The Building Blocks of Life

Biological organisms are often limited in the resources that they can use to make structural materials. Primary building blocks may be weak or brittle materials, such as minerals and biopolymers, and processing conditions by default have to be mild. Despite this, a wide range of strong and tough structures exist, including shells, bones, quills, and fibers. Meyers et al. (p. 773) review a wide range of materials and architectures used in nature to make strong and tough materials and show how many of the design principles have also been used or are being considered for manmade materials and structures.

Allostery Across DNA

Proteins, such as transcription factors and RNA polymerase, bind close to each other on DNA and their function is coordinated. Kim et al. (p. 816; see the Perspective by Crothers) report single-molecule experiments that show that the DNA binding affinity of a protein is significantly altered by a second protein bound nearby. The effect oscillates between stabilizing and destabilizing the binding with a periodicity equal to the helical pitch of DNA. Allosteric coupling between a transcriptional repressor and RNA polymerase modulated gene expression in living bacteria.

DNA Sensing Is a (c)GAS

DNA is normally localized to the nucleus, and so its cytoplasmic localization sends off alarm bells to the immune system because it indicates that a virus may have entered. But how does the immune system actually detect the DNA (see the Perspective by O’Neill)? Sun et al. (p. 786, published online 20 December) identify cyclic GMP-AMP (cGAMP) cyclase (cGAS), which can bind to cytoplasmic DNA directly and catalyze the production of cGAMP. cGAMP then acts as a second messenger to activate downstream signaling events that trigger antiviral immunity. Wu et al. (p. 826, published online 20 December) show that cGAMP, produced in response to cytoplasmic DNA, binds to and activates the signaling adaptor protein STING.

Macroscopic Uncertainty

According to the Heisenberg uncertainty principle, it is impossible to know both the position and the momentum of a microscopic particle with absolute certainty; pinpointing the location introduces an uncertainty in the velocity, which translates into position uncertainty at later times. Now, Purdy et al. (p. 801; see the Perspective by Milburn) have measured the position of a macroscopic object (a small, but visible-to-the-naked-eye membrane suspended in an optical cavity) at cryogenic temperatures and observed the uncertainty in its position caused by the recoiling photons used for the measurement.

Genome Editing >>

Clustered regularly interspaced short palindromic repeats (CRISPR) function as part of an adaptive immune system in a range of prokaryotes. Invading phage and plasmid DNA is targeted for cleavage by complementary CRISPR RNAs (crRNAs) bound to a CRISPR-associated endonuclease (see the Perspective by van der Oost). Cong et al. (p. 819, published online 3 January) and Mali et al. (p. 823, published online 3 January) adapted this defense system to function as a genome editing tool in eukaryotic cells.

So Different and So Similar

Most known meteorites from Mars fit into one class. Agee et al. (p. 780, published online 3 January; see the Perspective by Humayun) describe a meteorite, NWA 7034, which shares some characteristics with other Martian meteorites but does not fit within the usual classification. NWA 7034 matches the composition of Mars’ surface but is also richer in water than other Martian meteorites, and has different oxygen isotope composition, which suggests the existence of multiple oxygen isotopic reservoirs within Mars. Its radiometric age of 2.1 billion years makes it a unique sample of the Amazonian period on Mars.

Crystalline Pores Writ Large

Porous inorganic materials are often made by using molecular templates that help to maintain internal channels during synthesis. The success with small molecules for creating microporous zeolites and related materials with angstrom-scale channels has been extended with molecular assemblies such as vesicles being used to create mesoporous materials with nanometer-scale channels. However, the walls of these materials are usually amorphous. Lin et al. (p. 811, published online 24 January) now report that crystalline mesoporous gallium zincophosphites can be made with very large channels (up to 72-membered rings spanning 3.5 nanometers) by using long-chain amine templates. The materials have limited thermal stability that hinders template removal, but when appropriately doped and loaded with chromophores, the materials exhibit broadband photoluminescence.

Unintended Recipients of Antidepressants

Pharmaceuticals are used to treat a wide variety of ailments and conditions in humans. However, many animal species share physiologies, receptors, and pathways that may be acted upon by pharmaceutical compounds. Increasingly, pharmaceuticals are being found in natural aquatic systems. Such pharmaceutical pollution can cause mortality and alter development and reproduction of aquatic animals. Brodin et al. (p. 814) report that excreted drugs may also have far more subtle, yet eventually significant, impacts in natural systems. Benzodiazepines, which reduce anxiety in humans, alter social and foraging behavior in fish. European perch exposed to oxazepam were bolder, more active, less social and fed more rapidly.
Computing Power of Quantum Mechanics

There is much interest in developing quantum computers in order to perform certain tasks much faster than, or that are intractable for, a classical computer. A general quantum computer, however, requires the fabrication and operation a number of quantum logic devices (see the Perspective by Franson). Broome et al. (p. 794, published online 20 December) and Spring et al. (p. 798, published online 20 December) describe experiments in which single photons and quantum interference were used to perform a calculation (the permanent of a matrix) that is very difficult on a classical computer. Similar to random walks, quantum walks on a graph describe the movement of a walker on a set of predetermined paths; instead of flipping a coin to decide which way to go at each point, a quantum walker can take several paths at once. Childs et al. (p. 791) propose an architecture for a quantum computer, based on quantum walks of multiple interacting walkers. The system is capable of performing any quantum operation using a subset of its nodes, with the size of the subset scaling favorably with the complexity of the operation.

Quantum Critical Scattering

The temperature (T) dependence of the electrical resistivity offers clues about the behavior of electrical carriers. One of the more puzzling observations is the T-linear resistivity found in systems known or suspected to exhibit quantum criticality, such as cuprate and organic superconductors, and heavy fermion materials; the origin of this behavior remains elusive. Bruin et al. (p. 804) find that the ruthenate Sr$_3$Ru$_2$O$_7$ also exhibits T-linear resistivity in the vicinity of its quantum critical point, and that its scattering rate per kelvin is approximately given by the inverse of a characteristic time made up of the Planck and Boltzmann constants. A comprehensive analysis of other systems with T-linear resistivity, including ordinary metals at high temperatures, indicates that their scattering rates are similarly close to the characteristic rate. That the rates are similar across a wide range of materials with diverse microscopic scattering mechanisms may indicate universal behavior.

Accelerated Protons

Although cosmic rays were first detected a hundred years ago, their origin is still not fully understood. Cosmic rays are high-energy particles, mostly protons, which bombard Earth from outer space. Most of those that originate from within our galaxy are thought to be accelerated in the shock waves from the explosion of massive stars, or supernovae. Protons accelerated in a supernova remnant will collide with interstellar material producing pions, a type of subatomic particle, which will then decay into gamma rays. Ackermann et al. (p. 807) present measurements of the energy spectra of two supernova remnants in our galaxy, IC443 and W44, in the energy range below 100 MeV down to 60 MeV with the Fermi Gamma-Ray Space Telescope. The spectra reveal the pion-decay feature that is a signature of accelerated protons.

Overwriting Human Memory

A consolidated fear memory can enter a transient labile phase upon its reactivation. Pharmacological blockade of the subsequent protein synthesis-dependent restabilization produces a memory deficit. Sevenster et al. (p. 830) found that prediction error (a discrepancy between actual and expected events) is a necessary condition for reconsolidation of a fear memory in human subjects. Retrieval cued by a negative prediction error, for example, like a conditioned stimulus presented in the absence of the unconditioned stimulus, resulted in labilization and subsequent reconsolidation was blocked by the drug propranolol. However, if there was no prediction error because the conditioned stimulus and the aversive unconditioned stimulus were presented simultaneously, the memory did not enter a labile state and its reconsolidation could not be blocked.