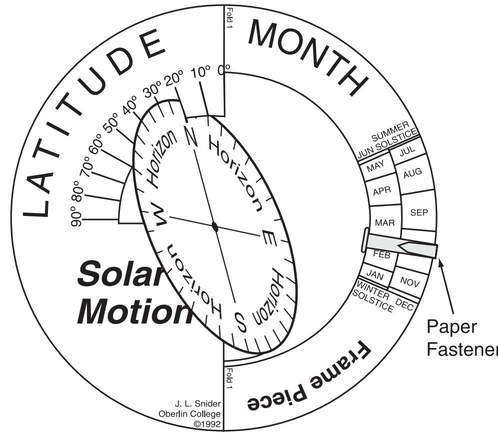
1. You are going to make a remarkable device that accurately models the motion of the Sun as seen from any place in the Northern Hemisphere, at any time of the year.

Give each student a Solar Motion Frame piece and a Horizon Disk piece. Hand out scissors and glue.

Go through each of the steps below, allowing time for each student to finish before moving to the next step.

2. With scissors cut out the Solar Motion Frame along its circular outline.
3. Carefully cut out the portions of the Frame marked “Remove” using scissors, a hobby knife, or paper cutter blade.
4. Crease the frame along a straight line passing through the hinge fold line (Folds 1 & 3: dividing the Frame vertically), by resting it against the sharp edge of a table or counter top. Line the Frame up with the edge of the counter top and rub it with the back of your scissors or other hard object until an indented groove is visible. Turn the Frame over and make an indented groove on the other side as well.
5. Repeat this creasing process for the short fold line (Fold 2) below the “Glue” section of the Frame.
6. Fold the Frame along the creased lines (Fold 1) so that the month half of the Frame swings all the way around to touch the latitude half of it. Repeat, pivoting the month piece in the opposite direction.
7. Fold the flap marked “Glue” (Fold 2) away from you and down as far as it will go, as seen from the printed side of the Frame. Bring it back to its original, flat, position.
8. Fold both the flap marked “Glue” and the quarter-circle below it with no printing on it (Fold 3) away from you as far as they will go, until the backside of the blank quarter-circle hits the backside of the Frame. Bring them back to their original, flat, position.
9. Use scissors to cut out the Horizon Disk along its circular outline.
10. Cut a small slot in the side of the Horizon Disk at the position of North. This slot should not be any wider than the cardboard is thick, and should be approximately 3 mm (1/8 inch) long.
11. Apply rubber cement or glue to the portion of the Frame labelled “Glue.” Press the northeast quadrant of the disk against the glued portion of the Frame. Position the disk so that its north-south line lines up with the frame’s hinges, and the mark for West is positioned over the 90-degree mark on the Frame. Make sure that the outer edges of the disk and Frame are accurately aligned. The correct alignment of Frame and disk is essential to the working of the device.
12. When the glue is dry pivot the disk on its hinge away from you through 90 degrees, and then slip the slot over the latitude scale. Make sure that the plane of the disk is perpendicular to the plane of the Frame.

13. Slip a paper fastener over the piece marked "MONTH," so that the head of the fastener is on the inner edge of the piece. Bend the head so that its plane is perpendicular to the plane of the piece. Bend one of the paper fastener's prongs around the edge of the piece so that its end lies flat against the front of the piece. Bend the other prong around and over the first one, so that its end lies flat on top of the first prong, behind the piece. The paper fastener should fit snugly around the piece, and also be easily moved to cover the appropriate date on the "MONTH" piece.



Your "Solar Motion Demonstrator" is finished!

Part 2: Using Your Solar Motion Demonstrator

How the Solar Motion Demonstrator models the Sun and the Earth:

- The "Horizon Disk" represents a piece of the surface of the Earth. You can imagine a tiny observer (represented by the black dot in the center), able to look out at the horizon in any direction, including North, East, South, and West.
- The round head of the brass paper fastener represents the Sun.
- The swinging "Month" arm of the Frame has two functions. Setting the Sun marker at the desired month adjusts for the time of the year. Swinging it from one side to the other (preferably East to West) moves the Sun in its apparent daily path over the Earth.
- The "Latitude" part of the Frame is used to adjust the Horizon Disk to set the imaginary observer at any latitude from the Equator (0°) to the North Pole (90°).

To use the Solar Motion Demonstrator, pivot the Horizon Disk along the North-South axis so that the right hand side of the disk moves away from you through 90 degrees. Line up the slot in the Horizon Disk with the edge of the Frame where it is labeled "Latitude." Slip the slot in the Horizon Disk over the Frame and align it with the latitude of your location (or one you may be interested in). The Horizon Disk must be perpendicular to the latitude part of the Frame. Next, slide the "Sun" along the outer rim of the Frame to the appropriate month.

The edge of the Horizon Disk represents the visible horizon for some imaginary person standing at the black dot in the center of the disk. To see the path the Sun makes across the sky for that particular latitude and time of year, swing the month portion of the Frame completely from the "East" to the "West" as marked on the Horizon Disk.

Compare the location of the sunrise and sunset at different times of the year. How does the length of day change with the seasons? At what latitude must you be so the Sun does not set on the longest day of the year (the summer solstice)? What would the Sun's motion look like if you lived at the North Pole?

You can answer these and many other questions with your Solar Motion Demonstrator.

Part 3: Activities

1. Where Will the Sun Set?

Hold the device in one hand so that the Horizon Disk is horizontal. Imagine that you are very small and standing at the black dot at the center of the Horizon Disk. It would look like a large open field with a clear horizon all around you. The geographical directions of North, East, South, and West are marked around the horizon. With your other hand, smoothly pivot the piece which carries the paper fastener "Sun." As the head of the paper fastener rises above the plane of the Horizon Disk, it represents sunrise and the beginning of daytime in the imaginary world of the Horizon Disk.

When the head of the paper fastener dips below the plane of the Horizon Disk, it represents sunset and the beginning of nighttime. The perimeter of the Horizon Disk is marked in 10-degree increments. You can read the direction to the point on the horizon where the Sun sets directly from the Horizon Disk.

For example, if you are at 40 degrees north latitude, and it is late June, the Sun will set about 30 degrees to the north of west. Use your device to check this example. If you can, take the device outdoors at sunset. Align the Horizon Disk so that "N" on the disk points toward true North. Keep the Horizon Disk horizontal and raise it to eye level. Sight along the line joining the central black dot and the paper fastener head when it is located at the sunset position. This line should point to the place on the horizon where the Sun will set.

Compare the position of sunset where you live with sunset at Stonehenge (51 degrees north latitude). On a given day, does the Sun set further to the North? South? Is there any day at which the Sun sets at the same place for Stonehenge and for you? (Hint: there are two days of the year when the answer is yes.)

2. How High is High Noon?

As you swing the "Sun" around, it gets higher in the sky above the horizon. This is its "angular height" above the horizon. If you imagine yourself to be at the location of the black dot, facing the Sun, the angular height of the Sun is the angle between your line of sight to a point on the horizon directly beneath the Sun and your line of sight to the Sun. The Sun reaches its greatest angular height at a time halfway between the times of sunrise and sunset; this time is not noon on your clock—it depends on where you are located in your time zone, whether or not you are on daylight savings time, and on details of the Earth's motion around the Sun.

By using your Solar Motion model, you can get a sense of how large this maximum angular height is for various times of the year.

3. Where will the Sun Rise?

Answer this question in the same way that you found where the Sun sets. Try using the device some day at sunrise, sighting across it to check that the Sun actually rises where the device predicts that it will. On any particular day, the Sun will rise just as many degrees north or south of East as it sets north or south of West.

4. Is Daytime as Long as Nighttime?

Pivot the piece carrying the "Sun" at a constant rate over its entire range. This corresponds to one rotation of the Earth, which takes 24 hours. Notice that the Sun lies above the horizon for part of this motion (daytime) and below it for the remainder (nighttime). You can determine the relative lengths of day and night in this way.

5. When are Day and Night Equally Long?

Use the device to show that on two particular days of the year, the Sun rises due East and sets due West for any latitude. Find the two months in which these days occur. These days are called the "spring equinox" and the "fall equinox" and are the only two days of the year when days and nights are of equal duration. The word "equinox" comes from the words meaning "equal night."

Answer:

The two equinox days occur in March and September.

6. When Will the Noon Sun be the Highest or Lowest in the Sky?

Use the Solar Motion device to find the month in which the largest angular height at noon occurs. In which month does the smallest angular height at noon occur? Also, in which month does the longest day of the year occur? In which month is the shortest day of the year?

Answers:

Largest angular height at noon and longest day of the year is in June, at the summer solstice. Smallest angular height at noon and shortest day of the year is in December, the winter solstice.

The word "solstice" comes from the words meaning "Sun stands still." Most of the year the rising and setting positions of the Sun are changing, moving further towards the north or south depending on the seasons. On the solstices, the rising and setting positions stop their motions north and south, and then head back in the opposite direction.

7. Why Does the Earth Have Seasons?

Move the paper fastener "Sun" up to its June position. Pivot the "Sun" and observe the relative lengths of day and night and the maximum angular height of the "Sun." Do the same with the "Sun" moved down to its December position. This demonstrates the two most important factors responsible for the seasons: the period of time over which the Sun's rays strike the ground (the length of day), and the angle at which they strike the ground.

8. Can You Always See a Sunset?

Actually, there are places on Earth where the Sun doesn't set. Explore the range of latitudes and times of year for which the paper fastener "Sun" remains above the Horizon Disk as you pivot it through an entire rotation. This corresponds to a 24-hour day, with the Sun still above the horizon at midnight. The phrase "land of the midnight Sun" is often used to describe the places where this occurs. For an observer anywhere north of the "Arctic Circle" (about $66^1/_2°$ latitude) the Sun will not set on at least one day of the year.

9. When and Where Will the Sun Pass Directly Overhead?

A point in the sky directly over your head is called the zenith. To find out when and where the Sun passes through the zenith, move the "Sun" to a position late in June and pivot it through its daily motion to see if it passes directly overhead (assuming that you are at the location of the black dot at the center of the Horizon Disk). Change the latitude setting of the Horizon Disk until you find a latitude at which the Sun passes through the zenith for an observer at that latitude. Explore the range of latitudes and times of year for which the Sun passes through the zenith.

Answer:

For an observer north of the "Tropic of Cancer" (at about $23^1/_2$ degrees north latitude) the Sun will never pass through the zenith. People who live along the Tropic of Cancer can see the Sun at the zenith only in June at the summer solstice. For lower latitudes than this, the Sun will pass through the zenith on only two days of the year. Can you tell approximately which days these are?

South of the equator, the behavior is similar, but the order of months on the Solar Motion Demonstrator would have to be reversed for southern latitudes. Observers along the Tropic of Capricorn (at $23^1/_2$ degrees South) see the Sun at the zenith only in December on their summer solstice. People South of the Tropic of Capricorn never see the Sun at the zenith.

10. What Path Does the Sun Take at the Equator?

Set the Horizon Disk to a latitude of 0°. Imagine that you are an observer positioned at the black dot at the center of the Horizon Disk. Vary the time of year and see how the path of the Sun across the sky changes.

What can you say about how the rising Sun appears to move in relation to the horizon? Notice that the setting Sun moves in the same way. At what times of year does the Sun pass through the zenith?

Answer:

March and September (the equinoxes).

11. What is the Motion of the Sun for an Observer at the North Pole?

Set the Horizon Disk to a latitude of 90°. Again, imagine that you are positioned at the black dot at the center of the Horizon Disk. Vary the time of year and see how the path of the Sun across the sky changes.

What can you say now about the motion of the Sun in relation to the horizon? Do you see that there will be six months of light and six months of darkness at the North Pole?

12. Would Stonehenge Work if it Were Moved to Your Home Town?

Set the Horizon Disk for the latitude of Stonehenge, 51° north latitude. Write down the rising and setting positions of the Sun for the summer and winter solstices. Now set the Horizon Disk for the latitude where you live. Again record the rising and setting positions of the Sun for the summer and winter solstices.

Unless you live close to the same latitude as Stonehenge, you will find that the rising and setting positions are different. To make a Stonehenge in your hometown, you would have to redesign Stonehenge, changing its symmetry, to make it function as a solstice marker in the way Hawkins suggests.

Ideas for Further Activities

You will be able to think of other ways in which you can use the "Solar Motion" device to increase your understanding of how the Sun appears to move in relation to the earth. Here are three.

1. Imagine yourself standing at the black dot at the center of the Horizon Disk. Try holding the "MONTH" piece fixed in space with your right hand, as you turn the rest of the device through its complete range of motion. As you do this, think of the Sun as being fixed in space, while the Earth's rotation turns you around with respect to the Sun. This is more nearly the situation in real life.
2. Try using the device as a compass. Set the "Solar Motion" model to your latitude and the time of year. Go outside and hold the device so that the Horizon Disk is horizontal. Pivot the "MONTH" piece and at the same time turn the compass piece (keeping its plane horizontal) so that the "N-S" line points in various directions. Your objective is to make the shadow of the "MONTH" piece be as thin a line as possible, while at the same time the shadow of the paper fastener "Sun" falls on the black dot at the center of the Horizon Disk. When you have achieved this, the Horizon Disk will show you the correct geographic directions.
3. Try constructing a giant Solar Motion Model. You can use a photocopier to enlarge the Frame and the Horizon Disk. You might want to mount these on stiffer cardboard, artists' "foamcore" material, or plywood. You may need to make stronger hinges out of cloth, or use metal hinges from a hardware store.