information became available to him. As a result, at least five different versions are recognized today (*6*). In understanding Smith's contribution to geology, the 1815 map cannot be considered in isolation; it was accompanied by an explanatory memoir describing the rocks and soils (*7*), and the small cross section on the map (see the first figure) was soon supplemented by a series of eight large geological cross sections showing the strata below the surface (*8*). Smith also produced more detailed geological maps of 21 English counties, with the same geological coloring as his large map (*9*). He explained his discoveries on the use of fossils in a series of colored plates (*10*) and in a catalog of his fossil collection, purchased by the British Museum (*11*).

Making a geological map remains a first step to understanding regional geology and in the search for raw materials and hydrocarbons. The location and development of resources such as rare earth minerals in places like Greenland requires a geological map at the outset. In hydrocarbon exploration today, seismic surveys extend the mapping into the subsurface in three or even four dimensions. Fossils are as essential in correlating rocks as they were in Smith's time and are important in the identification of strata in the oil industry today.

Geological maps have, since the time of NASA's Apollo program, extended beyond the terrestrial, as exemplified by a new geological map of Mars (see the second figure) (*12*). The paper map is now being replaced by the digital, and the same technology allows us to view Smith's map differently by rendering it in three dimensions (see the third figure) (*13*). In his own lifetime, Smith was hailed the "Father of English Geology," but he can equally be regarded as the Father of Stratigraphy and of the modern geological map. ■

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PHYSICS

New SQUID on the Bloch

A cloud of cold atoms can operate as an ultrasensitive interferometer

By **Austen Lamacraft**

Schrödinger's famous cat showed us that the matter waves inside an atom could manifest on macroscopic scales, but the real workhorse of the quantum world is the SQUID, or superconducting quantum interference device. This piece of technology is the key component of some hospital MRI (magnetic resonance imaging) scanners and other medical equipment because of its ability to detect tiny magnetic fields. On page 288 of this issue, Duca *et al.* (*1*) show that identical experimental principles can be used to detect the phases of the waves describing the motion of atoms in a periodic potential, known as Bloch states. Electrons moving in a crystal lattice are described by the same states, but although they are central to solid-state physics, their properties are usually inferred from other measurements—conductivity, for example. The study by Duca *et al.* provides a proof-of-principle demonstration of a new type of interferometry capable of providing much more detailed information than existing techniques.

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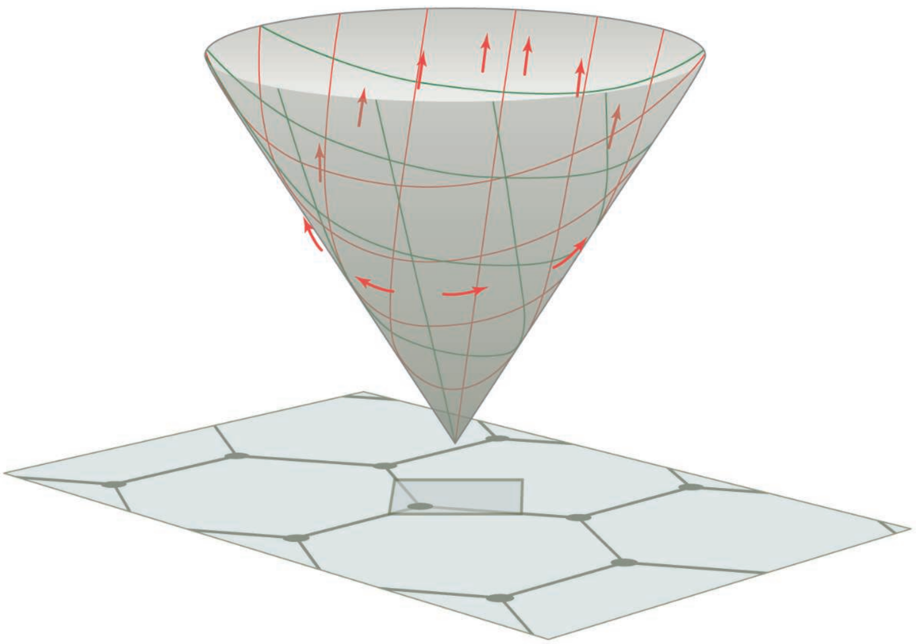
In a SQUID, superconducting currents flowing in a ring at the heart of the device are sensitive to tiny changes in the magnetic flux through the ring; this sensitivity is due to the interference of quantum waves propagating around each half, as in the two arms of an interferometer. In contrast, the two interfering paths in the experiment of Duca *et al.* form a loop in momentum space. The corresponding phase that is measured is an example of the far-reaching generalization of magnetic flux discovered by Berry in 1984 (*2*). Berry realized that for any family of quantum states labeled by continuous parameters (the momentum of the particle in this case), it is in general not possible to compare the phase of the states at two different values of the parameters.

A close analogy is provided by vectors lying tangent to a curved surface, where it is similarly difficult to compare the directions of vectors attached to different points. A natural resolution is to consider vectors close to each other and to determine the angle by which one vector has to twist about the normal to the surface in order to be parallel to the other—a process called the parallel transport of a vector. Surprisingly, this local comparison cannot be extended over finite distances; instead, parallel transport around a loop causes a rotation of the vector by an angle



Interfering atoms. In the Aharonov-Bohm interferometer of Duca *et al.* (*1*), trajectories of wave packets in momentum space passing either side of a point where the Berry curvature is concentrated pick up a relative phase of 180°. The effect is related to the rotation of a vector parallel transported around a cone with a 60° aperture angle.

ILLUSTRATION: ADAPTED BY P. HUEY/SCIENCE determined by the curvature of the surface inside. In the same way, Berry's phase carries information about an analogous property of the quantum states, often called Berry curvature. Berry's idea has found application in almost all areas of physics, most recently in the theory of topological insulators (*3*).

Instead of a superconductor, Duca *et al.* use a Bose-Einstein condensate of atoms to amplify the effects of single-atom interference. In addition, the tools of atomic physics allow precise control over the trajectory of the atoms in momentum space. They applied their technique to a hexagonal optical lattice formed by superimposing three laser beams, so that the Bloch states have a particularly simple distribution of Berry curvature concentrated at isolated values of momentum. Choosing trajectories to encircle these values reproduces the conditions of the Aharonov-Bohm effect, in which the interference of charged particles is affected by a magnetic flux in a region of space they do not enter. The Berry curvature matches that of a conical surface, which is concentrated at the tip of the cone. A trajectory that passes around the tip leads to a phase change of 180° (see the figure).

These effects are by now very familiar to condensed matter physicists, as they determine the conductivity of graphene in a magnetic field (*4*). Graphene consists of a two-dimensional sheet of carbon atoms arranged in a honeycomb lattice, so the Bloch states closely resemble those of the artificial lattice formed by laser light in the present experiment. An earlier experiment using an atomic Fermi gas was able to show that the energies of the Bloch states have the same conical features as those in graphene, but gave no information on the phases of the states (*5*). Although it was then clear that an interferometric measurement would be by far the cleanest and most convincing demonstration of the Berry phase, its achievement is an experimental tour de force.

The Berry phase measured by Duca *et al.* represents only the simplest example of a rich set of associated phenomena. The realization of more complex families of quantum states, involving the so-called non-Abelian Berry phases—where the quantum state rotates upon completing a circuit, rather than merely changing its phase—is a natural next milestone. ■

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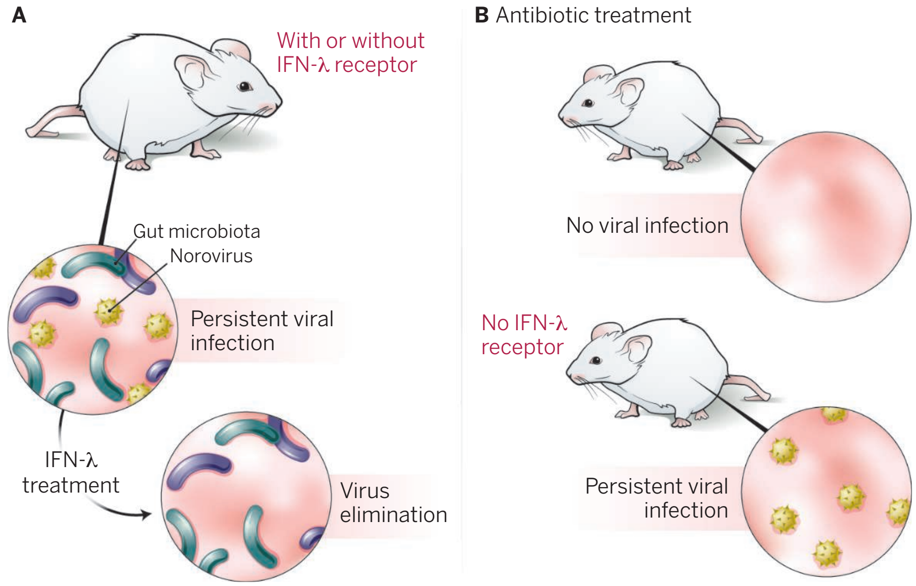

Controlling persistent infection. (**A**) Both wild-type mice and mice lacking the receptor for IFN-λ cannot clear murine norovirus (MNV) infection, but treatment with IFN-λ leads to virus elimination. (**B**) When the gut microbiota is eliminated by antibiotic treatment, MNV disappears from wild-type mice (and from mice that lack the adaptive immune system), but not from mice that lack IFN-λ signaling.

IMMUNOLOGY

Interfering with interferons

The gut microbiota helps norovirus to persist by controlling λ interferons

By **Jessica Wilks** *and* **Tatyana Golovkina**

Living organisms must resist viral infection. In mammals, both infected cells and innate immune cells release signals (cytokines) that program the infected cells for antiviral defense, as well as alert neighboring cells that trouble is afoot. These signals—exemplified by the type I (α and β), type II (γ), and type III (λ) interferons (IFNs)—control the mammalian response against the vast majority of viruses. The host's control of an enteric pathogen, rotavirus, requires type III IFNs (*1*, *2*). On page 269 and 266 of this issue, Nice (*3*) and Baldridge (*4*), respectively, show that protection provided by λ IFNs is generalizable to another enteric pathogen, norovirus. Notably, this protection is independent from the adaptive immune response, which has long thought to be absolutely required for clearing viral infection.

The principal difference between type I and type III IFNs lies in their cognate receptor (*5*, *6*). Whereas type I IFNs are recognized by the IFNαR1-R2 heterodimer (also called IFNαβR), type III IFNs are recognized by a distinct heterodimeric receptor composed of IFNλR1 and interleukin-10 receptor beta (IFNλR1-IL10Rβ1 or IFNλR). Even though the IFNαβR and IFNλR are independent, both receptors signal through a series of common adaptors leading to an indistinguishable antiviral immune response. Unlike IFNαβR, which is ubiquitously expressed in all nucleated cells, IFNλR is primarily expressed by the mucosal epithelium, with the highest expression in the small and large intestine.

A common cause of gastroenteritis, human norovirus is notoriously difficult to study in vitro and in vivo. For this reason, murine norovirus (MNV) has been an invaluable tool for analyzing the relationship between enteric viruses and the host immune system. To uncover the antiviral mechanism controlling persistent MNV infection, Nice *et al.* used a genetic approach to discover that type III IFN, but not type I IFN, is required to control persistent MNV, as virus shedding was substantially increased in IFNλR-deficient mice but not

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