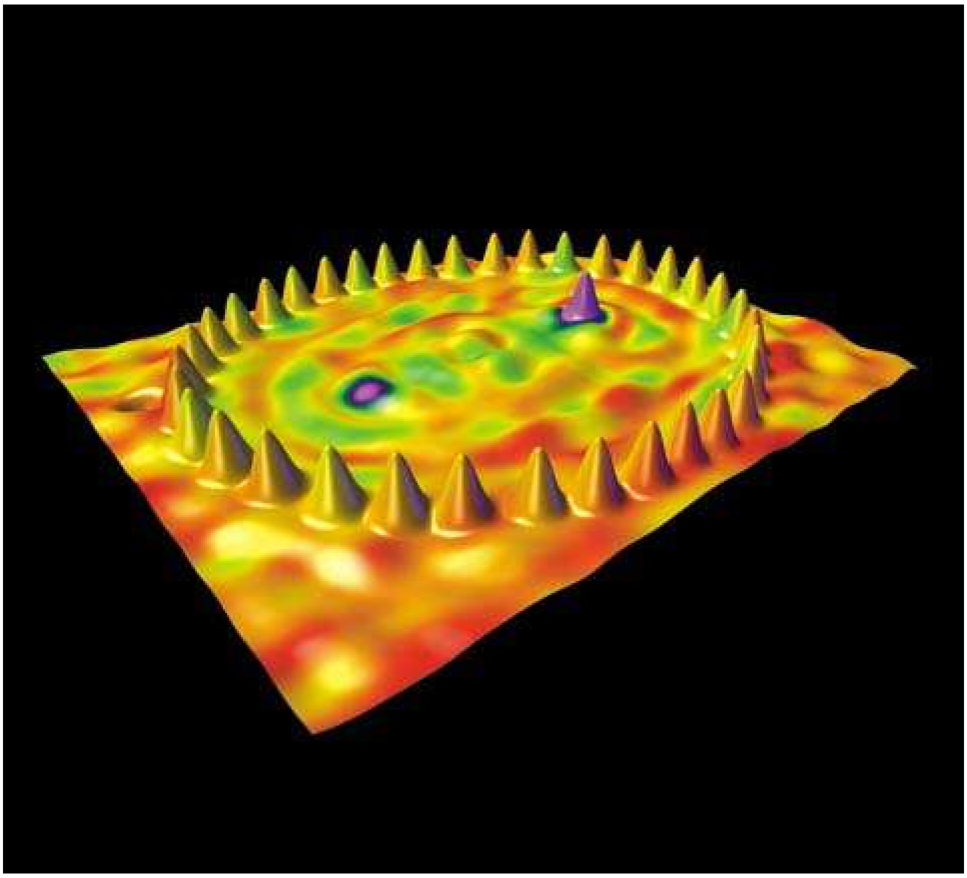
Miroir quantique pour les électrons

Les pics visibles sur cette image de microscopie à effet tunnel correspondent à trente-six atomes de cobalt qui dessinent le contour d'une ellipse sur une surface de cuivre. Un trente-septième atome, placé à l'un des foyers de l'ellipse, influence par sa présence les électrons du cuivre dans son voisinage (pic violet, à droite). Or, à l'autre foyer (point violet, à gauche), les électrons du cuivre se comportent aussi, quoique de façon atténuée, comme s'il y avait un atome de cobalt.

Ce « mirage quantique » est une manifestation du caractère ondulatoire de la matière à cette échelle : les ondes associées aux électrons se réfléchissent sur les parois de l'ellipse et forment une image au foyer inoccupé. Ce phénomène est présenté par ses découvreurs comme utilisable pour la transmission d'informations dans des nanocircuits.

H.C. Manoharan *et al., Nature, 403,* 512, 2000.



Quantum mirage

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In physics, a **quantum mirage** is a peculiar result in quantum chaos. Every system of quantum dynamical billiards will exhibit an effect called *scarring*, where the quantum probability density shows traces of the paths a classical billiard ball would take. For an elliptical arena, the scarring is particularly pronounced at the foci, as this is the region where many classical trajectories converge. The scars at the foci are colloquially referred to as the "quantum mirage".

The quantum mirage was first experimentally observed by Hari Manoharan, Christopher Lutz and Donald Eigler at the IBM Almaden Research Center in San Jose, California in 2000. The effect is quite remarkable but in general agreement with prior work on the quantum mechanics of dynamical billiards in elliptical arenas.

Quantum corral

The mirage occurs at the foci of a **quantum corral**, a ring of atoms arranged in an arbitrary shape on a substrate. The quantum corral was demonstrated in 1993 by Lutz, Eigler, and Michael Crommie, now a professor at the University of California, using an ellipitical ring of cobalt atoms on a copper surface. The ferromagnetic cobalt atoms reflected the surface electrons of the copper inside the ring into a wave pattern, as predicted by the theory of quantum mechanics.

The size and shape of the corral determine its quantum states, including the energy and distribution of the electrons. To make conditions suitable for the mirage the team at Almaden chose a configuration of the corral which concentrated the electrons at the foci of the ellipse.

When scientists placed a magnetic cobalt atom at one focus of the corral, a mirage of the atom appeared at the other focus. Specifically the same electronic properties were present in the electrons surrounding both foci, even though the cobalt atom was only present at one focus.

References

- "Quantum Mirage" may enable atom-scale circuits, IBM Research Almaden, 3rd Feb 2000
- Theory of Quantum Corrals and Quantum Mirages

Quantum Mirage

SAN JOSE, Calif. (February 3, 2000) -- IBM scientists have discovered a way to transport information on the atomic scale that uses the wave nature of electrons instead of conventional wiring. The new phenomenon, called the "quantum mirage" effect, may enable data transfer within future nanoscale electronic circuits too small to use wires.

"This is a fundamentally new way of guiding information through a solid," said IBM Fellow Donald M. Eigler, IBM's lead researcher on this project.. "We call it a mirage because we project information about one atom to another spot where there is no atom."

As computer circuit features shrink toward atomic dimensions -- which they have for decades in accordance with Moore's Law -- the behavior of electrons changes from being like particles described by classical physics to being like waves described by quantum mechanics. On such small scales, for example, tiny wires don't conduct electrons as well as classical theory predicts. So quantum analogs for many traditional functions must be available if nanocircuits are to achieve the desired performance advantages of their small size.

IBM's new quantum mirage technique may prove to be just such a substitute for the wires connecting nanocircuit components.

The quantum mirage was discovered by three physicists at IBM's Almaden Research Center here: Hari C. Manoharan, Christopher P. Lutz and Eigler. They reported their findings in the cover story of the February 3 issue of Nature, a prestigious international scientific journal published in London. They used the same low-temperature scanning tunneling microscope (STM) with which Eigler and Erhard Schweizer first positioned individual atoms 10 years ago, spelling out the letters I-B-M with 35 xenon atoms.

To create the quantum mirage, the scientists first moved several dozen cobalt atoms on a copper surface into an ellipse-shaped ring. As Michael Crommie (who is now a professor at the University of California-Berkeley), Lutz and Eigler had shown in 1993, the ring atoms acted as a "quantum corral" -- reflecting the copper's surface electrons within the ring into a wave pattern predicted by quantum mechanics.

The size and shape of the elliptical corral determine its "quantum states" -- the energy and spatial distribution of the confined electrons. The IBM scientists used a quantum state that concentrated large electron densities at each focus point of the elliptical corral. When the scientists placed an atom of magnetic cobalt at one focus, a mirage appeared at the other focus: the same electronic states in the surface electrons surrounding the cobalt atom were detected even though no magnetic atom was actually there. The intensity of the mirage is about one-third of the intensity around the cobalt atom.

"We have become quantum mechanics -- engineering and exploring the properties of quantum states," Eigler said. "We're paving the way for the future nanotechnicians."

The operation of the quantum mirage is similar to how light or sound waves is focused to a single spot by optical lenses, mirrors, parabolic reflectors or "whisper spots" in buildings. For example, faint sounds generated at either of the two "whisper spots" in the Old House of Representatives Chamber (now called Statuary Hall) in the U.S. Capitol Building in Washington, D.C., can be heard clearly far across the chamber at the other whisper spot.

"The quantum mirage technique permits us to do some very interesting scientific experiments such as remotely probing atoms and molecules, studying the origins of magnetism at the atomic level, and ultimately manipulating individual electron or nuclear spins," said Dr. Manoharan. "But we must make significant improvements before this method becomes useful in actual circuits. Making each ellipse with the STM is currently impractically slow. They would have to be easily and rapidly produced, connections to other components would also have to be devised and a rapid and power-efficient way to modulate the available quantum states would need to be developed."

The IBM scientists have built and tested elliptical corrals up to 20 nanometers long with the width as little as half that. (A nanometer is one billionth of a meter -- about 40 billionths of an inch -- or about the size of a five atoms placed side-by-side.) The electron density and intensity of the mirage depends on the quantum state, not the distance between the foci.

IBM Research operates in eight locations worldwide: the Thomas J. Watson Research Center in Yorktown Heights, NY; the Almaden Research Center in San Jose, Calif.; the Zurich Research Laboratory in Zurich, Switzerland; the Tokyo Research Laboratory in Yamato, Japan; the Haifa Research Laboratory in Haifa, Israel; the China Research Laboratory in Beijing, China, the Austin Research Laboratory in Austin, Texas, and the India Research Center in Dehli, India.

IBM Research has long been a leader in studying the properties of materials important to the information technology industry. In 1981, Gerd Binnig and Heinrich Rohrer of IBM's Zurich Research Laboratory in Switzerland invented the scanning tunneling microscope, which enabled scientists to see -- and in 1990, position -- individual atoms. For this achievement, they shared the 1986 Nobel Prize in Physics. In 1984, Binnig co-invented the Atomic Force Microscope, which led to a variety of new instruments that used various tiny cantilevers to extend near-atomic resolution imaging to many to many new forces, including friction and magnetism. IBM's Almaden (San Jose, Calif.), Watson (Yorktown Heights, N.Y.) and Zurich (Switzerland) laboratories continue active and complementary nanotechnology research efforts.

For more information on IBM Research, please visit the Website at:
http://www.research.ibm.com

Dramatic electronic images showing the quantum mirage are available at WWW URL:
http://www.almaden.ibm.com/almaden/media/image_mirage.html