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# Sunspots

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# S U N S P O T S

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This past semester the physics department began a study of the solar wind. Photographic plates have been sent up by balloon during periods of both maximum and minimum solar activity. The tracks made by high-energy particles on these emulsions are to be located and analyzed. Unfortunately, since the plates have yet to arrive, only a little practice scanning was done to become familiar with the technique. Meanwhile an attempt has been made to gather information about the sun and the solar wind. This paper is a part of that work.

There were numerous instances of sunspot sightings before the days of telescopes. However, the religion and philosophy of that time could not accept the idea of imperfections on one of the heavenly bodies. The spots were often explained to be the planet Mercury crossing the sun or some similar phenomena. Since only the very largest sunspots can be seen with the unaided eye, the telescope had to be invented before sunspots could be truly identified. Fabricius was the first to publish his findings in 1611. The following year Galileo claimed to have discovered them before Fabricius, and he is now often given credit for their discovery.

Sunspots consist of a dark central area known as the umbra and a lighter surrounding region called the penumbra. They are respectively about 30% and 75% as bright as the adjacent photosphere. The umbra is often circular or elliptical and covers about one fourth of the spot area. The penumbra is made up of fine lines extending approximately radially from the umbra. The center of a spot is depressed below the photospheric level, and material flows radially outward across the penumbra. Above the spot, however, the flow has been found to be radially inward. Spots often form in groups with several umbra connected by one large penumbra.

One of the first things noted about sunspots was that the number and latitude of the sunspots change in a definite cycle. The average interval between sunspot maxima is about eleven years although this may vary from eight to as many as seventeen years. Each cycle begins with a few spots at the higher latitudes, 30° to 40° N and S. As the cycle progresses, the spots increase in both size and number and gradually move to lower latitudes. The maximum occurs three to five years later when the spots are between 10° and 20°. The number of spots then declines as they near the equator. The cycle ends with a few small spots around 5°. The complete cycle takes about fourteen years. A new cycle begins several years before the last one has ended, however, making the period between maxima only eleven years.

Sunspots are always associated with strong magnetic fields which may have intensities of 50 to 4000 gauss in the center of the umbra. These fields are really the cause rather than a result of a spot. They appear before the spot forms and remain for a time after it has disappeared. As gas moves up along the magnetic lines of force, it expands and cools. Since the material is held by the magnetic field, it cannot be reheated by mixing with hotter gases nearby. Even though it is still quite hot (between 4500° and 5000°K), the gas appears as a dark spot against the 6000° photosphere.

Many sunspots are bipolar pairs with one spot preceding the other across the disk. During any particular cycle the leading spots all have the same polarity in the northern hemisphere, while in the southern hemisphere the leading spots have the opposite polarity. During the next cycle, however, these polarities are reversed. Thus the sunspots actually have a 22-year period rather than an 11-year one.

Sunspots near the edge are always surrounded by irregular, bright patches called faculae. These become invisible near the center where the photosphere is brighter. Apparently they are the white-light appearance of the phages, which are visible near the edge because they extend above the hazy photosphere.

Phages are large, irregular, bright patches which surround and often partially or completely cover sunspot groups. They can only be seen with the aid of filters. Phages usually appear a day or two before the sunspot, and they may remain several weeks after the spot has gone.

Flares are often associated with large sunspot groups. Intense magnetic storms usually occur on earth after large flares. These storms are caused by streams of particles from the sun disturbing the earth's magnetic field. Many times such storms occur when there have been no flares, however. Apparently the particles are emitted by some disturbance in the magnetic field of the sunspot. This same disturbance can also produce a flare but does not always do so.

Several theories have been proposed to explain the cause of sunspots. Using only thermo-hydrodynamical arguments, Bjerknes suggested that there is a meridional circulatory motion of the gas in the convection layer beneath the photospheric surface with a 22-year period. He postulated that there is a pair of oppositely directed vortex rings in one hemisphere and a mirror-image pair in the other. One vortex is near the surface and is moving toward the equator, while the other is in the deeper lying current flowing toward the pole. The shallow lying vortex could from time to time float to the surface and create a spot. When this vortex neared the equator it would be pulled down and started on its journey back to the pole. Meanwhile the other vortex would have reached the polar regions and would have started toward the equator in the in the upper current. Sunspots produced by this vortex would have opposite polarities from those of the earlier one.

Alfven, noting that the solar gas is fully ionized and thus highly conductive, considered both electromagnetic and hydrodynamic forces. He suggested that closed rings of magnetic flux were formed deep in the interior of the sun. When these traveled up and broke the surface, they formed bipolar sunspot pairs. He didn't explain the variation in latitude, however.

Today some theorists believe that the strong magnetic fields are created by the sun's differential rotation. The sun has a greater angular rotation at the equator than at the poles. There is a weak magnetic field of one or two gauss extending from the poles. The fast moving material near the equator tends to pull this field along and twist it. The more the field is distorted, the stronger it becomes. Calculations show that it would reach sufficient values to create sunspots first at higher latitudes and then gradually closer to the equator. As these ropes of magnetic flux near the equator, they apparently cancel each other. The poloidal field of the sun meanwhile reverses polarity. A new cycle then begins which forms spots of opposite polarities. This model seems to give a fairly good fit to known data, but it will still be some time before we completely understand the nature of sunspots.

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