'Hall effect' research reaches new plateaus

Experimenters must learn to expect the unexpected. Recently, physicists studying electron gases at low temperatures and in strong magnetic fields began tests aimed at revealing patterns in the charge density of the gas indicating the electrons were beginning to crystallize. Instead, they discovered a new phenomenon, dubbed the "fractionally quantized Hall effect," produced by what may be a liquid electron state, that defies complete theoretical explanation. The finding could conceivably point the way toward an ideal electrical conductor. Results of the work have just been released in the June 13 PHYSICAL REVIEW LETTERS by Horst L. Stormer, Jin C. M. Hwang, Arthur C. Gossard and William Wiegmann at Bell Laboratories in Murray Hill, N.J. and their colleagues Albert M. F. Chang and Daniel C. Tsui at Princeton University in Princeton, N.J.

The classical Hall effect is induced by a deflection in the motion of charge carriers in a current-carrying sample when it is immersed in a perpendicular magnetic field. The effect has long been used to determine the concentration of charge carriers in electrical samples. First evidence for a quantum mechanical version was discovered three years ago by Klaus von Klitzing at the University of Würzburg in West Germany. It is signaled by quantum steps or "plateaus" of constant electrical resistance in a direction perpendicular to the direction of the electrical field (the Hall resistance) as the voltage is varied. The plateaus can all be represented by the ratio of two fundamental physical constants divided by an integer. The effect has been used to determine the fine structure constant (the constant that measures the strength of the electromagnetic force) to high precision (SN: 1/16/82, p. 39).

Gaps between the energies of single electrons account for this integral version of the quantum Hall effect. This explanation is insufficient, however, to account for the new experimental data of Stormer and his co-workers. The Hall resistance plateaus in the new results are labeled by fractions of the form p/q (where p and q are integers and q is odd) rather than by integers. It is believed that these new plateaus arise for very different reasons than do the integral ones and are indications of a gap between the allowed energies of a collective state of many electrons rather than just a single one.

Current work of theoretical physicist Robert B. Laughlin, staff scientist at Lawrence Livermore National Laboratory in Livermore, Calif., has shed light on the probable quantum liquid nature of the new states. His theory predicts the presence of some, but not all, of the fractional quantum states. "The problem has not been completely solved," Stormer contends, "because there hasn't been any interpretation of the 2/5, 3/5 and 2/7 (states)." Laughlin agrees and admits, "I can't explain those states." Work continues to extend the experimental studies to even lower temperatures and stronger magnetic fields.

Until recently, according to Stormer, the lack of a material that permitted a high enough electron mobility prevented the discovery of the fractional quantization. The new hybrid structure that solved the problem for Stormer and his colleagues confined the electron gas to the two dimensional surface at the nearly perfect interface of two crystalline semiconductors. The interface provided a smooth background for the motion of the electrons.

Since the quantized Hall effect is characterized by an electrical resistance parallel to the electric field (to be distinguished from the Hall resistance) far below those of the best "normal" metals, it may hold implications for technology as an ideal electronic conductor. However, according to Stormer, the low temperature (around 4 Kelvins) and especially the high magnetic fields (tens of thousands of Gauss) needed to obtain the effect will provide obstacles for applications. —*P. D. Sackett*

Cosmic rays that may go straight

Cosmic rays have been studied for about 70 years, but still nobody knows for certain where they come from. Cosmic rays are — or used to be — electrically charged particles, mostly protons but with some atomic nuclei. As they move through space, the magnetic field of the galaxy bends their paths, and by the time they arrive at the earth they have been so twisted around that the directions from which they hit the top of the atmosphere tell nothing about their origin.

Lately, however, some strange cosmic-ray events have been recorded that appear to be from cosmic rays that have come straight through. These events have been seen in a detector that was set up 2,000 feet underground by a group from the University of Minnesota in Minneapolis led by Marvin Marshak and John Bartelt to look for radioactive decay of the proton. If these cosmic ray events do represent something that has come straight through the galactic magnetic field, they could represent the opening of a new branch of astronomy, Marshak says.

What is seen are showers of particles called muons. Such showers are ordinarily produced when cosmic rays strike the top of the atmosphere. That these showers penetrate through 2,000 feet of earth means that the particles that produced them hit the atmosphere with energies so high as to be rare even in cosmic rays, more than 10^{17} electron-volts. (This is about 200,000 times the highest energies that can be achieved in laboratory accelerators.)

More interesting, however, is that some of these high-energy muon showers show directional correlations. Over a few minutes, successive ones sometimes point backward in the same direction. Usually, successive cosmic-ray hits come from random directions. Two directions have so far been singled out, that of the constellation Cygnus and that of the north pole of the galaxy.

The observers put forward three hypotheses that may account for the finding. The high energies of the original cosmic rays may make them so "stiff" to a magnetic field that the field does not bend their paths much. These rays may be coming through regions where the galactic field is much less than average ("holes" or "bubbles" in the field), and so not get bent. Or the primaries may be neutral particles —such as very high-energy gamma rays— not affected by the magnetic field.

Marshak told SCIENCE NEWS that there is yet no way to choose among the hypotheses. "Currently the statistics are limited," he says. "Of 5,000 such multiple muon events, only 50 show anomalous [that is, correlated] behavior."

Marshak wants to correlate his own findings with those of two similar underground detectors, one under Mont Blanc on the French-Swiss border, and one in Kolar Gold Fields in India. He says he has informal information that both those detectors have seen similar things, but the physicists involved with them feel that they do not yet have enough hard data to make confirming claims formally. (Both of the other detectors are buried deeper than the one Marshak and Bartelt are working with, so they should see correspondingly fewer cosmic-ray events of any kind.) Marshak and Bartelt presented their findings at this week's meeting of the American Astronomical Society in Minneapolis.

Of the three hypotheses, the gamma-ray one seems to be the most exciting. It would open a new branch of astronomy— looking for the sources of such gamma rays — and possibly a new branch of astrophysics — trying to figure out what processes or what kind of object produces them. Marshak and co-workers intend to test for this hypothesis specifically in the near future by laying out electron detectors on the surface above the mine. If the directed muon showers are caused by high-energy gamma ray hits on the top of the atmosphere, those hits should also produce electron showers. Electrons will not penetrate the earth, but they are detectable on the surface. If electron showers are seen in correlation with the strange muon showers, that would go a long way in support of the gamma-ray hypothesis.

—*D. E. Thomsen*