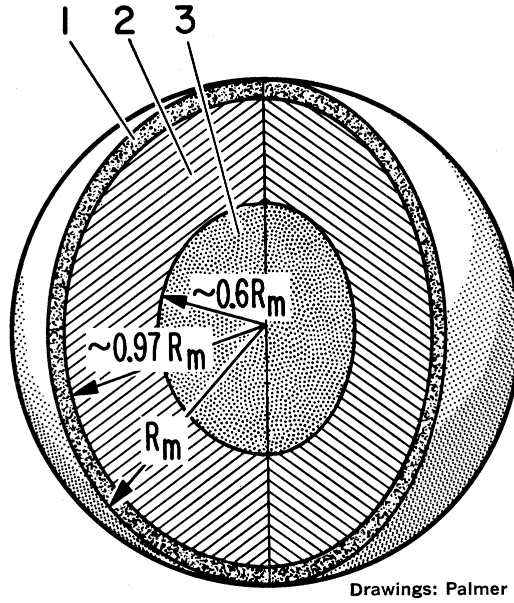
That magnetic moon: How did it get that way?

Existing theories are inadequate to explain the lunar magnetism



Drawings: Palmer Dyal

A moon model based on electrical conductivity.

by Everly Driscoll

"It would be much simpler to explain most of the things we understand about the moon, if we could somehow dispose of this magnetic field. Unfortunately, my colleagues will not allow me to do that."
—Paul W. Gast

Before the first lunar landing, scientists had some relatively simple models for the structure and composition of the moon. The most accepted one fell somewhere between the models for the earth's evolution, chemical differentiation and dynamic atmosphere and the still relatively primitive models for the outer planets.

The first big shocker from the Apollo samples was evidence that the lunar material had gone through extensive chemical differentiation, either before it accreted to form the moon, or on the moon itself. This did not fit the simple model.

Now the moon has thrown lunar scientists a more difficult curve—evidence in the rocks of a magnetic history for the moon (SN: 1/22/72, p. 54).

According to David W. Strangway of NASA's Manned Spacecraft Center (MSC), the moon rocks have a very stable remanent magnetism—as stable or more so than magnetism found in earth rocks. Remanent magnetism is acquired when a melted rock cools and passes through a certain temperature called its Curie point (about 800 degrees C. for iron). At this point, the rock acquires a magnetism that is proportional to the magnetic field it is exposed to. Strangway finds that the rocks—breccias as well as igneous—were exposed to a source field of about 500 to 1,000 gammas for a period of at least a billion years—at least over the period from 3.3 billion to 4.1 billion years ago.

Strangway's findings have been confirmed by two independent sources: the magnetometers taken to the surface of the moon and the magnetometers in the Apollo 15 and 16 subsatellites. The surface magnetometers measured the remanent fields as well as local anomalies. At the Apollo 12 site it registered a field of 38 gammas; the Apollo 14 portable magnetometer found one field of 103 gammas and another of 43 gammas. At the Apollo 15 site there was a 6-gamma field; and most recently at various locations at Apollo 16, the magnetometer measured fields of 120, 125, 180, 230 and 313 gammas. Calculations made from data from the surface instruments show a temperature for the center portion of the moon (using one particular rock model) to be 1,000 degrees C., according to Palmer Dyal of NASA's Ames Research Center. The temperatures for the outer bulk of the moon are about 730 degrees C. Peridotite is the rock used for both models.

Paul J. Coleman of the University of California at Los Angeles has been making a map of lunar magnetism from data of the orbital magnetometer. What he is finding are local perturbations caused by geological activity or crater impacts. The far side is much lumpier magnetically than the near side (which is also characteristic of the topography), and strong peaks are seen in craters such as Van de Graaff, Gagarin and Korolev on the far side (SN: 9/18/71, p. 194). The field seems to be vertical—pointing toward the center of the moon.

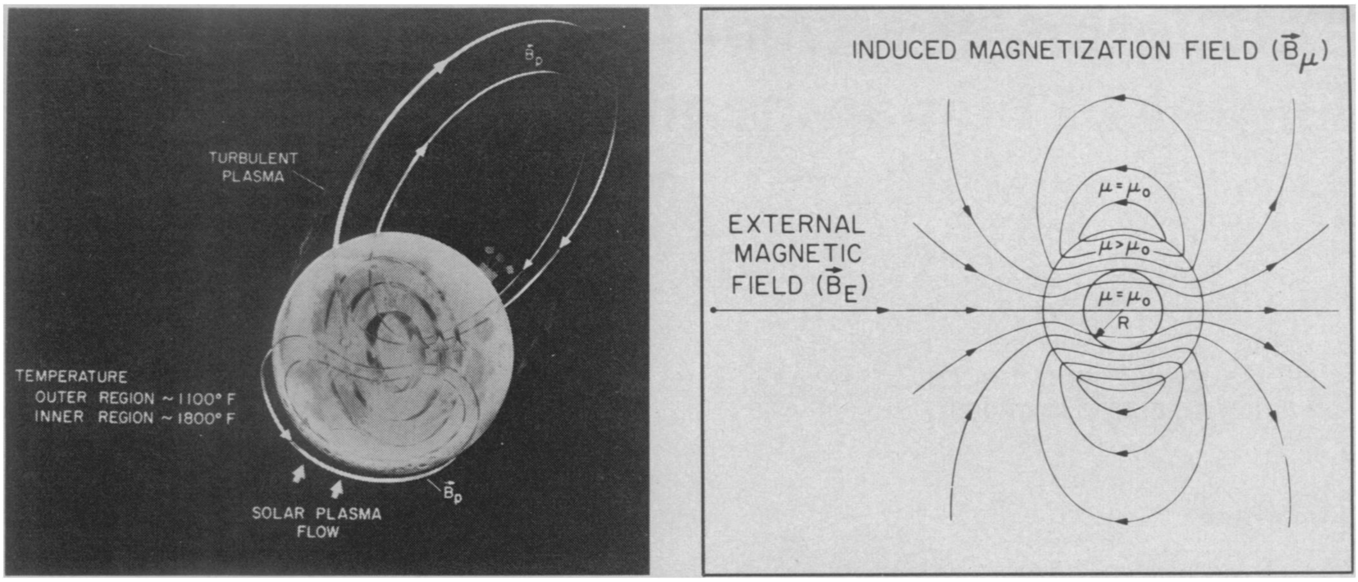
What does all this mean? It means the moon either had a magnetic field of its own or that it was exposed to another source field for at least a billion years. And that is a problem.

"We don't know the source of this field, although we suspect that there must have been a large-scale global field in the neighborhood of the moon during this time," says Charles P. Sonett, also of Ames. "This discovery, in my opinion, will have profound bearing upon the development of lunar theory over the next several years." Already it is causing much discussion.

There are three theories for this source field and there are problems with all three. One theory is that the magnetic field was acquired by the rocks during a close approach of the moon to the earth. The earth's field is sufficiently strong: today it is about 35,000 gammas at the equator and twice that at the magnetic poles. At the distance of the moon, however, it is only a few gammas. The moon could have been, at one time, close enough to the earth to be magnetized by it, but because of tidal action, the moon would have receded very quickly—within thousands of years. The magnetization of the moon would require presence of the source for a billion years or more.

"There are also grave difficulties with the second theory," says Sonett. This is the possibility that the source was the solar field. Today the magnetic field in the solar wind is only about 5 gammas at the distance the earth is from the sun. For the moon to have acquired it from the sun would require the sun to have been spinning much faster or have a larger magnetic field than it does today. Both of these are unlikely, says Sonett.

The third possibility—that the moon had a dynamo-produced field of its own—also has problems. Geophysicists believe that a planet may begin with no magnetic field of its own. If it has a fluid electrically conducting core and is spinning, and at the same time is exposed to a weak "seed" field, present in the galaxy, then the fluid core will interact with the seed field. As the fluid motions in the core interact, a dynamo process is started. The result is that the weak field becomes stronger.



The moon could have been magnetized by its own dynamo (cover), the solar magnetic field (left) or the earth's field.

"There are serious consequences in the conclusion that the moon had a magnetic field," says Paul W. Gast of MSC.

Presently the moon's spin is thought to be too slow to sustain a dynamo. This leaves scientists with the alternative that the moon was spinning faster at one time and then slowed down through capture by the earth. (There are problems unanswered with the capture theory also.)

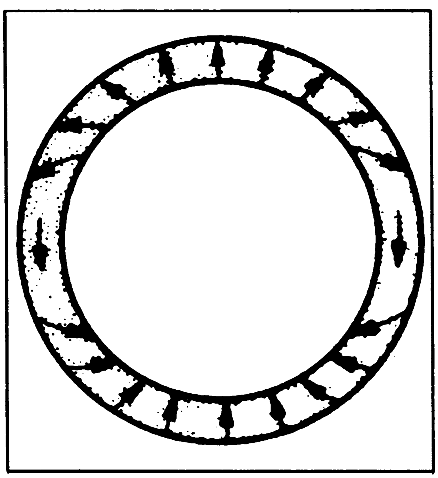
The underlying chemical problem of the magnetism is that one needs to form a dynamo (which in chemical terms is an iron or highly conducting core) very early in the moon's history. "There are essentially two simple-minded ways of doing this," Gast says. One is to start out growing the moon with iron and accrete the other material later. The other is to have metallic iron in the moon, and have it segregate to the core early. This, says Gast, probably takes very high temperatures (1,200 C. or higher). It would be nice just to be able to melt the core and melt the surface, without melting the whole moon. But to get enough iron to the core, the whole moon has to get hot in a relatively short period of time.

The problems with a whole moon-melt, notes Strangway, is that if the whole moon melted so that the heavy elements went to the core and the light ones to the surface, the result would be a stratified moon. What scientists know about the distribution of mass within the moon indicates that the moon is not stratified substantially, but is relatively homogeneous. "It's not a problem of having a core. It's a problem of making a core," says Strangway.

Another problem with the dynamo theory for the source of magnetization is temperature. The moon's interior is now relatively cool—800 degrees C. to 1,000 degrees C. (depending on the rock model), well below the melting point of metallic iron. To cool the whole moon from melting temperatures down to those values of today cannot be explained merely by conduction. Convection, involving actual flow of subsurface material, is also required. (S. Keith Runcorn of the University of Newcastle upon Tyne, England, first postulated several years ago that the moon had convection because of its non-symmetrical shape; not many scientists agreed with him.)

The problem with convection, says Strangway, is that it has too many variables. "Anything not understood can be attributed to convection, but it is difficult to make good solid quantitative models to fit convection." (Convection, for example, would tend to wipe out the concentrations of mass found on the moon called mascons.)

If the moon has to have a core to explain the magnetism—and an iron core is incompatible with what is known about the moon so far—then Robin Brett of MSC has an alternative. At the American Geophysical Union meeting in Washington in April, he suggested a core model that attempts to reconcile, as much as possible, the differences between the thermal situations needed by the magnetometrists and the geochemists. His model fits the temperature limitations of the current moon and the dynamo requirements of the old moon. It is a molten iron-nickel-sulfur core that occupies up to 20 percent of the moon's radius and requires a bulk sulfur content for the moon of only 0.3 percent by weight. This agrees with the fact that sulfur appears to be strongly depleted in lunar basalts compared to chondritic meteorites. Sulfur alloys readily with iron. The sulfur serves to lower the melting point, so the moon doesn't have to get as hot. The minimum melting point of a mixture of iron and iron sulfide is only 988 degrees C. at one atmosphere and 1,000 degrees C. at the estimated pressure at the center of the moon (50 kilobars). V. R. Murthy and his colleagues at the University of Minnesota had suggested a layer in the moon rich with iron and iron sulfide to explain a proposed layer of high electrical conductivity at 250 kilometers, as well as the observed moments of inertia, the heat production in the outer portions, and the depletion of some volatile elements. But, says Brett, they did not suggest that this layer might act also as a dynamo. Brett is now working on the conductivity of such a core.



A model for lunar magnetism today.

How the moon acquired its magnetization is obviously up for grabs. One thing is for sure, says Strangway: "the moon was magnetized."

"One of the exciting things about this paradox or enigma," says Gast, "is perhaps behind all of this is an explanation that none of us are thinking about today. Eventually some smart person will sit down and have a very bright idea which explains it all." □