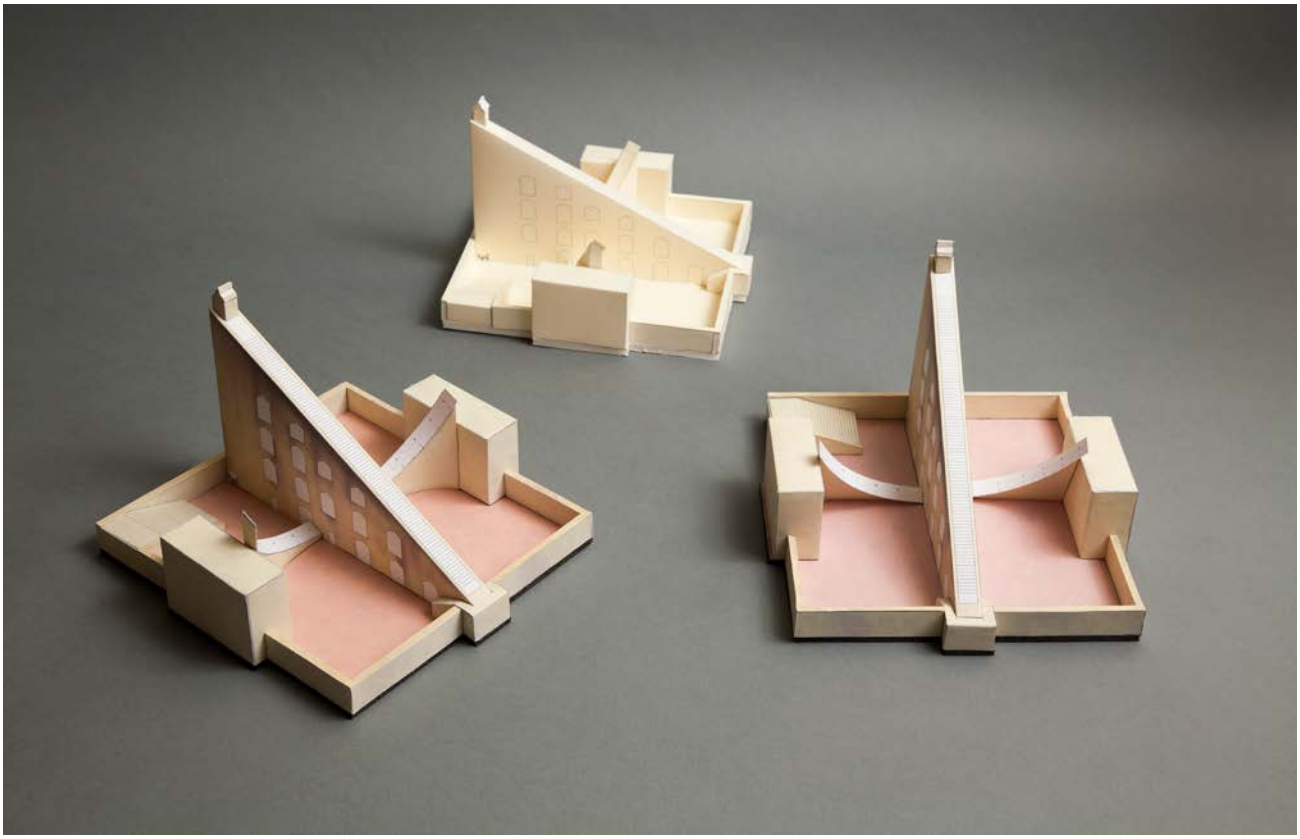


Paper Model of the

Samrat Yantra

Instructions

This instruction set is intended to accompany the Samrat Yantra model PDF from *jantarmantar.org*. The model PDF includes templates for both a simple and advanced version. I recommend starting with the simple version, especially if you have not had much experience crafting objects from paper. The two models are similar in appearance (in the photo above the advanced version is on the left and the simple version on the right). The only difference is that the advanced version has curved supports for the quadrant scales that are closer in form to the original. However, forming the curve correctly and attaching the index surface is quite challenging.

Tools

You will need a **smooth work surface** with a good cutting surface. I strongly recommend the self-healing type of cutting surface available at craft stores.

Ink jet or laser printer to print templates.

Scissors

Sharp craft knife such as an x-acto knife with #11 blade, or break-away blade cutter such as an Olfa. Buy extra blades! The advantage of the Olfa is that you can renew its blade tip frequently. The advantage of the x-acto #11 is that it has a very narrow tip that is good for precise cutting.

Metal ruler or straight edge. A ruler with a non-slip base is a plus, but you can add a strip of masking tape to the bottom of a plain metal ruler to improve its grip.

Pencil

Small wooden stick about 1/8" x 1/4" x 5".

"Bone folder" for scoring the lines to be folded. A traditional "bone folder" is best, but a scoring tool can be improvised from any hard thin object with a blunted edge. I've used a letter opener or even the rounded handle of a small binder clip as a substitute. The edge should be very smooth so it does not tear the paper.

Kneaded eraser. Used for cleaning up excess glue, fingerprints or smudges on the paper surface. This soft type of eraser absorbs stains and does not damage the surface.

Old credit card. Used for pressing and smoothing the paper template when gluing it to the foamcore. Also used as a folding tool to get straight clean folds on smaller parts.

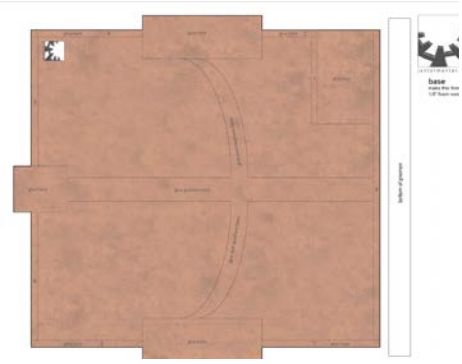
Supplies

White card stock (110 lb.) to print templates – at least 12 sheets of 8.5" x 11"

1/8" foam core board – (4) 8.5" x 11" sheets or the equivalent.

Fast-setting white glue (water base) that dries clear. I use Aleen's "Fast grab" Tacky Glue, but any "tacky" type craft glue should be fine. A fast-setting glue helps the build process to move along at a reasonable pace, as many of the pieces are made with multiple folds and glued joints that must be done one at a time.

Step-by-Step Instructions



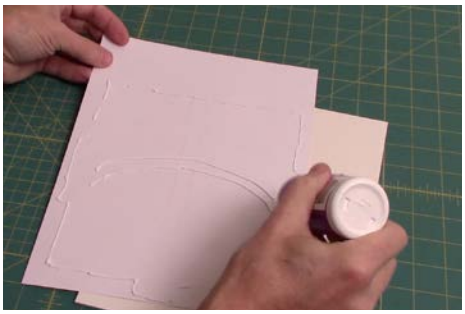
Base

Decide whether to build the simple or advanced version, and glue the appropriate paper base template to a sheet of 1/8" foam core. Follow these steps:

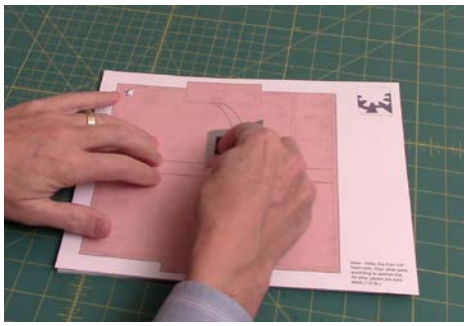
Glue

Hold the template up to the light, and on the back side draw lightly in pencil to trace the outer edge and the lines where the gnomon, quadrants, steps and other parts will be glued.

Apply glue to the back side of the template along these lines and also to a few spots in the areas in-between, so that there will be multiple points of contact to hold the paper flat to the foam core board.



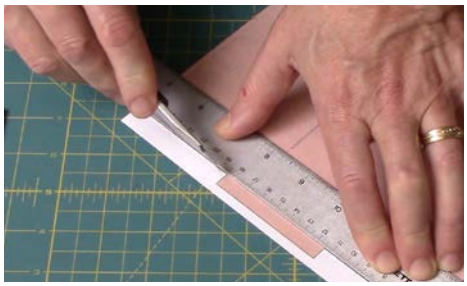
Flip the paper over and carefully place it on an 8.5" x 11" foam core board. Using an old credit card, press the paper into contact with the foam core with gentle strokes beginning from the center and working out towards the edges.



Trim

Cut the base from the glued template.

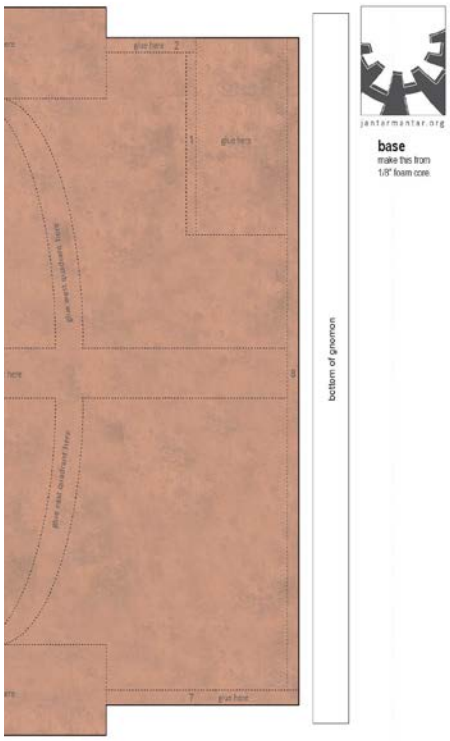
Tips - Whenever possible, place the straightedge so that it covers the printed area. That way, if your knife should drift away from the straightedge, your stray cut will not damage the area used for the model. Also, when cutting the inside corners, or any place where the lines of the model meet at a sharp angle, start the cut from the point where the lines meet and cut away from the model towards the outside of the sheet.



After you have cut the base from the template, you may wish to blacken the edge with a marker to make it cleaner looking. Carefully apply the marker directly to the edge of the foamcore. A 1/8" area along the edge will be covered by the side walls, so don't worry if the marker bleeds or overlaps a little onto the printed area.

Gnomon Bottom

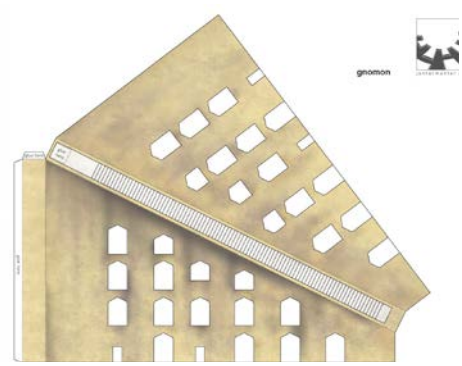
The gnomon bottom is part of the base template and will be used a little later when assembling the gnomon. Cut carefully along the outline to make the gnomon bottom.



Gnomon

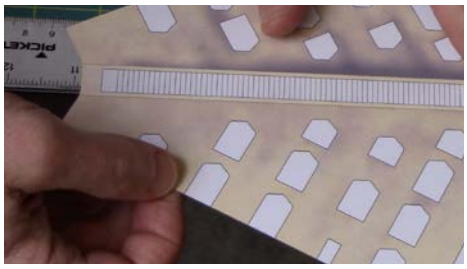
Cut

Carefully cut the gnomon from the printed template using a straightedge and knife.



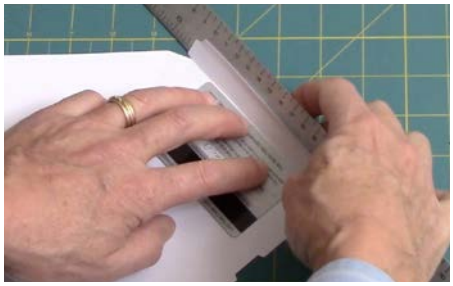
Score

Use a bone folder or similar tool and a straightedge to score the gnomon along the dotted lines in preparation for folding. Several strokes with medium pressure will produce a score so that when you fold, you get a nice straight edge.



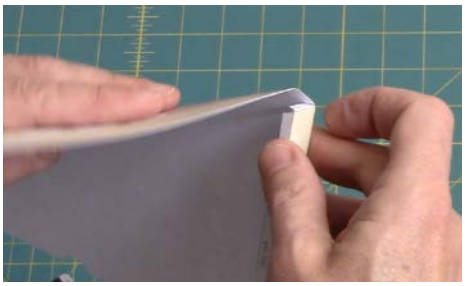
Fold

Fold the sides, back, and tabs of the gnomon away from the printed side at 90^0. It can help to use the sharp edge of a table, or a metal straightedge, to make the fold cleanly. In the photo above, I am using a metal ruler as an edge to fold against, and in the photo below, I am using a metal ruler underneath the part I am folding, and a credit card to hold the other part flat against the table. As I rotate the ruler up, it applies even pressure along the fold line, giving a nice clean, straight fold.



Test Fit

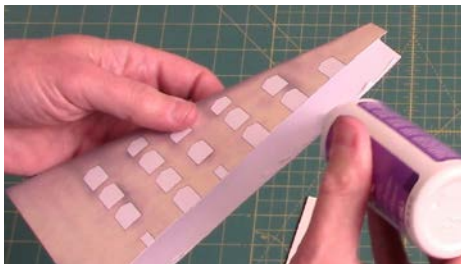
Test fit the folded parts to see that everything fits together and lines up. Look to see where the glue tab will fit and which surfaces will need to be glued.

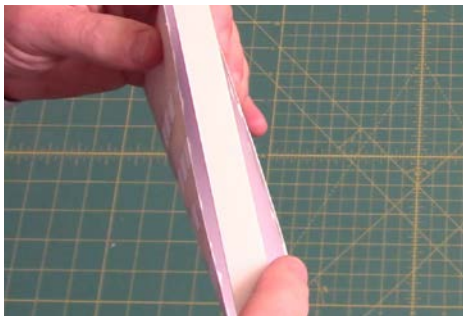


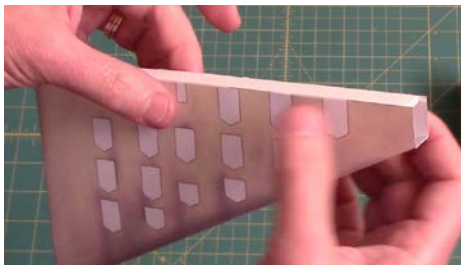
Glue

First, glue the small tab at the top of the back to the top section, then glue the tab that runs along the vertical edge of the back to the side section. Adjust the folds so that the vertical edges of the back and the edges of the sloping top form 90^0 angles with the sides.

Next, glue the bottom into place. Apply glue along the edges of the walls and insert the bottom so that it is flush with the edges of the gnomon walls and fits up against the back wall. See the photos (left). Once the bottom is fitted into position, press lightly all along the bottom edge of the walls to make the glue joint complete. Allow the glue to dry and proceed to make the quadrant supports.



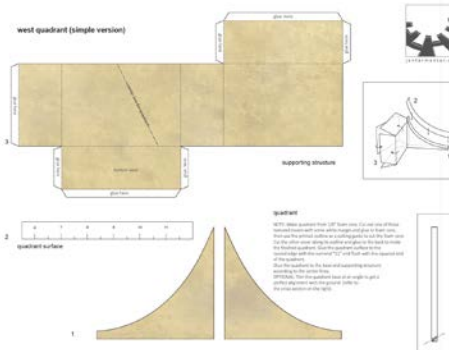




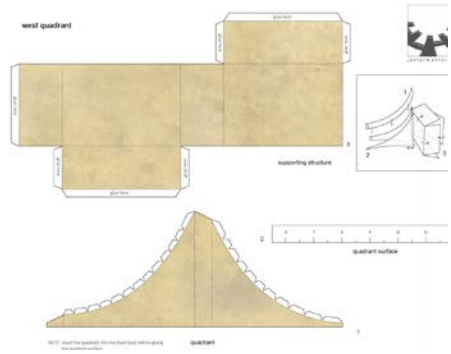
Quadrants

Supporting Structures

Decide which version you will make. There are four templates - two each for an advanced and a simple version. Each version has an east and west quadrant.



Simple quadrant template



Advanced quadrant template

Supporting Structure - West Quadrant.

Cut: Carefully cut the **supporting structure** from the appropriate printed template for the west quadrant using a straightedge and knife.

Score: Use a bone folder or similar tool and a straightedge to score along the dotted lines in preparation for folding. Several strokes with medium pressure will produce a score so that when you fold, you get a nice straight edge.

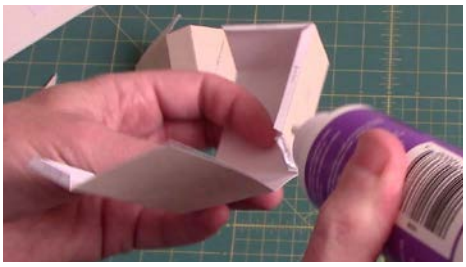
Fold along the dotted lines to make 90^0 angles. It can help to use the sharp edge of a table, or a metal straightedge, to make the fold cleanly.

Test fit the folded parts to see that everything fits together and lines up. Look to see where the glue tabs will fit and which surfaces will need to be glued.

Glue: First, be sure the three tabs on the bottom and the one tab on the side are folded 90^0 away from the printed side. Apply glue to them. Then fold the bottom away from the printed side and bring the four sides around to meet the bottom tabs. Press lightly along the glue joint to make certain the tabs and sides make good contact. Check to be sure the corners are square, so that when you place the structure on its bottom, the walls seem vertical (not tilted); adjust if necessary. It is possible to separate a glue joint and reposition it if you act quickly!

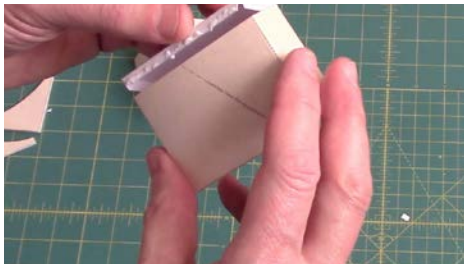
A small stick, as mentioned in the "tools" section, is very handy for applying pressure to glue joints from the inside. It will also help when tucking tabs into place when there is no access to the inside of a form. In the final step, gluing the top into place, it may be helpful to start at one corner and gradually push the tab inside as you work towards the other corner.

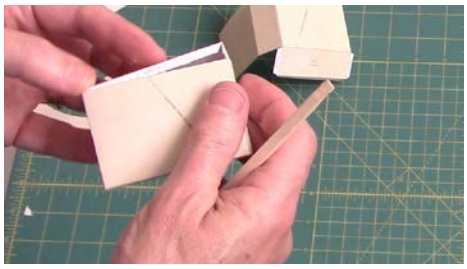
Tip: If you get glue on your fingers, you can quickly rub your fingers together to dry and remove the glue. It's a good idea to keep your fingers free from glue so that you don't get glue marks on the printed surfaces of the model.

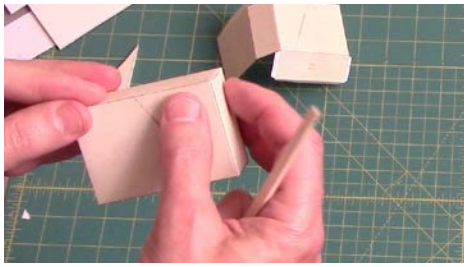


Bring the four sides around to meet the bottom tabs.

Use a small stick to press the tabs against the side walls from inside.



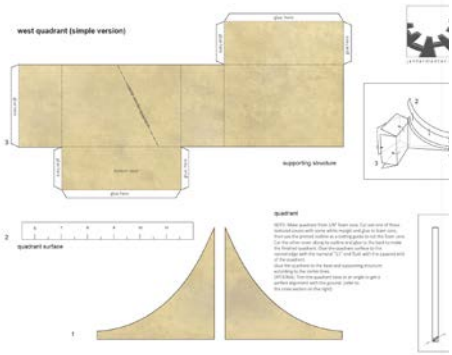




The finished support structure is a simple rectangular box.

Supporting Structure - East Quadrant.

Repeat the previous steps to make the supporting structure for the east quadrant.

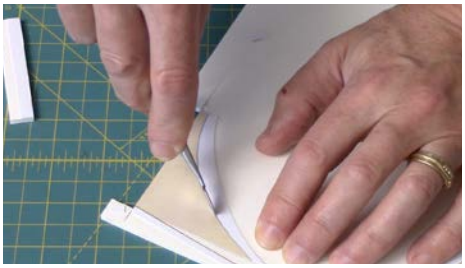


Quadrants

If you are making the advanced version, I recommend that you wait until later to make the quadrant. This is the most difficult part of the model because of its compound curve, and it will help to have more experience from building other parts of the model first.

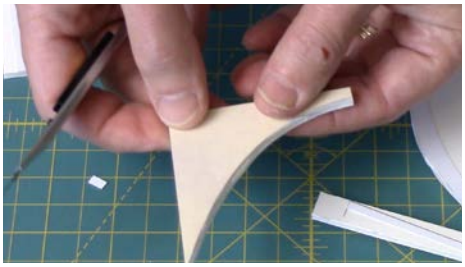
Simple Version

For the simple version, the east and west quadrants are identical. Cut both **quadrant shapes** from the **west quadrant** printed sheet, leaving at least 1/4" of white border. Glue these to 1/8" foamcore and allow the glue to dry. Then cut along their outlines to make an east and west quadrant. Cut the second set of quadrant shapes from the **east quadrant** sheet, **cutting exactly along their outlines**. Glue these to the other side of the foamcore to make the finished quadrants.



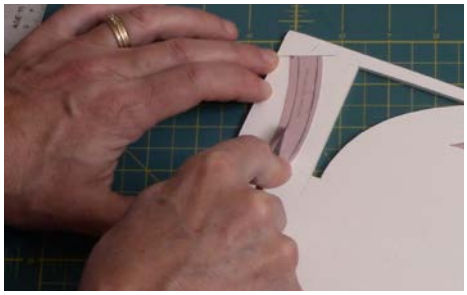
Use multiple strokes with your knife to cut through the template and foamcore. Especially when cutting a curved piece, several light strokes will make a cleaner cut, and allow you to cut with more precision.

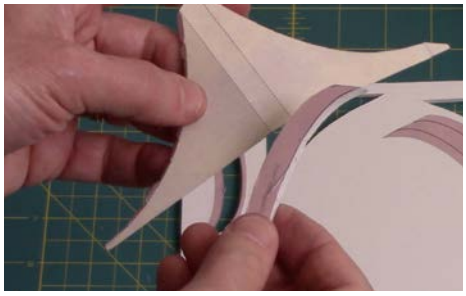
Wait until final assembly of the model before you attach the index surface and make the angled cut on the bottom edge.



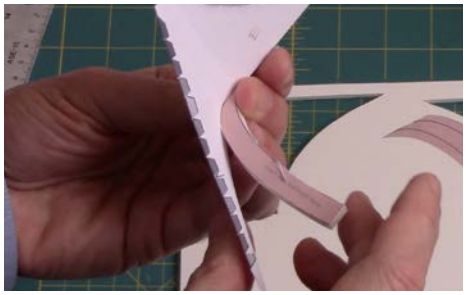
Advanced Version

For the advanced version, cut the quadrant and quadrant surface from both the east and west quadrant template sheets, and be sure to write "east" and "west" on the back side of each part. Cut the east and west quadrant bottoms oversize from the base walls template sheet, and glue them to 1/8" foamcore. Be sure to leave the printed text visible (glue the other side). Once the glue has dried, carefully trim them to their exact shape. Use multiple light strokes and hold the knife so that it cuts down through the foamcore vertically. It's important that these edges be as square as possible.

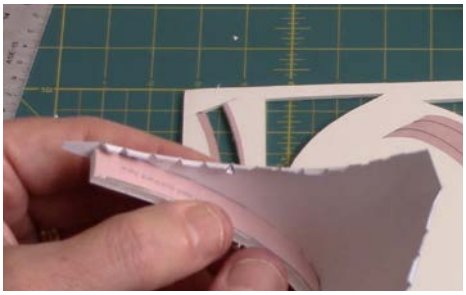




Score and fold the quadrant along the dotted lines, and test fit the bottom piece against the bottom edge of the quadrant.The fold that corresponds to the edge of the shorter side will be a much sharper bend, almost doubling back on itself, to conform the the sharp, pointed corner of the bottom. The fold making the edge of the high side will have a very shallow angle. It looks as though the bottom curves all the way to the point, but in fact there is a short section (about 1/2") that is flat. In the final assembly, this flat section will be up against the quadrant support structure. Once you have test fitted the quadrant and bottom, and understand how they fit together, you can begin to glue.

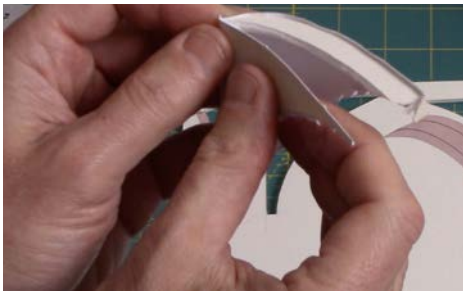


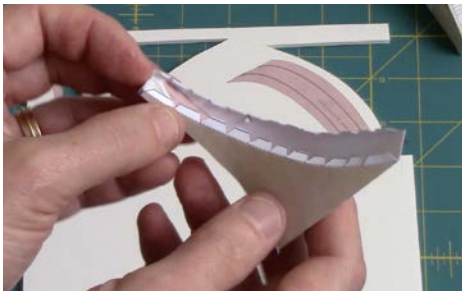
Test fit - the pointed end of the bottom should be at the fold that corresponds to the edge of the lower side (2nd fold) and the square end should be even with the fold of the small end tab



Glue the quadrant to the bottom, beginning at the lower end of the high side, and fitting the bottom so that the square end just lines up with the fold of the small end tab. Try to have the bottom piece flush with the bottom edge of the quadrant.

Continue gluing the quadrant to the bottom, insuring that the fold that marks the edge of the shorter side is just at the sharp endpoint of the bottom, and continuing around - the end of the lower side should be at the corner of the square end of the bottom piece.

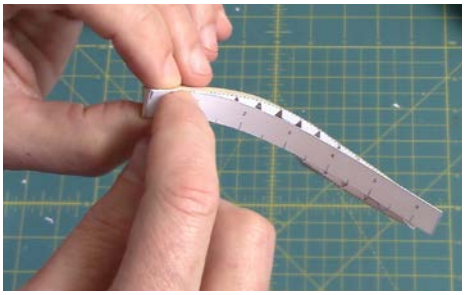




This is how the quadrant should look after gluing the walls to the base.

Begin gluing the index, or hour scale, to the small tabs on the curved edge of the quadrant walls. The end that would correspond to 12:00 should be even with the lowest end of the quadrant and the hour marks should line up with the edge of the lower wall. Having the index even with the end of the quadrant is important for time telling accuracy, because the wall of the gnomon represents noon in observed solar time, and the low end of the quadrant is attached to the wall of the gnomon. The west quadrant shows the hours from 6:00 A.M. to noon and the east quadrant shows noon to 6:00 P.M.

Apply glue only to the first three or four tabs, and carefully position the index. Note that the tabs on the ligher side of the quadrant need to bend at a sharper angle than the tabs on the lower side. This will become more pronounced as you progress up to the top of the quadrant.

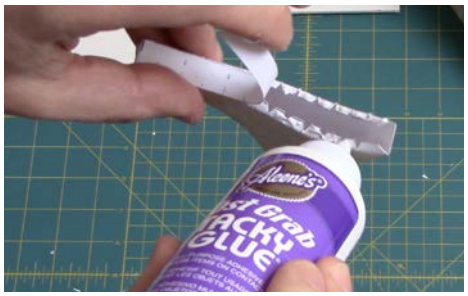


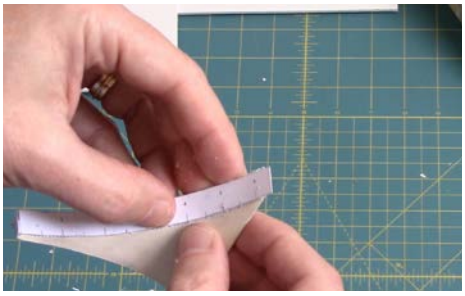
Carefully bend the index back, and apply glue to the next three or four tabs.

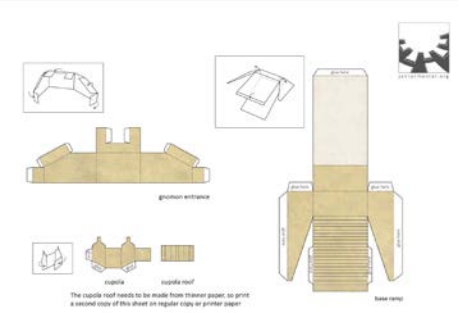
Press the index into place, adjusting the curve of the quadrant with the fingers of one hand while fitting and pressing the index into place with the other.

This process of bending, or adjusting the curved edges of the quadrant to fit the index is how the exact shape of the quadrant is achieved. The index is a perfect quarter circle in the plane of the equator, and when the quadrant sides have been made even with its edge, they will be in their correct architectural form.

Now apply glue to the remaining tabs and finish pressing the index into place. At its correct length, the index extends about 1/8" beyond the top of the quadrant.







Entry Steps, Gnomon Entrance, and Cupola

Follow the same procedures that you used to make the quadrant supports to make the entry steps, gnomon entrance, and cupola. The photos at left and below show these parts at various stages of assembly.

Entry Steps

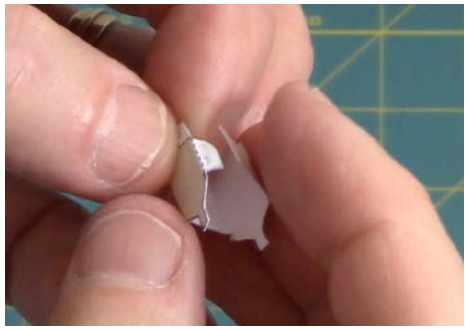
Glue one section at a time, and allow the glue to set before moving to the next section.

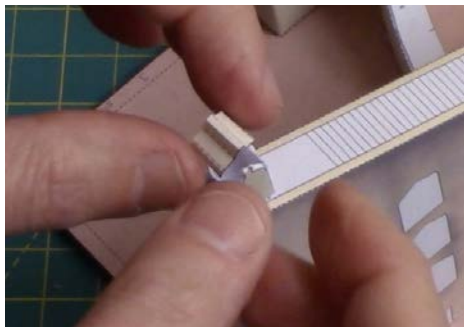
Gnomon Entry

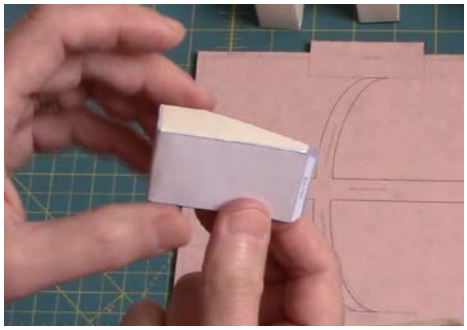
Old credit cards make good tools for bending small pieces and tabs

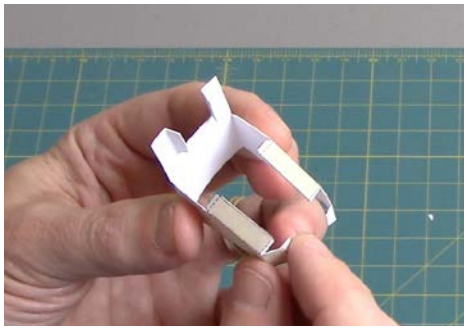
Cupola

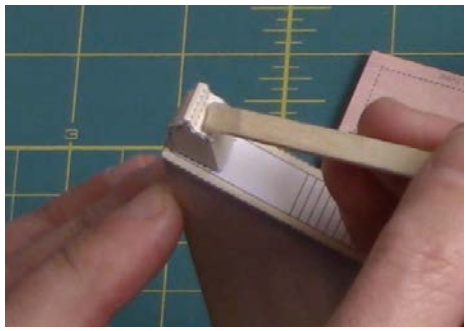
The cupola is very small. Use the edge of a credit card to help make the folds. Use a small flat wooden stick to press the roof into place when gluing.

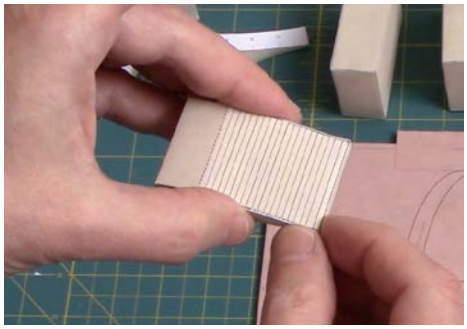


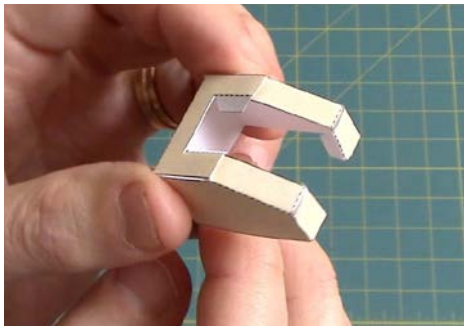


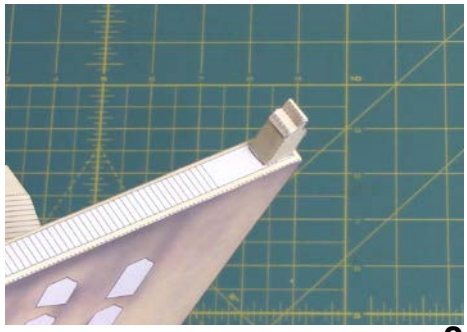




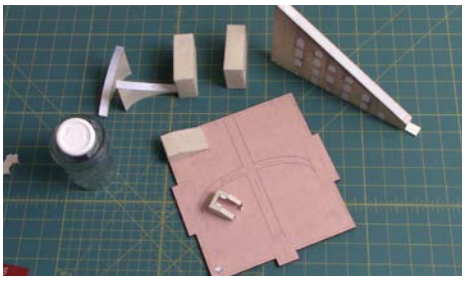








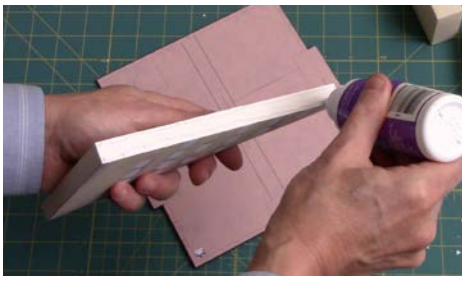
Final Assembly



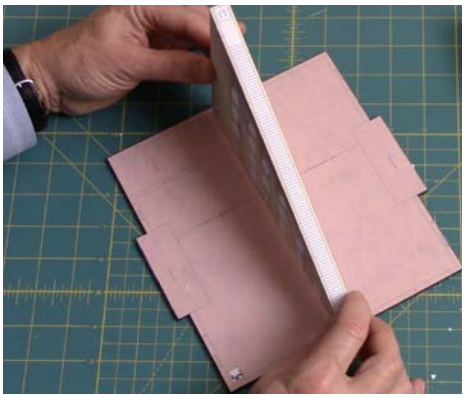
Now that you have completed all the parts, it is time to attach them to the base.

Gnomon

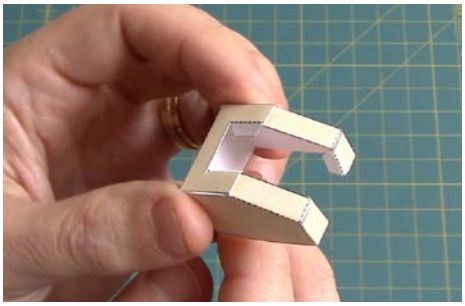
Begin with the gnomon, applying a line of glue to each side of the bottom piece



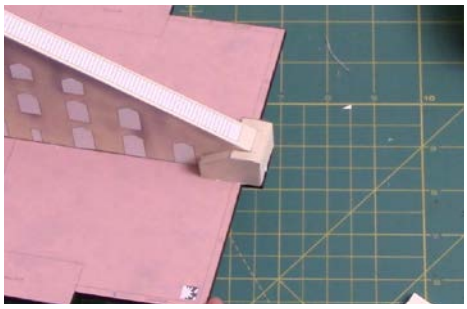
Carefully position the gnomon over the outline on the base, and press into place, holding firmly until the glue sets.



Gnomon entry vestibule



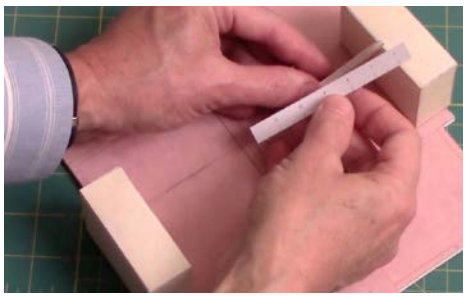
Attach the gnomon entry vestibule by applying glue to the inside edges and tabs and carefully slipping it into place around the gnomon, lining up with the outline on the base.



Quadrants and Supporting Structures

Test fit the east quadrant and its support structure to the base. If you made the simple quadrant, note the angled line on the supporting structure. This shows the correct angle for the quadrant. If you feel confident with straightedge and knife, you may wish to trim the bottom edge of the quadrant at an angle so that it will be flat on the base when glued. It isn't necessary, but will give a slightly cleaner look.

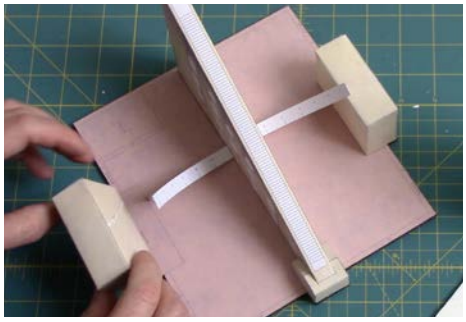
This is the time to glue the index, or hour scale, to the quadrant (if you built the advanced quadrant you've already done this step). The end that would correspond to 12:00 should be even with the lowest end of the quadrant. The curved edge of the quadrant should be in the middle of the index. Having the index even with the end of the quadrant is important for time telling accuracy, because the wall of the gnomon represents noon in observed solar time, and the low end of the quadrant is attached to the wall of the gnomon. The west quadrant shows the hours from 6:00 A.M. to noon and the east quadrant shows noon to 6:00 P.M.

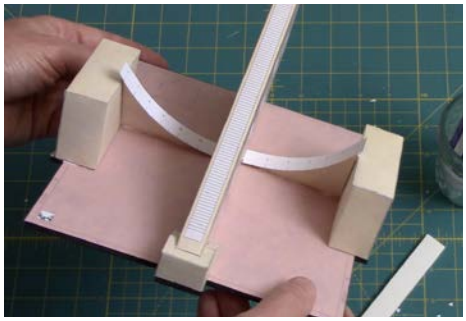


The photo above shows the index being positioned on the east quadrant without the gnomon in place.

Apply glue to the bottom of the east quadrant support, and also to the bottom and side edges of the east quadrant. Place the quadrant on the base with the lower end against the gnomon, and immediately place the quadrant support on the base so that the dotted line on its inside edge meets the quadrant, and it fits into its outline on the base.

Follow the same steps to attach the west quadrant and supporting structure.

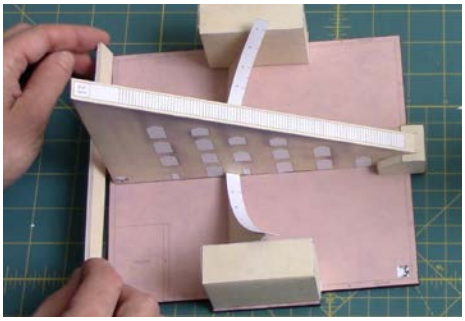




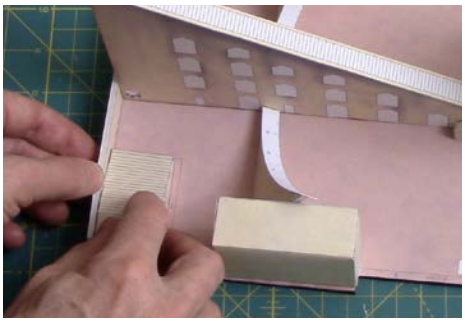
This is how your model should look at this stage (simple version). If you made the advanced quadrants, follow the same procedure to glue them into place. They will be at the correct angle when their bottom is glued down to the base.

Base Walls and Entry Steps

Test fit and then glue the long wall (wall section #8) to the base in the corresponding location. The wall sections are numbered and corresponding numbers are printed on the base. **Be sure you glue the wall section to the base with the printed side facing in.** The outer surface will be covered with a printed texture in a later step!

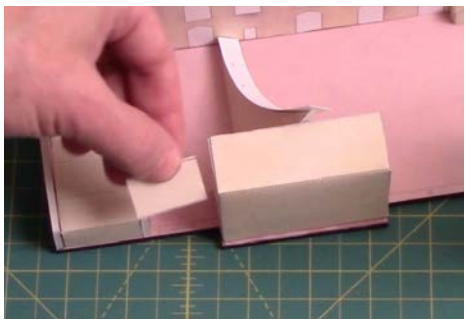


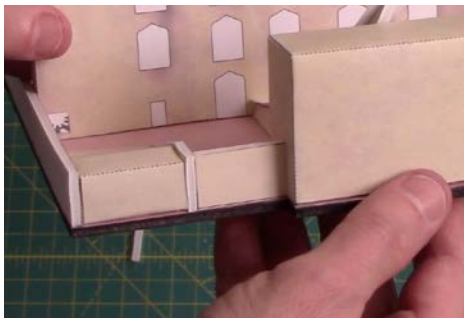
Test fit and glue the entry steps into position on the base. Apply glue to the bottom and side of the steps where they will meet the base wall.



Glue the entry step wall (wall section #1) to the side of the entry steps so that the sloped edge of the wall matches the slope of the steps. The printed side of this wall faces out (away from the steps).

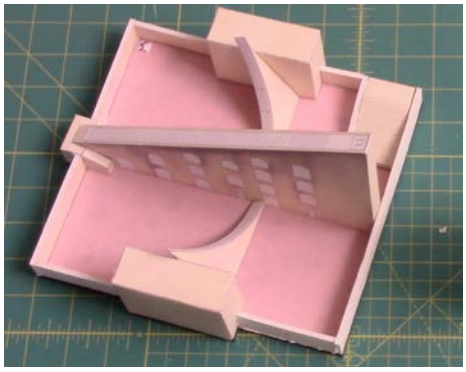
Test fit the short wall section (#2) between the entry steps and the quadrant support. Apply glue only to the bottom edge and the edge that will meet the quadrant support. The outer surface, including the joints with the steps and step wall, will be covered with a printed texture that will also help hold the wall section in place. **Remember to install with the printed side facing in.**





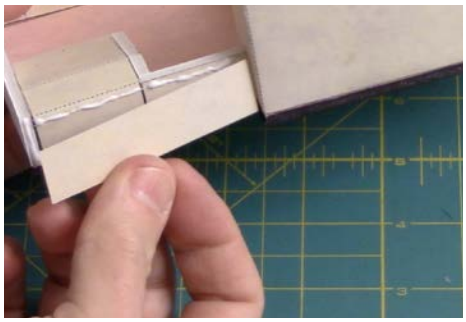
Continue to fit and then glue the remaining wall sections, 3 through 7, always with the printed side facing in.

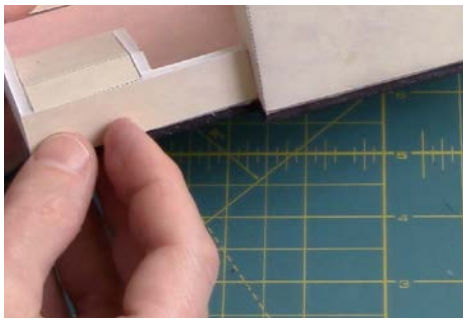
Your model should now look like this.



Outer Wall Surface

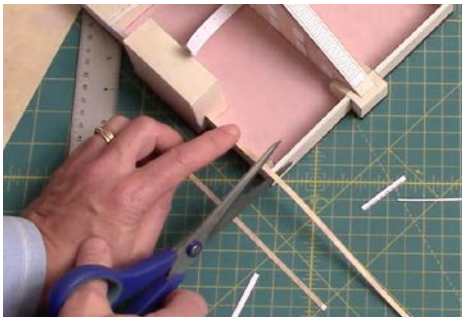
Cut the outer wall surfaces from the printed sheet, being sure to write the number of each section on the back. Apply glue along the top, bottom, and sides of the outer surface of the wall, and press the wall surface into place. Use a credit card to smooth and flatten the paper. Repeat this process to complete the outer wall surfaces.



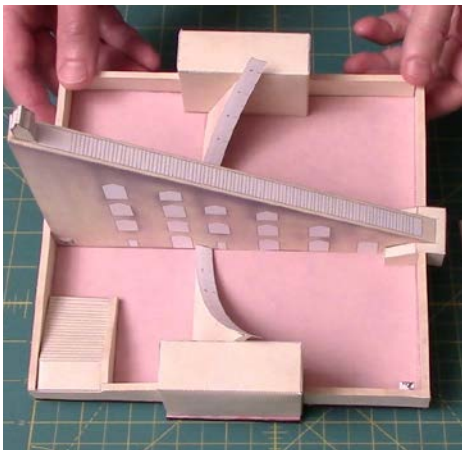


Wall Caps

Cut 3/16" (5mm) wide strips from the sheet of base wall texture. Apply glue to the top of a wall section and press one of the strips into place. Once the glue has set, trim the strip flush with the end of the wall section using sharp scissors or a modeling knife.

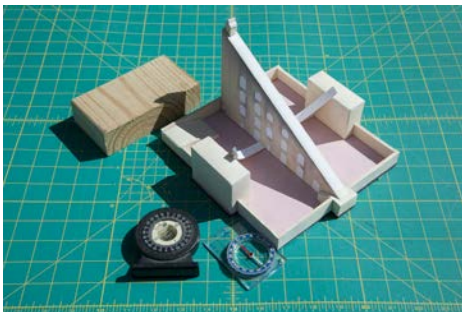


Repeat this process for the remaining wall sections, and **your model is complete!**



Telling Time

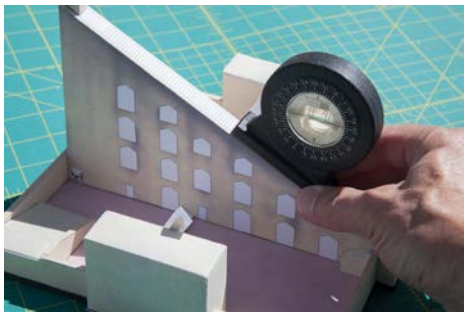
The Samrat Yantra is what is called an equinoctial or equatorial sundial. When the gnomon is oriented north-south, with the high side facing north, shadow of the gnomon on the quadrant will move along the quadrant at a constant rate.



To set up your sundial, use a compass to determine magnetic north, and align the sundial so that the gnomon is parallel to the compass needle with the high side of the gnomon to the north. For greater accuracy, you may wish to look up the magnetic deviation from true north for your location, but a magnetic north will give pretty good results.

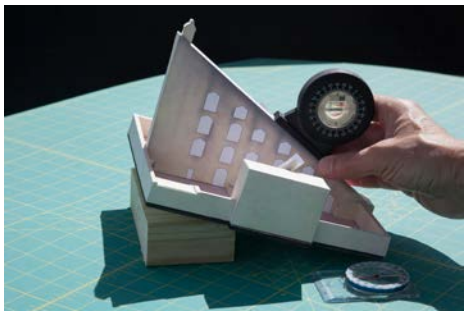
In the photo below, I've used a compass to find magnetic north and made the gnomon paralell to the compass needle.

The original Samrat Yantra is located in Jaipur, India, which has a latitude of about 27 degrees. Look up the latitude for your location, and use shims (small blocks of wood are good for this) under the base to adjust the angle of the gnomon. Use an angle finder to adjust the model so that the slope of the top edge of the gnomon corresponds to the latitude at your location.



The photo above shows the angle of the gnomon to be 27^0 with the sundial flat on a table.

The photo below shows the sundial shimmed with a block of wood at the front to put the angle of the gnomon at 42^0 (which is my lattitude here in Ithaca, NY).



You can use a bubble level style angle finder as shown above, or there are handy apps for smartphones, like the one in the photo below.

Once you have your sundial set up, you will be observing "local time." To determine the correct time for your location, you will have to adjust for three variables.

The first variable is your longitude (how far east or west you are in your time zone).

To adjust for the longitude of your location, you need to determine how far east or west you are from the center of your time zone.

The center longitude of your time zone can be determined by how many hours your clock differs from Greenwich Mean Time GMT. Each hour corresponds to one time zone which = 15^0. For example, New York City has a longitude of 74^0. It is in the eastern time zone (EST) which is 5 hours behind GMT. The center longitude of EST is $5 \times 15^0 = 75^0$, so New York City's longitude is 1^0 east of the center longitude.

If you live west of the center of your time zone, add 4 minutes for each degree of difference from the center of your time zone. If you live east of the center, then subtract 4 minutes for each degree. Thus for New York City, you would **subtract** 4 minutes from the observed time. If you lived in Cleveland, Ohio, longitude 81.7^0 west, (6.7^0 west of the center of the eastern time zone) you would **add** $4 \times 6.7 = 26.8$ minutes to the observed time.

The second variable is the difference between *apparent solar time* and *mean solar time.* Due to the obliquity of the earth's equator, and the eccentricity of the earth's orbit, the apparent or observed solar time (what you will record on your sundial) varies from clock time throughout the year. Your sundial time will run behind clock time from 0-15 minutes in January-March and June-August, and will be ahead of clock time by the same amount in April-May and September-December. The adjustment is given by the *equation of time* and there are many websites that provide tables and graphs to give you the precise number of minutes to add or subtract to your observed solar time in order to "equate" with clock time.

The third variable is daylight saving time. If you are observing daylight saving time, you will need to add another hour to your sundial time to compensate.