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Length of the Day

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The length of the day is something we take for granted. Yet, much can be learned about the day -- and the way the Earth moves -- from careful observations of the Sun and a more distant star, over as little as 24 hours, with a home-made viewer and a good clock.

OBJECTIVES: Measure the length of the day using the rotation of the Earth, with the Sun and a star as celestial landmarks; work at refining the measurement process. Discover that the Sun is not exactly in the same place at the same clock time every day. Understand that the changes are due to motions of the Earth, and lead to differences in solar, star, and sidereal time.

WARNING: Observing the Sun can be EXTREMELY HAZARDOUS TO EYESIGHT. Shadows may be safely observed without protection (though regular sunglasses may increase comfort), but OBSERVING THE SUN DIRECTLY REQUIRES SAFE SOLAR FILTERS (e.g. Welder's Glass No. 14). DO NOT LOOK DIRECTLY AT THE SUN WITHOUT A SAFE SOLAR FILTER. OTHERWISE, BLINDNESS CAN RESULT.

APPARATUS: (1) One or more **alignment devices** to view stars. The devices may be home made **sighting tubes**, front/sight/rear/sight devices, telescopes, etc. Sighting tubes can be made from toilet paper and paper towel roll cores, plastic or galvanized pipe, soda straws, or virtually anything that is tubular and straight. The length and internal diameter will affect the precision of the time determination: it may be easier to find the star, but harder to judge centering, when a larger radius surrounds the target before the tube walls are reached. A light-weight sighting tube is easier to use, but it should be strong enough not to bend under its own weight.

(2) A setup for measuring the **position of the Sun**. Create an image of the Sun by putting a pin hole, thumbtack hole, or larger hole in a piece of cardboard, and projecting the Sun's image on the ground. The smaller the hole and the longer the projection distance, the sharper and fainter is the image of the Sun. Note the direction of motion of the Sun's image on the ground and draw a line perpendicular to the direction of motion for use as a time mark. Make the length of the line three or four times the image diameter to allow for the Sun's slow seasonal motion.

(3) A wall **clock** or wrist watch, accurate to at least few seconds per day. Instead of the clock, you can use a **stop watch** that, in advance of its expected use, has been synchronized with the hourly time tone from the local CBS radio network affiliate. The stop watch acts as a portable source of accurate time. Or, if a short wave radio is available, you can tune to short wave stations WWV or WWVH at 5, 10, and 15 MHz, that provide time tones on the minute, accurate to milliseconds.

(4) An experiment notebook.

The **sighting tubes must be mounted** in fixed positions for the duration of the experiment. Sight on the desired star the night before you plan to begin taking data, to determine the star's

transit point. The star sighting tube should be taped to a pole, tree limb, fence post, etc. in a fixed position, so it can view the star on subsequent nights.

For greater precision, you may drill the sighting tube and mount it permanently to a tripod or other support. Or make a frontsight/rearsight device, by partially driving nails (so the heads are above the surface, by as much as an inch) into a yardstick or similar light weight, long, sturdy material. It, too, can be attached to a pole, tree limb, fence post, etc. in a fixed position, once the transit point of the desired star is known. The Sun motion setup must also be in exactly the same position every time it is used.

PROCEDURE: During class hours, use the clock to check the **clock time of the Sun's passage** by the ground mark for several days in a row. Also measure the exact position of the sun's image at that time. Watch the Sun's disk slowly move across the ground. When its leading edge is tangent to the reference mark the clock time should be recorded. The clock time can also be recorded when the trailing edge of the disk is tangent to the mark. The moment of tangency is easier to note than the time when the Sun is centered on the marker.

At home during the evening hours, have the students measure the clock time when a star of their choice falls into alignment. Repeat these measurements on subsequent days, being prepared to note the respective transit times starting 23 hours 50 minutes after the first measurements. Remember that the alignment devices must not be moved from day to day.

The **transit time** is defined as the period from when the Sun or star is first perfectly aligned in the sighting device until it returns to exactly the same position in its east-to-west daily motion. Note that the star will be at the same position in the alignment device each night, but the Sun will change its position up or down slightly every day. The change will hardly be detectable at the solstices, in June and December; it will be greatest around the equinoxes, in March and September.

DISCUSSION: Why is the star day about 4 minutes shorter than the solar day? The Earth moves around the Sun in the same direction as it rotates on its axis. So one sidereal rotation after sunrise, for example, the Earth has also moved part way around the Sun, and must rotate a little farther to reach dawn on the next day.

As viewed from Earth, the Sun appears to move toward the east, relative to distant stars, about 1 degree, the equivalent of about 4 minutes of time, each day. In a year, the Sun appears to move full circle (360 degrees) -- on Earth we view the Sun from all angles as we complete an annual orbit. You can demonstrate this by having one student play the "Sun;" other students can walk around the Sun, and report on what pattern of "background stars" (the classroom walls) they see during "noon" (facing the Sun) and "midnight" (facing away from the Sun). Our clocks are based on the solar day.

Why does the Sun's crossing point on the mark appear to gradually move up, then down with the changing seasons? Earth acts like a gyroscope; its rotation axis points in the same direction relative to distant stars all year. (This is why you can always use Polaris to find North.) But the rotation axis is tilted relative to the plane of Earth's orbit around the Sun (called the "ecliptic"). If you mark the location of the tip of a stick fixed in the ground at the same clock time every day for a year, the marks will trace out a figure "8." This shape is sometimes called an "analemma." They are often drawn on globes.

Do the day lengths vary with season? Measurements made in January and July (June is almost as good) will show differences due to the Earth's orbital speed. It is fastest during January, when Earth's elliptical orbit brings it closer to the Sun. In July, Earth is at its farthest, and moving slowest. Note that the apparent size of the Sun will vary with season, and this can be demonstrated by timing the duration of its transit across the mark

FOR MORE INFORMATION: Earth's motions relative to the Sun are discussed and illustrated in most encyclopedias under "Earth," "Earth's Orbit," "Day", or "Seasons."