Overview
The Sun, the source of all life on Earth, is a dynamic, changing star. With the naked eye, we can tell very little about it. However, with some simple tools, we can start to learn much about its physical properties through the observation of sunspots. In this lesson students will observe the Sun in three different ways, and will determine how fast it rotates. If time or interest permits, students can also graph the Sun’s sunspot history to see solar activity over the centuries.

Science Standards (Vermont)
S7-8:23 Students demonstrate their understanding of Heat Energy by…
• Creating a diagram, model, or analogy to explain differences among conduction, convection, and radiation, and using their visual to explain how heat energy travels in different directions and through different materials by each method of energy transfer.
S7-8:28 Students demonstrate their understanding of Light Energy by…
• Designing demonstrations that represent the characteristics of light energy transfer.

Focus Question
What can we learn about the Sun through simple observations?

Objectives
Through this lesson, students will:
• Learn that the Sun is not a static object in the sky, but a dynamic star that changes by the minute.
• Calculate (roughly) the rotational velocity of the Sun through simple observations.
• Arrive at a fuller understanding of the Sun’s place in our lives, including its cyclic changes and their effects on Earth.

Background
Modified from Astronomy 1 Lab Manual, Sunspots and Solar Radiation:

Humans have noticed dark spots on the surface of the Sun for thousands of years. The first written record of sunspots was made by Chinese astronomers in 364 BC, and Chinese astronomers regularly recorded sunspot observations starting in 28 BC. These naked eye observations were quite difficult, and we know today that only the largest sunspots (diameters greater than about 40 arc seconds) can be seen with the naked eye. You should never try to observe the Sun directly, as doing so can lead to blindness! Modern observers of the Sun always use special filters to reduce the glare and safely observe the Sun.

Europeans did not know about the observations of sunspots by Chinese astronomers, and the first study of sunspots in Europe did not occur until after the invention of the telescope. Sunspots were first observed through a telescope in late 1610 in Europe. A lively scientific debate ensued as European astronomers
debated the nature of spots on the Sun. The German Jesuit Christoph Scheiner started observing sunspots in March 1611 and wrote a letter to his friend Marc Welser in January 1612. Jesuits were conservative on cosmological issues, and insisted that the heavens, including the Sun were perfect. As a result, Scheiner hypothesized that sunspots were shadows created by planets crossing the disk of the Sun.

During the summer of 1612 Galileo observed the Sun on most clear days. Galileo used his telescope to project an image of the Sun, so that he could safely view the projection. He made detailed drawings of his observations, an example of which is shown below. Galileo concluded that sunspots were features on the surface of the Sun and that the Sun was rotating. This contradicted the prevailing cosmological view, in place since Aristotle’s time, that the Sun was perfect and unchanging.

![Figure 1: One of Galileo’s drawings of the Sun made in the summer of 1612.](image)

In response to the observations made by Scheiner, Galileo wrote several letters to Mark Welser in the fall of 1612. Galileo describes his observations of sunspots and his interpretation of them as surface features on a rotating Sun. He made a number of arguments as to why the sunspots must be on the surface of the Sun, and not due to shadows of planets passing in front of the Sun.

These included:
- “First, to see twenty or thirty spots at a time move with one common movement is a strong reason for believing that each does not go wandering about by itself...” and
- “To begin with, the spots at their first appearance and final disappearance near the edges of the sun generally seem to have very little breadth, but to have the same length that they show in the central parts of the suns disk. Those who understand what is meant by foreshortening on a spherical surface will see this to be a manifest argument that the sun is a globe, that the spots are close to its surface, and that as they are carried on that surface toward the center they will always grow in breadth while preserving the same length.”
We know now that sunspots are actually cooler portions of the Sun’s surface, caused by twisted magnetic lines penetrating the surface. The Sun has a magnetic field, just like the Earth, but as it rotates its magnetic field lines get twisted and tangled, like a rubber band. These eventually “snap”, and can poke into the surface of the Sun. The particles that the Sun is constantly emitting are highly attracted to these lines, and spiral up and in on them when they are able to. When the lines penetrate the Sun’s surface, particles from the surface flow up onto them, creating slightly cooler spots (because there is physically less stellar material) at the penetration points.

These spots are still very hot, but because they are less hot than the rest of the Sun’s surface, we see them as physically being much darker. If we could remove a sunspot and look at it alone, it would be brighter than the Moon.

Sunspots are useful for various reasons:

- They show that the Sun rotates, and can be used to determine its rotation rate.
- They show that the Sun can have its own changing features, like weather, and is not a static orb in the sky.
- They show that the Sun is spherical.
- Long term study of them can show trends in solar activity over years, namely an ~11 year solar activity cycle.

For more information about sunspots, a good place to start is the associated Wikipedia article, found at:

  The cited links in that article, and associated linked articles, will actually give one an excellent backing in the Sun and sunspots. Wikipedia’s scientific articles are usually of very high quality.

**Materials**

- Minimum one solar projection telescope from the Department of Physics and Astronomy (more depending on how many students are present).
- Clean, white paper to attach to telescope for recording observations.
- Paper for students to record other observations.
- Pens/pencils.
- A ruler or measuring tape.
- Optional: cameras/phones with which to take pictures of observations.
- One solar observing telescope with hydrogen-alpha filter.
- Bag of solar viewing glasses.
- NASA Solar Dynamics Observatory (SDO) images of Sun/sunspots (link to this follows below, and two sample images are included in the supporting materials).
- Optional: sunspot data over the centuries.
  - Computers with graphing software, like Excel.

Please contact Jan Largent or Alan Goldblatt at the Department of Physics and Astronomy to arrange to pick up the telescopes and solar shades:

- Jan Largent: largent@dartmouth.edu, 603-646-2740
- Alan Goldblatt: alan.goldblatt@dartmouth.edu, 603-646-3454

If neither are available, please contact the department directly and explain the situation:

- Department of Physics and Astronomy: physics.department@dartmouth.edu, 603-646-2854

Please make contact well ahead of time, as the telescopes are not universally available, and it may take time to schedule their use.
**Preparation**
Practice setting up telescopes and making observations before doing so with students. This is a must. Allow yourself an hour to familiarize yourself with the equipment. A guide for this is given as an appendix to this document.

**Procedure**
Note: Without clear skies, this module obviously will not work.

Modified from Astronomy 1 Lab Manual, Sunspots and Solar Radiation:

1. Begin with brief talk about what sunspots are, culled as desired from background information (and any further research you would like to do, as described above). It may be beneficial to show a picture or two from the SDO to give an example of the Sun with visible sunspots.

2. Introduce students to the three different ways of viewing the sun with the provided equipment. Explain the fragile nature of these tools, and the importance of not jostling the telescopes. Emphasize the importance of not looking at the sun with the naked eye.

3. Direct Observations: Take out the bag of solar viewing glasses ("eclipse shades"). These glasses contain a special filter which makes it safe to view the Sun. Put the glasses over your eyes and look at the Sun. Do you see anything on the surface of the Sun? If so, record your observations in words. Briefly describe what you see, indicating the sizes, locations, colors, etc. of anything you see. Make a sketch of your observation, showing the Sun as the circle and drawing any features you see.

4. Direct Observations using a Solar Telescope: The solar telescope is equipped with a special filter, centered on the Hydrogen-alpha line. This allows you to clearly observe surface detail, and prominences on the Sun. When you are at the telescope, carefully sketch what you observe. Be sure not to jostle the telescope while observing. Does what you see have to do with heating or convection?

5. Observing the Sun in Projection: See Figure 2 for the refracting telescope setup. Using the paper clips on the projection stand, clip in a folded piece of paper. Extend the silver tube at the end of the telescope so that you are close to focus (as in Figure 2). Loosen the screw at the base of the telescope (circled in white in Figure 2), so that the telescope moves freely, and point the telescope at the Sun. **Do not look through the telescope!** You can tell if you are pointed at the Sun by looking at the shadow of the telescope. You want the shadow of the telescope to be visible on the paper holder, as in Figure 2. Once you see the shadow on the paper holder, tighten the screw so the telescope is fixed. The round knobs near the base of the telescope move the telescope by small amounts and are used to center the image of the Sun in the middle of the telescope shadow. Rotate the focus knob near the eyepiece until you see a sharp image.

If a camera is available, take a picture of the projected image of the Sun, ensuring that the image of the Sun takes up most of picture. After taking the picture, carefully trace the image onto the paper.

Finally, measure the distance between the image of the Sun and the eyepiece of the telescope. Similarly, measure the equatorial diameter of the image of the Sun. These two numbers will help us to find the Sun’s actual equatorial diameter later on.
6. Two sunspot data points are needed to measure the rotational velocity of the Sun. After Step 3 above, we have one data point. To continue, two paths can be taken:
   a. To complete the lesson in one day, head inside and use provided images of the Sun/sunspots from the SDO.
      i. The teacher can use the two provided images, or can download fresh images from: http://sdo.gsfc.nasa.gov/data/aiahmi/. When downloading images, be sure to:
         1. Choose “HMI Intensitygram (orange)” from the “Telescopes” drop-down menu.
         2. Select the “Frames Download” radio button option under the “Choose a format” section.
         3. Choose whatever resolution you desire (in my experience, the bigger the better).
         4. The “Display one image per nth (optional)” section can be slightly confusing. Whatever number you enter into that field, the website will return one in every n of that number. For instance, if you enter five, it will return one in five images. Experiment a little, and you will soon see how this parameter is best modified for your specific situation.
ii. It could be beneficial to download an image from 24 hours prior to the students’ observing, to provide them with the “first” data point – theirs would be the “second”.

b. To complete the lesson in two days and have students take all data, repeat Step 3 above at roughly the same time the following day. A few potential problems exist with this method:
   i. Inclement weather preventing a second observation.
   ii. It is rare, but possible that students might only see sunspots at the Sun’s fringes, which prevents accurate observations (due to the Sun’s spherical nature, and this lesson does not assume a knowledge of trigonometry). Taking path 4a is recommended, not only for instructional ease, but also to expose students to stunning solar observations from NASA.

7. As the Sun is a sphere, to accurately calculate the rotational velocity, one must account for its curvature. This is doable with some trigonometry, but we will make some simplifications at this time – namely, we assume the Sun is a flat disk, and that sunspots move across it at a constant rate (that all parts of the Sun rotate at equal speeds, which is far from true on a sphere).

Rotational velocity is now simply calculated by finding the distance traveled by the sunspot divided by the time elapsed. To find distance traveled, we need to know the Sun’s diameter. This can be done in two ways:
   a. If the Earth is ~150,000,000 km from the Sun, then we can use the ratio found during observing to find the diameter of the Sun (e.g., 150,000,000 km / 5 in = x km / 2.5 in, and solve for x).
   b. By giving students the Sun’s equatorial diameter, which is ~1,400,000 km.

With the equatorial diameter in hand, one can make an estimate as to the diameter of the Sun at any given latitude with a simple ratio by measuring the physical diameter on the paper/screen at the equator and at the desired latitude (e.g., 1,400,000 km / 5 in = x km / 2.5 in, and solve for x).

The time elapsed should be 24 hours, or however long the instructor chooses. (Twenty four hours at minimum should show a noticeable distance.)

To check, the Sun’s actual rotational velocity is 7,189 km/h. If answers are anywhere between 1,000-10,000 km/h, students are in a great ballpark. We made some extreme simplifications, and to still be within the same order of magnitude is actually an excellent result. (Doing this roughly on my own I was only off by a few hundred km/h.)

8. Finally, estimate the size of a sunspot and compare it to the size of the Earth (diameter 12,742 km). The size of a sunspot can be found using the same system of ratios as above.

Assessment
Questions given on attached worksheet.

Extensions
Have the students graph the sunspot count over the months and years with the given data. In the Excel data sheet, there are five columns:
1. YEAR: The year the measurement was taken.
2. MONTH: The month the measurement was taken.
3. TIME: An added combination of year and month in order to make graphing the x-axis simpler.
4. SSN: Sunspot number in that given month of that given year.
5. DEV: The standard deviation of the sunspot number in that given month of that given year. What trends can they find from this? “Zoom in” on a period of 50 years or so to see a clearer picture of the cycle’s sinusoidal nature. How might the 11 year cycle be important to us on Earth?

Reference Materials
Worksheets, two SDO images, and the historical sunspot data file are provided as digital attachments, and should be kept in the same directory as this guide. Also included is an appendix which contains instructions on how to put the two telescopes together.