Glimpsing the Weak Magnetic Field of Light
Harald Giessen, *et al.*
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PHYSICS

Glimpsing the Weak Magnetic Field of Light

An instrument has been fabricated that can detect the weak magnetic field of infrared light.

Harald Giessen[1] and Ralf Vogelgesang[2]

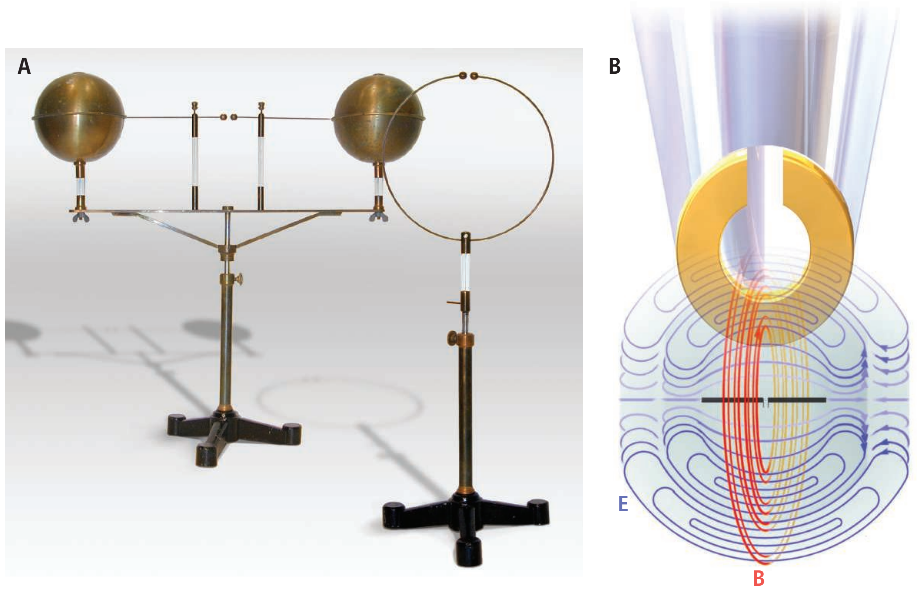
Since the work of James Clerk Maxwell and Heinrich Hertz, we have known that light is an electromagnetic wave. An intricate mechanism generates magnetic fields around the electric fields, and vice versa. In the optical-wavelength range, experimental studies have been limited to probing only the electric-field components. On page 550 of this issue, Burresi *et al*. (*1*) report direct measurements of the magnetic-field components of light obtained with a nanostructured metallic probe at the tip of a sharp glass fiber.

The instrument used by Burresi *et al*. can be viewed as a variant of the scanning tunneling microscope (*2*). Rather than imaging atoms on the surface, scanning near-field optical microscopy (SNOM) (*3*, *4*) collects light from an object in the near field—that is, at a distance less than the wavelength of light λ. Thus, its resolution is not limited by the classical Abbe diffraction limit (roughly about 0.5 λ/NA, where NA is the numerical aperture), which for infrared light is on the order of 500 nm.

SNOM allowed measurement of the local electric-field components of light, and hence the nanoscale optical features of surface plasmons, quantum dots, and individual molecules could be mapped. In the original setups, tapered fibers with subwavelength metallic holes at the end were used as probes. Subsequently, opaque tips allowed even higher resolution down to a few nanometers in so-called apertureless-scattering SNOM variants (*5*–*8*). More sophisticated variants of SNOM enabled researchers to determine the phase and the polarization of all three spatial vector components of the electric-field components of light (*9*). In the latter case, a linear polarizer in the setup allowed mapping of the three-dimensional character of the electric-field orientation.

The greater difficulty in determining the corresponding magnetic-field components of light arises from the weakness of this field relative to the electric field. The origin of the difference can be understood in a simplified picture with the Lorentz force, which describes the effects of magnetic and electric fields of light on moving charges. These charges could be the electrons in atoms or in solid-state nanostructures. The ratio of the magnetic contribution to the electric counterpart scales as the ratio of the velocity of the charges v to the speed of light c. This ratio is the fine-structure constant α of atomic physics. For atoms, α is 1/137; in solid-state systems, v is roughly the Fermi velocity and v/c is about 1/300. The magnetic susceptibility χ_m scales as $(v/c)^2$, which makes magnetism weaker than its electric counterpart by four orders of magnitude (*10*). This difference in strength is the key reason why physicists have long ignored magnetism at optical frequencies, despite having been detected by Hertz for radio waves, where the wavelengths are centimeters to meters (see the figure, panel A). The circumference of the receiver scales roughly with the wavelength. In Hertz's case, the wavelength was about 3 m.

However, in a material that has structural features on a scale much smaller than λ, called a metamaterial, things are different (*11*). The magnetic moments in a metallic split-ring resonator (a ring with a notch in it) can be much greater than in atoms and conventional solids. The reason is that the magnetic flux is given by the product of current and area, and optical split-ring resonators can easily cover an area of 100 nm by 100 nm, or six orders of magnitude greater than the square of the Bohr radius in atoms.



Divide and conquer. (**A**) Heinrich Hertz used this emitter (left) and receiver (right) to detect the magnetic component of electromagnetic waves. The spark inside the gap of the receiver, the first split-ring setup, was especially strong when the ring was aligned with respect to the magnetic field. (**B**) The magnetic field **B** of optical waves (red lines) can be detected with an interferometer that reads out the scattered light from a scanning near-field optical microscope with a metallic split-ring resonator at the tip of a glass fiber. The lines of the electric field **E** are shown in blue.

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Burresi *et al*. fabricated a metallic split-ring resonator at the tip of a glass fiber, which serves as a near-field optical probe (see the figure, panel B). The asymmetry created by the gap in the split ring causes the magnetic field to interact strongly with the nanostructure. This interaction couples the light into the structure and creates a measurable light signal at the other end of the fiber. Burresi *et al*. subsequently mixed this signal with reference light from their laser and extracted the amplitude and phase of the measured magnetic-field component at the fiber tip.

As an initial demonstration, Burresi *et al*. analyzed the magnetic field above an optical waveguide made from silicon nitride and showed convincingly that the detected magnetic-field signal is exactly 90° out of phase with the electric-field signal. When they replaced the split ring with a continuous ring, the signal vanished completely.

This method has the potential to give us a complete tomography of the optical vector field. One might envision a suitable nanoscopic

[1]Physikalisches Institut, Universität Stuttgart, 70550 Stuttgart, Germany. [2]Max-Planck-Institut für Festkörperforschung, 70569 Stuttgart, Germany. E-mail: giessen@physik.uni-stuttgart.de; r.vogelgesang@fkf.mpg.de

scatterer, along with polarized detection, to determine all six optical vector field components (three electrical and three magnetic components). This capability is especially important for the design of complex nanoscopic geometries and intricate materials. Measurements could be made in the vicinity of sophisticated nanoantennas, in chiral (*12*) and multipolar metamaterials (*13*), in uniaxial and bianisotropic structures, as well as in multiferroics and high-temperature superconductors. Furthermore, spins in solids that are also associated with a magnetic moment could be assessed and controlled in the appropriate spectral region. One could send light into the SNOM fiber and convert it into a magnetic-field component at the tip with the split ring. Also, magnetic dipole transitions in quantum emitters might show enhanced interaction with such a probe.

The electric- and magnetic-field components are intertwined with each other via the material properties and are described by the complex frequency-dependent permittivities and permeabilities. When the electric and magnetic optical responses can be measured independently in the vicinity of materials, we can obtain information about the complex local material properties. This capability may pave the way toward completely new effects, such as optically induced magnetism. We can only speculate as to how this concept might find application, such as in the read-write heads of ultrahigh-density magnetic storage devices.

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VIROLOGY

A New Virus for Old Diseases?

A retrovirus associated with cancer is linked to chronic fatigue syndrome.

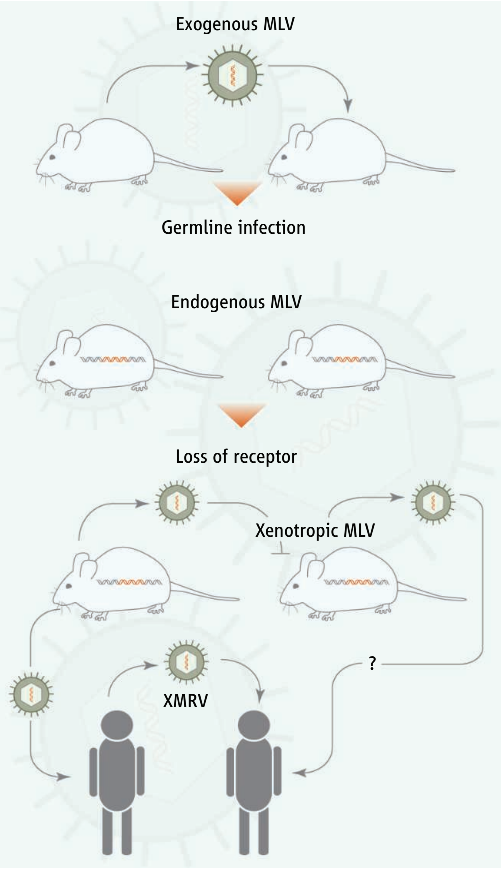
John M. Coffin[1] and Jonathan P. Stoye[2]

There is little consensus in the medical community on whether chronic fatigue syndrome is a distinct disease. As its name implies, the condition is characterized by debilitating fatigue persisting for many years, and it affects as much as 1% of the world's population. Although chronic inflammation is often found in these patients, no infectious or toxic agent has been clearly implicated in this disease, which is diagnosed largely by excluding other conditions that cause similar symptoms (*1*). On page 585 of this issue, Lombardi *et al*. (*2*) describe the detection of xenotropic murine leukemia virus–related virus (XMRV) in about two-thirds of patients diagnosed with chronic fatigue syndrome. Both laboratory and epidemiological studies are now needed to determine whether this virus has a causative role, not only in this disease, but perhaps in others as well.

Chronic fatigue syndrome is not the first human disease to which XMRV has been linked. The virus first was described about 3 years ago in a few prostate cancer patients (*3*), and recently detected in nearly a quarter of all prostate cancer biopsies (*4*). It has been isolated from both prostate cancer and chronic fatigue syndrome patients, and is similar to a group of endogenous murine leukemia viruses (MLVs) found in the genomes of inbred and related wild mice. Although a half century of studies on MLVs and other gammaretroviruses have led to important discoveries on which much of our current understanding of cancer rests, there has been no clear evidence demonstrating human infection with gammaretroviruses, or associating these agents with any human disease.

Endogenous viruses, such as xenotropic MLV, arise when retroviruses infect germline cells. The integrated viral DNA, or provirus, is passed on to offspring as part of the host genome (see the figure). Endogenous proviruses form a large part of the genetic complement of modern mammals—about 8% of the human genome, for example. Xenotropic proviruses first entered the mouse germ line about a million years ago, but cannot infect cells of the mice that carry them because of a mutation in the cellular receptor for the virus presumed to have arisen after viral entry into the germ line. The propensity of xenotropic MLVs to infect rapidly dividing human cells has made them common contaminants in cultured cells, particularly in certain human tumor cell lines (*5*).

There is more than 90% DNA sequence identity between XMRV and xenotropic MLV, and their biological properties are virtually indistinguishable (*6*–*9*), leaving little doubt that the former is derived from the latter by one or more cross-species transmission events. There are several lines of evidence that transmission happened in the outside world and was not a laboratory contaminant. One is that XMRVs from disparate locations and from both chronic fatigue syn-



Path to human infection. Although xenotropic murine leukemia virus (MLV)—derived from exogenous MLVs that became established as proviruses in the mouse germ line—can no longer infect mice, it can infect humans, apparently leading to one or more cross-species infection events to become XMRV.

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[1]Department of Molecular Microbiology, Tufts University, Boston, MA 02111, USA. [2]National Institute for Medical Research, Mill Hill, London NW4 1AA, UK. E-mail: john.coffin@tufts.edu

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