Name _____ Date _____ Period _____

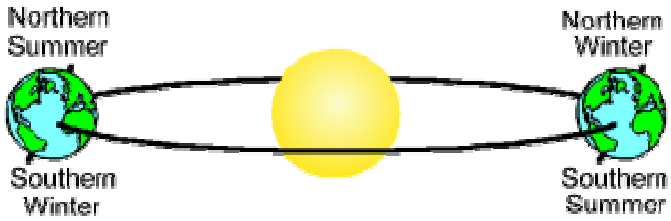
# Lab: Constructing a Sundial

**PRACTICAL PHYSICS**

Background: As the earth turns on its axis, the sun appears to move across our sky. The shadows cast by the sun move in a clockwise (hence the definition of clockwise) direction for objects in the northern hemisphere.

Shadow sticks or obelisks are simple sundials. If the sun rose and set at the same time and spot on the horizon every day, they would be fairly accurate clocks. However, the sun's path through the sky changes every day because the earth's axis is tilted. On earth's yearly trip around the sun the North Pole is tilted toward the sun half of the time and away from the sun the other half. This means the shadows cast by the sun change from day to day.

In addition, because the earth's surface is curved, the ground at the base of the shadow stick or obelisk is not at the same angle to the sun's rays as at the equator. This means that the shadow does not move at a uniform rate during the day. That is, if you mark the shadow at sunrise and sunset, you cannot evenly divide the space between for the individual hours.




There are several ways to overcome these problems. One is to build a ***horizontal*** sundial, where the base plate is level, and the "stick," called the style, is angled so it is parallel to the earth's axis. The hour marks can then be drawn by trigonometric calculations, correcting for the sundial's latitude.

Another solution is an ***equatorial*** sundial, where the base plate is titled at an angle equal to the latitude, and the style is perpendicular to the base, which will align it with the earth's axis. The base can then be marked with regularly-spaced hour marks.

In this activity, you will have a chance to construct three different sundials.

## Procedure:

1. Follow the directions in each section to construct your three different sundials. You may work with a partner, or construct your own sundial.
2. Obtains handouts and copied sundial patterns to cut out. *(NOTE: Be very careful when using the exacto knifes……they are extremely sharp!)*
3. Answer questions in each section before moving on to the next.
4. Clean up after yourself and put away all materials and tools!

PART 1: Definition of Terms: Define the following terms before moving on the construction phase of this lab. *(There are links on my website that might help!)*

1. gnomon-

2. Dial face-

3. Dial furniture-

4. Equation of time-

5. Longitude-

6. Latitude-

7. equinoxes-

8. Solstices-

9. Solar time-

10. Declination-

## PART 2: Building an Equatorial Sundial

One of the first tools to measure the flow of time, a sundial, is simply a stick that casts a shadow on the face marked with units of time. As Earth spins, the stick's shadow sweeps across the face. The face of the sundial represents the plane of Earth's equator, and the stick represents Earth's spin axes.

### Proceedure:

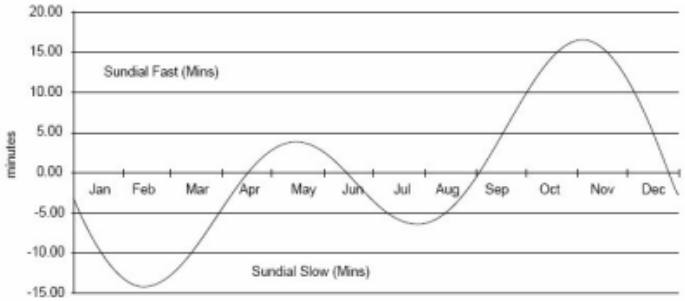
1. Obtain a copy of the **Equatorial Sundial template** *(you may also download and print your own if you would like – links are available on my website)*. The paper template works best if you use card-stock paper.
2. Carefully cut out the template using a pair of scissors.
3. Using the latitude strip on the guide, carefully mark the latitude lines onto a length of wooden dowel *(you may use a pencil if you like as well)*. First mark the bottom of the scale at one end, and then mark each of the latitudes.
4. Fold and glue the template. Make sure the dial faces are lined up.
5. Cut out the center hole.

6. Place the wooden dowel in the hole with the top face lined up with your latitude. The dowel should fit snugly. Make sure the stick and face are perpendicular. You may add a small drop of glue to hold in place if necessary. The bottom end goes on the ground.
7. You are now ready to test your sundial. On a sunny day, take the sundial outside and direct the pointed end toward north. *(You will have to figure out which way is north. You may use a map and/or a compass to accomplish this)*
8. Answer the questions below.

**Questions:**

1. How accurate was your sundial (how far from the correct time did it read, (+) or (-)? If your sundial time did not match clock time, explain why.

You must remember that the sun's orbit in the sky changes with the seasons, and a correction of up to about 15 minutes for the "Equation of Time" must be made. You can read the correction from the graph below. Did this improve your sundials accuracy?




*Correction for the "Equation of Time"*

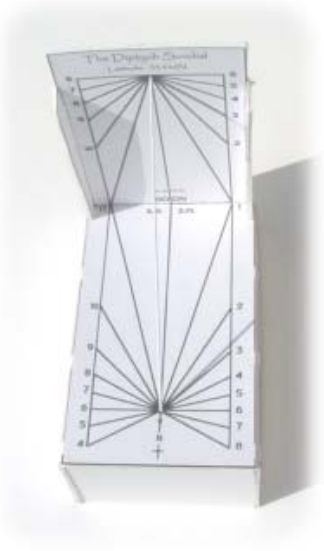
2. Why does the sundial have front and back faces?

3. When you get an opportunity, record the time on the sundial at least four times throughout the day. Each time, record the "clock" time for your date and location. In addition to this, record the length of the shadow at the different times of day. Record your data in the chart below. (You might want to try this experiment during different months of the year as well)

| Sundial Time | Clock Time | Length of shadow (cm) |
|---|---|---|
| | | |
| | | |
| | | |
| | | |

4. What would happen if you tried to use this sundial in the southern hemisphere?  Would it work?

## PART 3: Building an Diptych Dial



The folding sundial you are about to make is called a Diptych dial. Such dials have been made for four or five centuries and were traditionally made of ivory or boxwood. The Diptych dial provided here was designed by Dr. Allan Mills, Astronomy Group, Leicester University, UK .  The scanned images and text were originally prepared by Dr. Randall Brooks, National Museum of Science and Technology, Ottawa, Canada. The template was later updated and redrawn by Anders Bergström who also wrote the Capuchin dial project below.  I have modified this project slightly and taken into account our latitude here at San Clemente High School.

### Proceedure:

1. Obtain a copy of the **Diptych Sundial template** *(you may also download and print your own if you would like – links are available on my website)*.  The paper template works best if you use card-stock paper.
2. Paste the paper dial onto a piece of mat-board or heavy card making sure that glue is spread evenly over the entire surface.
3. Trim along the outside lines on the template diagram.  (You may do this carefully with a pair of scissors.  If you use an Exacto knife, take EXTREME CARE!)
4. To provide accurate time, the sundial must be orientated properly. The first step is to determine the latitude of the site using an atlas. (I have already done this. Your latitude here in San Clemente is 33.426 N).  On the right and left of the lower half of the dial (the base), you will see two scales marked 30°-55°. Once you have determined the required latitude, mark the latitude angle off on both scales drawing lines through each of the X symbols at the top. Cut the flaps off along these lines.  At the top you may want to write the location and latitude and/or perhaps your name, i.e. "Sam Smith, Fecit" (Fecit is Latin for "maker" and often appears on early instruments).
5. Note the dashed lines; two of these are marked "score on back, fold forward" and two marked "score on front, fold down". Folds must be made along these lines and if you score these lines lightly with a sharp exacto knife, the folds will be sharper and the sundial will stand better and look more finished. However, in making these scores, do not cut all the way through the card backing! After scoring, make the necessary folds in the direction indicated.
6. Along the line with "Noon" above and "a.m. p.m." below, make another score line on the back and fold the upper section forward so that the two panels make a right angle.
7. To finish the dial attach a string (preferably elastic string) through holes at the top and bottom at the points where all the hour lines converge. The easiest way to accomplish this is to use a thick needle and thread the string through tying knots on each end so that the string is taught when the dial is folded and ready for use. This string is the gnomon (pronounced no-mon) and casts the shadow to indicate the time.
8. You may wish to embellish the back of your dial with an old-style graphic from a book on sundials, a drawing of your pet or whatever appeals to you. This is where you can individualize your diptych dial!
9. It is now time to test your sundial.

- **Positioning your sundial**: The sundial must be orientated with the gnomon pointing north/south and, of course, the dial must be located where a shadow will be cast by the gnomon most of the day (though one can move the dial from window to window as the day progresses if necessary).
- **Method 1:** (The Purist's Method) To determine the orientation without reference to other mechanical devices, North can be found by observing Polaris, the North Star, at night. In orientating the sundial, the gnomon is actually being pointed to the North Celestial Pole which is within 1° of the North Star. Thus, if you can find Polaris at the end of the Little Dipper, line up your dial by pointing the gnomon towards Polaris. You might want to record the orientation for your dial by making light pencil marks on a window sill for future reference. Those in southern latitudes will not be able to use this method as there is no bright star near the South Celestial Pole.
- **Method 2:** (The Practical Method) A magnetic compass may be used to determine the north/south line, but, because of the difference between magnetic north and true north, the dial reading could be out by an hour or more depending on the local difference between magnetic and true north (or south if in southern latitudes).
- **Method 3:** (The Lazy Person's Method) To a first approximation, the orientation can be found by finding the orientation at any time from a clock or watch and orientating the dial so the shadow shows the correct time. However, if left in this position, there could be an error of up to 30 minutes over the year as a result of what is known as the "equation of time". Because of the Earth's orbital motion around the Sun, the solar day (approximately 24 hours) is not exactly the same length from day to day varying by up to ±16 minutes a day. However, if the orientation is carried out on April 15, June 10, Sept. 1 or Dec. 20, this error will be negligible and any orientation made between April 15 and 1 Sept. will be in error by, at most, a few minutes (but don't forget the effect of daylight savings time).

## Questions:

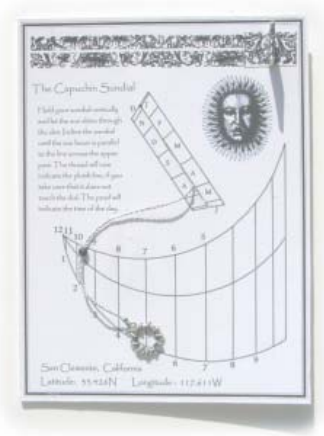
1. How accurate was your Diptych Sundial?

2. What is more or less accurate than the Equatorial Sundial? What might account for the differences?

3. Place the Equatorial and Diptych sundials next to each other. Do you see any geometrical similarities (angles) between the two sundials? Explain.

4. What might you do to improve upon this design in order to construct a more accurate Diptych sundial?

# PART 4: Building an Capuchin Sundial

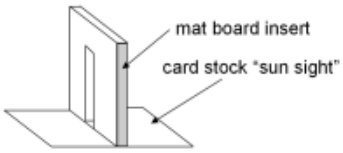



The Capuchin Sundial is an altitude dial, which tells time by the altitude of the sun above the horizon. It can be drawn on a card, and is very portable. The Capuchin sundial takes its name from the hoods of Capuchin monks who belonged to a branch of the Roman Catholic Order of Franciscans, which were apparently long and pointed and resembled the design on the sundial. The Capuchin hoods also gave their name to the Capuchin monkey, whose hair resembles the hood coloring, and the Cappuccino coffee, whose color and froth also resemble the hood.

This particular Capuchin sundial is designed to work only at a specific latitude (In this case, our latitude here at San Clemente). Universal Capuchin sundials were also designed to be used at any latitude, though it is cumbersome above 70 degrees. The design below was modified from a project produced by Anders Bergström and originally published in Swedish on his website (Links to these sites can be found on my website)

## Proceedure:

1. Obtain a copy of the **Capuchin Sundial template** *(you may also download and print your own if you would like – links are available on my website)*. The paper template works best if you use card-stock paper.
2. Carefully cut out the sundial along the dashed lines as shown. Also cut out the “sun sight” along the dashed lines.
3. Cut out the mat board template piece and transfer these lines to a small piece of mat board. You will need to carefully cut this out with an exacto knife. You need to be careful to cut out the “slit” that will allow the sun to shine through.
4. Glue the “sun sight” together as shown to the right.




5. You will also want to cut out a piece of mat board onto which you can glue your sundial. The mat board should be 6 ¼” x 8¼”. Glue the card stock sundial to the mat board. Make sure to center it as you glue it together.
6. Now you are ready to glue the complete “sun sight” to your sundial. Glue it to the right hand side of the sighting area. This is marked on the template.
7. Carefully cut a slot through the sundial between the month markings. This is also marked by a dashed line on the template,
8. Get a cotton thread with a small weight and a small bead which can slide up and down the thread. Insert the thread in the slot cut out in step 7. Fix a small button on the back side to make it possible to slide the thread up and down along the slot.
9. Calibrate the sundial by moving the thread to current date. Then align the thread with the tip of the "hood" and move the bead to the tip ("Twelve noon").
10. Hold your sundial vertically and let the sun shine through the slot. Incline the sundial until the sun beam is parallel to the line across the upper part. The thread will now indicate the plumb line, if you take care that it does not touch the dial. The bead will indicate the time of the day.
11. If you wish to construct your own Capuchin sundial, there are links on my website to can use to design your own custom dial.

**Questions:**

1. How accurate was your Capuchin Sundial?  How far off of clock time was it?

2. The sundial only shows "correct" time, that is Clock Time only four times a year, in the middle of April, the middle of June, the beginning of September and around Christmas. Other periods during the year the fault can be more than 15 minutes, forwards or backwards.  Explain.

3. How does the Capuchin sundial differ from the Equatorial and Diptych dials?  How are they similar?

**Conclusion Questions:**  Now that your sundials are working, here are some things to think about. When doesn't a sundial work?

1.  Do your sundials match your watch time? Which was the most accurate?  What could account for this?

2.  If the earth rotates every 24 hours (approximately), how many degrees does the sun appear to move in one hour? In four minutes? (Hint: one full rotation of the earth is 360 degrees).

3.  The sun's diameter in the sky is about 0.5 degree. About how long does it take for the sun to appear to move its own diameter across the sky?

4. Why don't we use local solar time instead of time zones in our everyday lives? Would it be easy to know what time your favorite TV program starts?

5. Why do time zones generally run north-south instead of east-west?

6. Does a sundial work the same north and south of the equator?

7. What would be different about a sundial at the North Pole? The South Pole?

8. Would your sundial read the same time as another sundial 100 miles directly north of you? Would the shadows be the same length?

*If you visit my website, there are a number of other sundial projects you might want to try!*