SOLAR PHYSICS

Magnetism of the Sun

"A Classic of Science"

THE EARTH AND SUN AS MAGNETS. By Dr. George Ellery Hale. Address delivered at the semi-centennial of the National Academy of Sciences, at Washington, D. C., May, 1913. Published in the Annual Report of the Smithsonian Institution for 1913. Washington, 1914.

IN CERTAIN regions of the sun we have strong evidence of the existence of free electrons. This leads us to the question of solar magnetism and suggests a comparison of the very different conditions in the sun and earth. Much alike in chemical composition, these bodies differ principally in size, in density, and in temperature. The diameter of the sun is more than 100 times that of the earth, while its density is only one-quarter as great. But the most striking point of difference is the high temperature of the sun, which is much more than sufficient to vaporize all known substances. This means that no permanent magnetism, such as is exhibited by a steel magnet or a lodestone, can exist in the sun. For if we bring a steel magnet to a red heat it loses its magnetism and drops the iron bar which it previously supported. Hence, while some theories attribute terrestrial magnetism to the presence within the earth of permanent magnets, no such theory can apply to the sun. If magnetic phenomena are to be found there they must result from other causes.

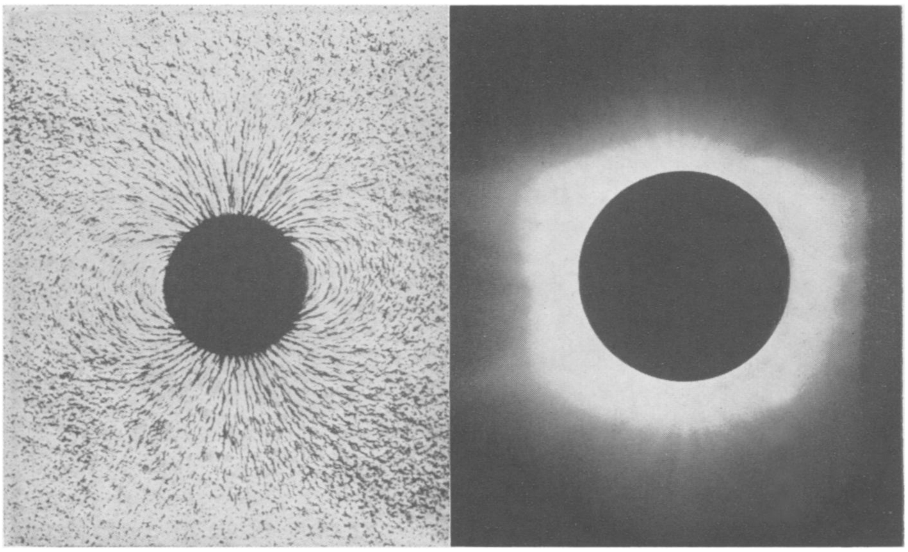
The familiar case of the helix illustrates how a magnetic field is produced by an electric current flowing through a coil of wire. But according to the modern theory, an electric current is a stream of electrons. Thus a stream of electrons in the sun should give rise to a magnetic field. If the electrons were whirled in a powerful vortex, resembling our tornadoes or waterspouts, the analogy with the wire helix would be exact, and the magnetic field might be sufficiently intense to be detected by spectroscopic observations.

A sun spot, as seen with a telescope or photographed in the ordinary way, does not appear to be a vortex. If we examine the solar atmosphere above and about the spots, we find extensive clouds of luminous calcium vapor, invisible to the eye, but easily photographed with the spectroheliograph by admitting no light to the sensitive plate except that radiated by calcium vapor. These calcium flocculi, like the cumulus clouds of the earth's atmosphere, exhibit no well-defined linear structure. But if we photograph the sun with the red light of hydrogen, we find a very different condition of affairs. In this higher region of the solar atmosphere, first photographed on Mount Wilson in 1908, cyclonic whirls, centering in sun spots, are clearly shown.

The idea that sun spots may be solar tornadoes, which was strongly suggested by such photographs, soon received striking confirmation. A great cloud of hydrogen, which had hung for several days on the edge of one of these vortex structures, was suddenly swept into the spot at a velocity of about 60 miles per second. More recently Slocum has photographed at the Yerkes Observatory a prominence at the edge of the sun, flowing into a spot with a somewhat lower velocity.

Thus we were led to the hypothesis that sun spots are closely analogous to tornadoes or waterspouts in the earth's atmosphere. If this were true, electrons caught and whirled in the spot vortex should produce a magnetic field. Fortunately, this could be put to a conclusive test through the well-known influence of magnetism on light discovered by Zeeman in 1896.

In Zeeman's experiment a flame containing sodium vapor was placed between the poles of a powerful electromagnet. The two yellow sodium lines, observed with a spectroscope of high dispersion, were seen to widen the instant a magnetic field was produced by passing a current through the coils of the magnet. It was subsequently found that most of the lines of the spectrum, which are single under ordinary conditions, are split into three components when the radiating source is in a sufficiently intense magnetic field. This is the case when the observation is made at right angles to the lines of force. When looking along the lines of force, the central line of such a triplet disappears, and the light of the two side components is found to be circularly polarized in opposite directions. With suitable polarizing apparatus, either component of such a line can be cut off at will, leaving the other unchanged.



Smithsonian Report, 1913—Hale Lick Observatory

POLAR STREAMERS OF THE SUN'S CORONA

Shown in the photograph on the right suggest the lines of force about a spherical magnet, made visible with iron filings in the picture on the left.

Furthermore, a double line having these characteristic properties can be produced only by a magnetic field. Thus it becomes a simple matter to detect a magnetic field at any distance by observing its effect on light emitted within the field. If a sun spot is an electric vortex, and the observer is supposed to look along the axis of the whirling vapor, which would correspond with the direction of the lines of force, he should find the spectrum lines double, and be able to cut off either component with the polarizing attachment of his spectroscope.

I applied this test to sun spots on Mount Wilson in June, 1908, with the 60-foot tower telescope, and at once found all of the characteristic features of the Zeeman effect. Most of the lines of the sun-spot spectrum are merely widened by the magnetic field, but others are split into separate components, which can be cut off at will by the observer. Moreover, the opportune formation of two large spots, which appeared on the spectroheliograph plates to be rotating in opposite directions, permitted a still more exacting experiment to be tried. In the laboratory, where the polarizing apparatus is so adjusted as to transmit one component of a line doubled by a magnetic field, this disappears and is replaced by the other component when the direction of the current is reversed. In other words, one component is visible alone when the observer looks toward the north pole of the magnet, while the other appears alone when he looks toward the south pole. If electrons of the same kind are rotating in opposite directions in two sun spot vortexes, the observer should be looking toward a north pole in one spot and toward a south pole in the other. Hence the opposite components of a magnetic double line should appear in two such spots. As our photographs show, the result of the test was in harmony with my anticipation. . . .

We thus have abundant evidence of the existence on the sun of local magnetic fields of great intensity—fields so extensive that the earth is small in comparison with many of them. But how may we account for the copious supply of electrons needed to generate the powerful currents required in such enormous electromagnets? Neutral molecules, postulated in theories of the earth's field, will not suffice. A marked preponderance of electrons of one sign is clearly indicated.

An interesting experiment, due to Harker, will help us here. Imagine a pair of carbon rods insulated within a furnace heated to a temperature of two or three thousand degrees. The outer ends of the rods projecting from the furnace are connected to a galvanometer. Harker found that when one of the carbon terminals within the furnace was cooler than the other a stream of negative electrons flowed toward it from the hotter electrode. Even at atmospheric pressure currents of several amperes were produced in this way.[1]

Our spectroscopic investigations, interpreted by laboratory experiments, are in harmony with those of Fowler in proving that sun spots are comparatively cool regions in the solar atmosphere. They are hot enough, it is true, to volatilize such refractory elements as titanium, but cool enough to permit the formation of certain compounds not found elsewhere in the sun. Hence, from Harker's experiment, we may expect a flow of negative electrons toward spots. These, caught and whirled in the vortex, would easily account for the observed magnetic fields.

[1] King has recently found that the current decreases very rapidly as the pressure increases, but is still appreciable at a pressure of 20 atmospheres.

The conditions existing in sun spots are thus without any close parallel among the natural phenomena of the earth. The sun-spot vortex is not unlike a terrestrial tornado, on a vast scale, but if the whirl of ions in a tornado produces a magnetic field, it is too feeble to be readily detected. Thus, while we have demonstrated the existence of solar magnetism, it is confined to limited areas. We must look further if we would throw new light on the theory of the magnetic properties of rotating bodies.

This leads us to the question with which we started: Is the sun a magnet like the earth? The structure of the corona, as revealed at total eclipses, points strongly in this direction. Remembering the lines of force of our magnetized steel sphere, we can not fail to be struck by their close resemblance to the polar streamers in the beautiful photographs of the corona. . . Bigelow, in 1889, investigated this coronal structure and showed that it is very similar to the lines of force of a spherical magnet. Stömer, guided by his own researches on the aurora, has calculated the trajectories of electrons moving out from the sun under the influence of a general magnetic field and compared these trajectories with the coronel streamers. The resemblance is apparently too close to be the result of chance. Finally, Deslandres has investigated the forms and motion of solar prominences, which he finds to behave as they would in a magnetic field of intensity about one-millionth that of the earth. We may thus infer the existence of a general solar magnetic field. But since the sign of the charge of the outflowing electrons is not certainly known, we can not determine the polarity of the sun in this way. Furthermore, our present uncertainty as to the proportion at different levels of positive and negative electrons and of the perturbations due to currents in the solar atmosphere must delay the most effective application of these methods, though they promise much future knowledge of the magnetic field at high levels in the solar atmosphere.

Science News Letter, February 28, 1931