Background Material: History and Modern Research

Please be sure to read all the lesson pages, as they provide background for the research activity. The Web URL for the lesson is: http://cse.ssl.berkeley.edu/Segway/lessons/sunspots/. If you are using a CD, opening the folder SUNSPOTS will start the lesson, with a navigation system for accessing all sections.

History and Hands-on Sunspot Observation. Read these pages in the lesson by selecting the "HISTORY" tab near the upper right corner of the screen. Underlined terms are linked to the online glossary, where you may also go to the first instance of the word in the lesson pages.

Ancient cultures worshipped and studied the Sun because they perceived its power and importance. Ancient cultures had practical reasons for wanting to understand the Sun: its movements throughout the year marked the seasons, telling them when to plant, expect rainy seasons, harvest and hold religious rites. Whether there was drought, heat, floods or cold may also have been attributed to the Sun. Many ancient cultures recorded solar observations, and some made accurate predictions of the Sun's seasonal movements that are still valid today. On the other hand, connections between the Sun and climate changes on earth have not been clearly established, although some patterns and research suggest them.

European scientists of the Renaissance made sunspot observations, but they could not agree on what they thought sunspots were. Drawing daily pictures of sunspots over time showed that the spots evolved. Many academics, including authorities of the Catholic Church, continued holding Aristotle's belief that the heavens were perfect. Blotches on the Sun seemed inadmissible, so they were thought by many to be planets, moons or clouds orbiting around the Sun. The introduction of telescopes in 1608 vastly improved the observation of sunspots in clarity and detail. Using a telescope, Galileo noticed that sunspots foreshorten as they near the sun's edge, and used this physical evidence to argue that the spots were indeed part of the sun. Early researchers could avoid severe damage to their vision by observing the Sun through fog or at sunset, when its UV radiation is much attenuated. Looking at the solar disk through any focusing optic can badly damage the retina and should be avoided. Study questions for this section are provided as a student worksheet, Dawn of Sun Science.

You can observe sunspots safely by projecting an image from a focusing optic onto a flat surface. You can do this with a small (3-inch diameter) telescope or commonly available binoculars. See History, page 4 for pictures and instructions. You may wish to repeat observations over several days or weeks to watch sunspots move and change.

Modern Research
Read these lesson pages by selecting the "MODERN RESEARCH" tab in the upper right corner of the frame.

Modern telescopes now detect not only much more detail, but also the non-visible parts of the sun's light, such as infrared, ultraviolet, x-rays, and gamma rays. The first page of the modern research section, research.html, shows three images from different wavelength regions, to give some ideas of how different the Sun appears when you examine different areas of the spectrum. Most images are made by specialized telescopes and/or filters that pass only a certain part of the
spectrum. The wavelength of light is usually specified in Angstroms, with the symbol Å. One Angstrom is 10^{-10} meter.

- **Visible**: This image was made with a filter for light at a wavelength of 6562 Å, emitted by hydrogen, and referred to as "H-alpha." This emission comes from a region just above the sun's surface, where the temperature is about 10,000 degrees Kelvin (abbreviated 10,000 K). The sun's visible spectrum peaks at about 5500 Å.

- **Extreme ultraviolet**: This image is from NASA's SOlar and Heliospheric Observatory (SOHO) satellite. This image was made with 304 Å light, emitted in a transition region between the sun's lower and upper atmosphere. The temperature of this layer is about 60,000 K.

- **Extreme ultraviolet**: Although labeled simply "ultraviolet," this SOHO satellite image shows the Sun at an even shorter wavelength: 195 Å in the extreme ultraviolet. The shorter wavelength filter shows a hotter region of the sun's outer atmosphere, or corona, at a temperature of about 10^6 (1 million K).

New information from images like these enables scientists to solve problems and better understand the Sun as a complex system. It also raises many new questions, as researchers try to understand what they see in each part of the sun's surface or atmosphere, and how those processes interact.

**The Sun is an example of what physicists call a thermal "black body,"** because the spectrum of light emitted from its surface is determined by its temperature. Most of the light emitted from the sun's surface results from collisions between particles in a hot, dense gas. This produces a continuous spectrum which peaks at a characteristic wavelength that depends only on the temperature. For the Sun this is about 5800 degrees K, and is the temperature of the sun's visible surface.

**The temperature of the sun's outer atmosphere (corona), however, is about 1-2 million K**, much hotter than the surface temperature. How does this happen? This is one of the most compelling questions in solar research today. Researchers use high-temperature solar data from satellites as they try to understand what happens between the surface and the corona. These problems involve mechanical/magnetic or "dynamo" processes, of which sunspots are perhaps the best-known kind of evidence. Scientists now know a sunspot is a cool place on the sun's surface, where a strong magnetic field emerges from the surface. Sunspots are as big as the earth in diameter on average, while the solar disk is about 109 Earth diameters across.

**The sun's interior has several layers** including, from the center outwards:

- **Core**, where nuclear fusion turns hydrogen into helium, releasing energy as radiation that heats the surrounding material.

- **Radiation zone**, where the hydrogen is no longer hot enough to fuse, but still very hot and dense. Energy in the form of a quantum particle of light, or photon, can take 1 million
years to emerge from this zone! This zone is not strongly emphasized in the lesson, but it is the direct source of heat for the convection zone.

- **Convection zone**, where thermal energy from the radiation zone is transported outward to the cooler photosphere by a circulating layer of hot, ionized atoms called plasma, just as heat is transported to the surface of a pot of water on a stove. The granular pattern seen in high resolution photographs of the sun’s surface shows convection cells where hot plasma reaches the surface, cools, and falls down again.

- **Photosphere**, the visible "surface" of the sun, where the light our eyes see is emitted. Temperature is about 5800 K.

- **Chromosphere**, a thin transitional region between the photosphere and corona, with a temperature of about 10,000 K. It has not been mentioned explicitly in this lesson. For simplicity, we have grouped the chromosphere and corona together as the solar atmosphere.

- **Corona**, or outer atmosphere. At 1-2 million K, this super-hot plasma envelope is the source of the Sun's x-ray emissions. This region extends far out into space--effectively the solar wind is the thin outer region of the corona.

**Sunspots result** from events in the sun's induced magnetic field. Circulating plasma of charged particles in the convection zone create solenoid currents, analogous to a simple electromagnet. However, the current here is driven by the temperature difference between the radiation zone and photosphere, not an electro-motive force like a battery. The convection cells are visible in some high-resolution images of the photosphere as a surface granularity. Fields from convection cells exert torques on the field in the radiation zone below, creating magnetic flux bundles that become twisted into dense ropes or "flux tubes."

**These dense bundles of field lines have high magnetic pressures** inside. The local plasma is pushed out of this structure, so that the total pressure (magnetic pressure + gas pressure) is conserved in the loop. In some cases, a flux tube is actually drawn upwards into the convection zone, where it floats up and bows out into the corona in a loop. The sunspots are cross-sections of the flux loops where they emerge from and re-enter the sun's surface. The lower gas pressure makes sunspots somewhat cooler than other areas on the surface. They appear very dark, because light output is very sensitive to temperature.

**The average number of sunspots** increases and decreases on a regular sunspot cycle, averaging 10.8 years. The direction of the Sun's magnetic field reverses after each 11-year cycle. The total cycle is two reversals, or ~22 years. Locations at which sunspots appear draw closer to the equator as each half of the cycle progresses. Several periods with low sunspot numbers, including the Maunder Minimum, coincided with a "Little-Ice-Age" of very low temperatures on Earth, which began during the so-called "Dark Ages" (~800 - 1000 CE) in Europe, and continued, on and off, into the 18th century.

**Interaction between the dense fields in sunspots and solar plasma** causes flares and coronal mass ejections (CME's), which can give rise to shock waves that have various effects, when they reach Earth. **Geomagnetic storms** occur when large bursts of energetic charged particles and
high-energy photons from a flare or CME hit the earth's magnetosphere. The magnetosphere constantly protects Earth from the sun's magnetic field, and from lower levels of charged particle influx called the solar wind. Study questions for this section are introduced as a Researcher Qualifications sheet.

The effects of geomagnetic storms in near-earth space can be detected down to the ground. Auroras are enhanced by these sudden injections of particles. Current sheets build up in the ionosphere that can disrupt or damage satellite electronics. The ionosphere expands with the added magnetic energy and particles and increases the drag on satellites. Higher energy particles penetrate lower into the atmosphere. They can cause fluctuating magnetic fields that overload power grids and drown out radio transmissions with static. Astronauts and even commercial airline pilots and passengers on trans-polar routes risk higher levels of radiation exposure.

Connections between solar activity and the earth's climate are not established, but neither are they ruled out. The ultraviolet output of the Sun increases markedly with sunspot activity, although the change in the total luminosity is small. Ultraviolet light strongly affects chemical processes in the ionosphere that may in turn affect climate. The earth, with its atmosphere and ionosphere, is a very complex system affected by many factors; it is not yet known which factors are more important and which have less effect. Future research must address questions about how the earth responds to changes in the sun, how factors within the earth system (including humans) affect climate, and the relative importance of each. A Research Proposal worksheet is provided to prompt students in designing a solar research investigation.