evolved to promote and integrate virus production with VS formation.

In addition to initiating signal transduction in the infected cell, adhesion molecule engagement at the VS ostensibly activates the uninfected target cell. Activation would ensure expression of virus receptors by the uninfected cell and promote virus replication once the virus has entered its new target. The identity of the HTLV-I receptor has eluded investigators for two decades, but recent work with a soluble version of the HTLV-I Env glycoprotein promises to remedy this situation. These new studies show that a cell surface protein that binds to the soluble form of the HTLV-I Env glycoprotein was rapidly expressed by naïve T cells activated by immunological or pharmacological means (*6, 7*). The possibility that the HTLV-I receptor is expressed by the uninfected T cell and segregates to the cell-cell interface during the later stages of VS formation is attractive. If this did not take place later during VS formation, then association of the HTLV-I receptor with the viral Env expressed by the infected T cell would lead to premature cell fusion.

Although HTLV-I appears to be especially dependent on cell-to-cell transmission, this may be the rule rather than the exception. Recent reports indicate that other viruses including HIV-1 and the Ebola virus, which efficiently infect cells by a cell-free route in vitro, may rely on cell-to-cell transmission in vivo (*8*). During the early stages of infection, both viruses preferentially infect macrophages, which then migrate to different sites in the body and transfer concentrated packages of virus in a cell-to-cell fashion. In addition, infectivity of these two viruses is enhanced when they are presented on the surface of dendritic cells via interactions of their viral envelope proteins with the C-type lectin DC-SIGN expressed by dendritic cells (*9*). Experiments by Emerman's group underscore the importance of contact between T cells and dendritic cells for the rapid and efficient propagation of HIV-1 when the life-span of the infected cell is very brief (*10*). This mode of virus transmission sustains high virus loads in the face of an antiviral immune response.

HTLV-I has evolved intricate and integrated systems to establish persistent infection of T cells. Virus transmission through the VS may be a cornerstone of this process. In addition to addressing longstanding issues related to cell-to-cell versus cell-free transmission of HTLV-I, the work of Igakura *et al.* poses many new questions and provides an attractive framework for future studies. In particular, it will be interesting to examine whether postentry events, which appear to be blocked in cell-free infections (*11*), are overcome when virus particles are transmitted through the VS. It will be exciting to watch as the details of this new picture of retrovirus transmission develop.

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PHYSICS

Topology from the Bottom Up

Randall D. Kamien

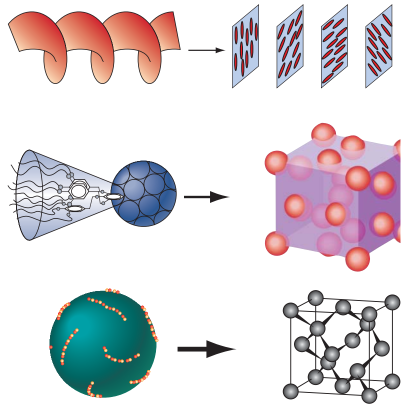
The use of topology and geometry to understand the physical world is commonplace, yet it has only recently become central to the design and control of new materials. Every soccer ball has 12 pentagons, even when it is deflated. On page 1716 of this issue, Bausch *et al.* (*1*) exploit this topological property to pave the way for a novel approach to the bottom-up design of new materials.

The use of topology and geometry is not confined to materials science. Data from the cosmic microwave background explorer (COBE) not only shed light on the geometry of the universe and the cosmological constant, but they also constrain the allowed topology (*2*), ruling out the possibility of the universe being spatially periodic. The classical theory of electromagnetism can be recast geometrically, serving as the simplest example of the gauge theories of elementary particles. These theories are the basis for the standard model of particle physics; their deep connection to modern topology has led to major advances in pure mathematics (*3*).

In the realm of condensed matter and materials physics, the role of topology is well known. For instance, the number of times a closed string winds around a point is independent of its exact conformation and is therefore a topological property. The persistence of currents in superconductors and superfluids is guaranteed by this very same topology, as is the existence of Abrikosov flux lines in type II superconductors and defects in smectic liquid crystals (*4*). These topological defects are at best a profound example of a macroscopic quantum state and at worst a nuisance for technology.

In a series of elegant experiments, Bausch *et al.* (*1*) confirm that the topology of a sphere or soccer ball can be used to understand the structure of two-dimensional (2D) colloidal crystals assembled on spheres. Not just a curiosity, these structured "colloidosomes" will be the building blocks for complex, self-assembled structures with novel optoelectronic, mechanical, and photonic properties.

Today's most promising methods for predicting and controlling the assembly of complex materials are based on self-assembly: They exploit the ability of identical molecules and supramolecular assemblies to self-assemble into structures that reflect their molecular architecture (*5*).



Controlled self-assembly. Control over molecular geometry and topology can lead to the rational design and control of macroscopic structure. The cholesteric phase of chiral mesogens and the $Pm\bar{3}n$ phases of dendrimers are the precursors to the new phases, which can be built from scarred colloidosomes.

Perhaps the simplest example of self-assembly is a chiral nematic or cholesteric liquid crystal (*4*). In these materials, control of the rigidity, aspect ratio, and chirality of the molecules allows for the self-assembly of a singly periodic cholesteric phase (a one-dimensional crystal). This level of macroscopic structure is suffi-

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cient for making temperature probes, field-controlled diffraction gratings, and optical switches. The chiral molecular structure often leads to exotic liquid-crystalline blue phases that control light in three dimensions and exhibit mirrorless lasing (*6*).

The ability to control the topology of the molecules in addition to their geometry leads to concomitant advances in the spectrum of materials properties. Polymers with attached, side-chain, nematic-forming molecules, called nematogens, form liquid crystalline elastomers (*7*) with extraordinary optomechanical responses, exhibiting strains between 10 and 400%. Thus, by merely changing the connectivity (and hence topology) of the nematogens and their polymer backbones, one can drastically alter the materials' properties. These materials are likely to find their way into a variety of actuators and sensors, including artificial muscle.

Another example of topological control is in the synthesis of branched, dendritic polymers (called dendrimers). By controlling the location (geometry) and number of branches (topology) at each junction, it has become possible to assemble supramolecular, nanometer-scale structures with specific form and function. Recent advances in dendrimer synthesis have led to an entirely new class of complex, electronic materials. These materials owe their great technological potential to the ability to self-assemble into the nanometer-scale geometries that modern molecular electronics requires (*8*). Further advances promise mechanical actuators, chemical sensors, and anisotropic conductors.

The work by Bausch *et al*. opens up an entirely new mode of self-assembly. By relying on the elegant topological arguments that ensure 12 scars in the two-dimensional colloidal crystal on each colloidosome, the authors have self-assembled micrometer-sized building blocks. The behavior is universal (it is independent of the colloidal interactions). It should therefore be possible to use this method to design macroscopic materials without the need for difficult and costly synthetic methods.

Moreover, because the length of the scars can be controlled rationally, the surface properties can be tailored to enhance or inhibit the binding of specific agents. The scars can be used as scaffolds that can template the assembly of functional nanomolecules or form the connectors for a space-filling lattice of functionalized spheres. Indeed, the colloidosome building blocks can be easily synthesized, controlled, and assembled so that greater attention can be lavished upon the active chemical or biochemical sites.

Finally, the colloidosomes themselves can be filled and functionalized with a vast array of therapeutics, biomaterials, and nanostructures, enabling the assembly of truly hierarchical, self-assembled materials. The use of topological effects, which are independent of specific interactions, should prove to be a valuable and versatile technique in the quest for the next generation of complex functional materials.

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GEOCRYOLOGY

(Un)frozen in Time

Frederick E. Nelson

When the Russian academician Baer reported to the Royal Geographical Society of London in 1838 that the ground in central Siberia was frozen to a depth of more than 100 m, the observation was met with disbelief. Permafrost remained a scientific curiosity until Soviet experiences with construction on frozen ground led to the development of geocryology (permafrost studies) as a discipline. Thaw-induced damage to military installations and roads in Alaska and northern Canada in the 1940s led to the rapid development of an English-language literature on permafrost.

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Because the distribution, thickness, temperature, and stability of permafrost are determined to a large extent by the temperature at Earth's surface, geocryology emerged in the 1990s as an important component of climate change studies. These developments were reflected at the American Geophysical Union (AGU) 2002 Fall Meeting in San Francisco, where more than 50 presentations by scientists from nine countries focused on permafrost and its roles in environmental change (*1*).

Permafrost is defined as any subsurface Earth materials that remain at or below 0°C continuously for two or more years. The permafrost regions occupy nearly a quarter of Earth's terrestrial surface (*2*), including extensive areas of the Arctic and Antarctic, high-elevation terrain in mid-latitude mountain ranges, and even mountain tops in the subtropics. Permafrost is up to 1500 m thick in parts of Siberia that remained unglaciated during the Pleistocene.

Permafrost represents a complex, integrated response to the energy balance at Earth's surface (*3*). Subsurface temperature is influenced by many factors, including air temperature; the thickness, density, and composition of the surface cover (vegetation, snow, or water); the thermal properties of the substrate; and the amount, phase, and mobility of water. Numerical and stochastic models of permafrost behavior have been developed to handle this complexity (*3*, *4*).

Permafrost is dynamic, and its distribution, thickness, and composition have varied substantially over geological time. Plant remains, animals, and human artifacts preserved in permafrost are invaluable for reconstructing paleoenvironments. Stratigraphic analysis of ground ice and periglacial landforms can also help to elucidate past climatic changes (*5*). Model studies indicate that extensive degradation of permafrost may occur in the Northern Hemisphere over the next century in response to anthropogenic climate change (*6*). Observations presented at the meeting and in the specialist literature support model results. Widespread changes, possibly related to greenhouse warming, are already occurring in the permafrost regions. Many have serious implications for natural ecosystems and human activities (*7, 8*) (see the figure).

Permafrost preserves a record of temperature change at Earth's surface. Because heat transfer occurs primarily by conduction in frozen ground, permafrost functions as a natural filter of short-term, "noisy" temperature oscillations. Hence, under appropriate circumstances, it can be used as an archive of temperature changes at the surface over periods of centuries. Precise

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