Single Electron Transistor Explained

Cincinnati—A group of researchers at the Massachusetts Institute of Technology may have solved the Mystery of the Single Electron Transistor. If their solution holds water, then it will shed some new light on the behavior of electrons confined to very small spaces.

Last August, physicists Marc Kastner, Paul McEuen, and Ethan Foxman at MIT and Shalom Wind at IBM reported the development of a super-sensitive transistor in which the current switches on and off as electrons are passed almost single file through a cramped, micron-sized space (see *Science*, 10 August, p. 629). But their device displayed a curious anomaly: The current flowing through the space fluctuated wildly, causing some to wonder whether they had stumbled upon some new physical phenomenon. Now another MIT group, theoretical physicists Patrick Lee, Yigal Meir, and Ned Wingreen, has explained the anomaly in terms of the quantum effects that rule an electron's behavior in an atom.

"Just last summer an article in *Science* magazine said theory hadn't yet caught up with experiment," says Wingreen, who reported his group's results at a meeting of the American Physical Society here last month. "Now, we have developed a theory and confirmed it with another experiment."

In the original experiment, Kastner and his colleagues developed a device that forces electrons to trickle one at a time through a narrow passage. The device—which works only at very low temperatures, just a nudge above absolute zero—first crams electrons into a plane between surfaces of gallium arsenide and aluminum-gallium arsenide, and then squeezes them into a narrow lane between two charged metal "gates." Using strategically placed constrictions in the gates, the researchers cut the line of electrons in two places, stranding 50 or so electrons in a tiny area they dubbed a "Coulomb island."

The experimenters found that, by varying the voltage between electrodes on their device, they could add electrons one by one to the island. As they did that, they measured a series of sharp peaks in current (in this case current roughly corresponds to how easily the researchers can add more electrons to the island). The low points occur, Wingreen explains, when the island holds a whole number of electrons. Mutual repulsion between electrons makes them into an exclusive club that takes a lot of energy to join.

The peaks appear when the voltage across the electrodes results in a half-number of electrons on the island (meaning there are, say, 6 half the time and 7 half the time). At those voltages, Wingreen says, the device allows electrons to flow. "The strange thing, though, is that we get all these peaks of different heights," he says. "Each peak behaves in a completely different manner," adds Meir. Stranger still, raising the temperature of the device evens out the peaks, shrinking the high ones and raising the low ones.

To explain these anomalies, Meir looks at electrons as waves that can have only certain frequencies, or energies. They tend to act that way in atoms, taking on only specific allowed energy levels. "We are seeing two quantum effects," says Meir, "the quantization of charge, which allows you to have only a discrete number of electrons, as well as the quantization of the energy states assumed by those electrons."

Meir reasoned that the rules of the island dictate that each electron added must take on a different wave function—or energy state—from those already there. Flowing electrons approaching the island can slip into some of these energy states much more easily than others. "The seventh state may be harder to enter than the sixth, but the eighth may then be easier than the seventh," says Meir. Hence, the current peaks of different heights.

Raising the temperature, Meir surmised, would allow the electrons flexibility over which energy state they can enter: At higher temperatures, electrons on the island can swap energy states, so everything gets averaged out. "The temperature effect was a big mystery to us," says Kastner. "This part of the theory is especially important, and beautiful."

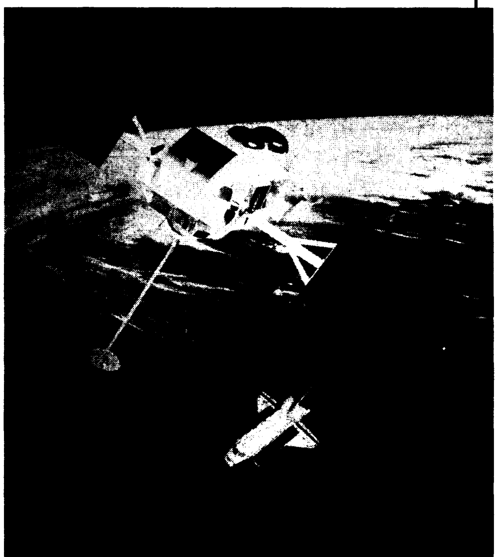
Meir's group tested the theory with an experiment to see whether the electrons in the island really were taking on discrete energy states. The researchers did that by applying a magnetic field to the device, which Kastner says makes the electron energy states very predictable. The island-bound electrons in the magnetic field did, indeed, seem to take on the discrete energies that the theorists predicted.

Meir says the device's ability to change its current drastically with a tiny change in applied voltage could prove very useful. First, though, researchers will have to make it work at much higher temperatures, since transistors that only work close to absolute zero are not exactly practical. "And the way to do that," says Meir, "is to understand the physics."

■ FAYE FLAM

A New Star Is Born

Death and birth on a cosmic scale are hot and tumultuous—yet often undetectable by even the most powerful of conventional telescopes. Enter the Gamma-Ray Observatory (GRO), which was launched with the Space Shuttle Atlantis on 5 April.



GRO's ability to detect gamma rays, which are not visible to earth-bound telescopes, should open another new window on supernovae, quasars, black holes, and other celestial phenomena. The first was the Hubble Telescope, which was deployed last year and detects visible and ultraviolet light. And NASA is planning two more—specializing in the x-ray and infrared portions of the electromagnetic spectrum—in its ambitious suite of "Great Observatories."

If all goes well, GRO's instruments will be turned on sometime this month. But unless its detectors pick up a gamma-ray burst or a bright solar flare, GRO will spend its first year-and-a-half in orbit generating a gamma-ray profile of the universe. Only then will it focus in on specific sources for the remainder of it's 5-year orbit. Stephen Holt, director of Space Sciences at NASA's Goddard Space Flight Center in Greenbelt, Maryland, cautions that a year may pass before GRO makes any new discoveries.

■ MICHELLE HOFFMAN