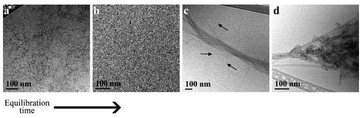
Self-Synthesis, from Soup to Nanotubes

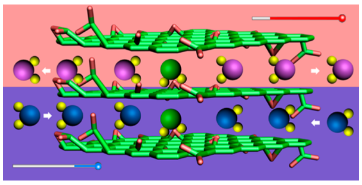
Researchers are increasingly focusing their work on understanding the self-assembly of amphiphilic biomolecules, including fatty acids, proteins, and peptides. These molecules can form a variety of structures in water, such as fibrils, nanotubes, α-helices, and β-sheets. Grasping how these structures form and self-replicate has implications for chemistry and cell biology alike. Some of these materials are not just self-assembling, but also self-synthesizing, promoting their own formation and assembly into larger superstructures from basic building blocks. Although such self-assembling materials have been studied since the 1980s, starting with a drive to understand the origins of life, most studies have focused on relatively complicated molecules that serve as templates for self-assembly, such as α-helix molecules at least 30 amino acids long.

In a new study, Rubinov *et al.* (DOI: 10.1021/nn302223v) probe the self-assembly of a far simpler amphiphilic peptide that accelerates its own formation from electrophilic and nucleophilic precursors, which come together into a peptide composed of only 13 amino acids. The researchers probed the self-assembly pathway of this molecule, showing through several different analytical techniques that the precursors in the presence of the assembled template formed various structures, including β-sheets, fibrils of various widths, and nanotubes. Kinetic data suggest that these three structures form sequentially over longer equilibration times, with fibrils present for only a short time acting as catalysts. Simulations suggest that these structures propagate similarly to prion proteins responsible for spreading pathology in the brain and other neural tissues. The authors suggest that β-sheet superstructures, even short-lived ones, may play a pivotal role in self-assembly behavior in nature and in the lab.



Graphene Oxide Takes the Heat

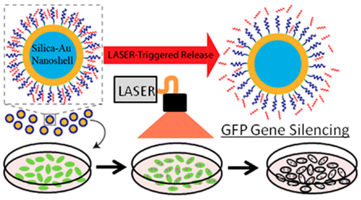
Most materials expand with heat and contract with cold, and thus have a positive coefficient of thermal expansion (CTE). However, a minority of solids display the opposite characteristics, showing negative thermal expansion (NTE). These unusual materials are fundamentally interesting and have the potential for a wide variety of applications, but their usefulness has been limited thus far by poor scalability, toxicity, or very small or anisotropic NTE effects. To make applications including actuators, sensors, and memory materials possible, researchers will need to find large NTE materials with strong mechanical properties.



Bringing this goal closer to reality, Zhu *et al.* (DOI: 10.1021/nn3031244) investigated the properties of graphene oxide (GO), which they find displays a large NTE that is highly dependent on temperature-induced removal or insertion of water between this material's layers. This pseudonegative thermal expansion (PNTE) was evident when the researchers studied GO in a thermal mechanical analyzer, showing that the length of GO paper shows reversible contraction upon heating and expansion upon cooling. Further investigation showed that humidity, even if carefully controlled, was impossible to eliminate completely in samples. Ultimately, they found using X-ray diffraction, nuclear magnetic resonance, and Fourier transform infrared spectroscopy that small quantities of confined water between GO layers decreased when temperature rose and humidity decreased, partially collapsing the layered structure and shrinking the material. The opposite scenario appears to happen when temperature decreases and humidity increases. Taking advantage of this unusual property, the researchers created composites with polyvinyl alcohol that displayed PNTE effects. The authors suggest that GO could hold promise for a variety of applications requiring NTE characteristics.

Gold Nanoshells Run Interference

RNA interference (RNAi), a technique that muffles the influence of specific genes and downregulates expression of their encoded proteins through the use of short-interfering RNAs (siRNAs) and antisense DNA oligonucleotides, has attracted significant attention over the past several years as a potent way to dissect gene function in fundamental studies and as a potential way to attack genetic diseases. However, RNAi has been held back considerably by the lack of delivery vehicles that can take siRNAs and antisense oligonucleotides to the desired cells and tissues while protecting them from degradation in circulation.



Focusing their efforts on a new kind of carrier, Huschka *et al.* (D01:10.1021/nn301135w) investigated gold nanoshells composed of a spherical silica core coated with a thin Au shell. These materials, which have been shown to be biocompatible and are already being used in other biomedical applications, have benefits including highly tunable plasmon resonance and easy surface functionalization though well-established Au–thiol bold chemistry. The researchers took advantage of these qualities by functionalizing the nanoshells' surfaces with cationic poly-(L)-lysine, which easily picks up anionic siRNAs and antisense DNA oligonucleotides. By irradiating these nanoshell vehicles with an 800 nm laser, a wavelength in which tissue is effectively transparent, the researchers showed that these carriers released their cargo on demand within several minutes. Further tests showed that the loaded nanoshells were taken up in high numbers by a model cell line, downregulating a desired gene by about 50% with minimal toxicity. The authors suggest that this new carrier could hold promise for gene silencing in lab studies and pharmaceuticals.

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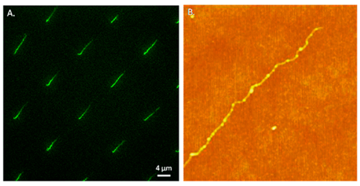
Stretching Chromatin No Longer a Stretch



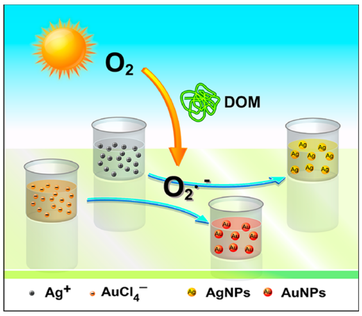
Chromatin, the combination of DNA and histone proteins that form repeating nucleosome units, fill the cell nucleus and allow cells controlled access to specific genes through condensing or unwrapping specific sections of DNA. The ability to view chromatin at high resolution, enabled by stretching and immobilization, would provide a direct approach to identify epigenetic modifications that have been linked with various diseases and success of treatments. While stretching has been exploited for bare DNA, and various visualization techniques have been used on chromatin at macroscopic levels of chromosomes, visualizing stretched, isolated chromatin had not yet been attempted.

In a new study, Cerf *et al.* (DOI: 10.1021/nn3023624) filled this research gap by developing a method to spread stretched chromatin molecules into ordered arrays on solid substrates compatible with high resolution optical imaging. The researchers deposited a drop of liquid with isolated chromatin onto a polydimethylsiloxane (PDMS) stamp microstructured with an array of cavities. Using a glass spreader, they then dragged the meniscus of the liquid across the PDMS surface, trapping chromatin in individual wells and pulling the chromatin as the spreader advanced across the surface. After spreading was complete, the researchers pressed the stamp onto a coated coverslip, leaving stretched chromatin behind after the PDMS was peeled away. Fluorescence images and atomic force microscopy showed high-density arrays of stretched and isolated chromatin fragments. These fragments showed a beads-on-a-string configuration, suggesting that this technique did not strip histones from DNA. The authors suggest that this technique is both affordable and quick, making it especially suitable for clinical applications.

Getting to the Bottom of Nanoparticles in River Water

Metal engineered nanoparticles (MENPs) have been gaining ground in a variety of consumer products over the past several years, with silver nanoparticles (AgNPs) now commonly used as antimicrobial agents. These MENPs are inevitably discharged into the environment through creating, using, disposing, and recycling products that contain them. While their toxicity and bioaccumulation is currently being studied, their potential to cause harm makes it necessary to investigate their fates and behaviors in the environment. Complicating this issue is the fact that MENPs can also form naturally in the environment, a phenomenon that is not yet well understood and that can cause difficulties with investigating industrial MENPs' environmental distribution.

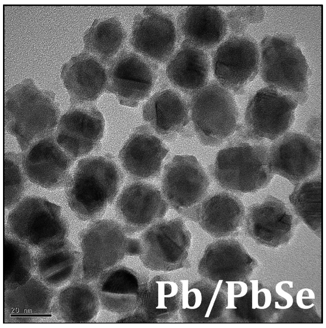
To understand natural MENP formation, Yin *et al.* (DOI: 10.1021/nn302293r) investigated the effects of dissolved organic material (DOM) in river water, a factor already shown to affect the fate and behavior of other pollutants. Spiking water from the Chaobai River in Beijing with small amounts of $AgClO_4$ and irradiating the mixture with sunlight, the researchers show the formation of AgNPs. Using water from other Chinese and American rivers and humic acid, along with varying concentrations of Ag ions as a model for DOM, produced similar results. The findings were reproduced with Au ions, producing gold nanoparticles when $AuCl_4^-$ was added to river water and irradiated. Further tests showed that inorganic ions and dissolved oxygen were pivotal to the reduction process. The authors suggest that metals with high reduction potentials could be as-yet unacknowledged sources of MENPs produced naturally in the environment.



Turning Insulators into Superconductors

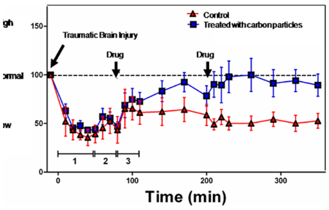
Researchers are actively investigating colloidal nanocrystals as components of novel composite materials that cannot be built with top-down approaches. Although superconductivity could be a useful attribute to applications that would use these materials, colloidal nanoparticles of superconducting metals remain understudied. Potentially, researchers could eventually fine-tune electrical properties of composites by nanostructuring films of colloidal nanocrystals. To determine what factors affect superconductivity in nanocrystal films, prior experiments have focused on films of disordered materials, such as InO_x and TiN, prepared by gas condensation methods. However, these materials lack the scalability, size control, and chemical versatility of colloidal nanocrystal films.

To understand superconductivity in colloidal nanocrystals, Zolotavin and Guyot-Sionnest (DOI: 10.1021/nn302709d) undertook a study of nanocrystals made of a Pb core surrounded by PbO. After dropcasting these nanocrystals into a film using a toluene solution, tests showed that the long organic ligands on the nanocrystal surfaces in combination with the oxide shell prevented electrical conductivity. Even after ligand removal, this material acted as a strong insulator. However, when the film was exposed to reactive chalcogenide sources, the oxide shell converted to sulfide or selenide, with corresponding and dramatic changes of the colloidal nanocrystal films from insulating to superconducting, increasing conductivity 10^9-fold. Tests showed that this chalcogenide conversion reduced the bandgap by more than 10-fold, vastly lowering the tunneling resistance. Further investigation showed that the temperature at which the material switched from insulating to superconducting depended on the degree of coupling between nanoparticles. The authors suggest that further studying this process could eventually help researchers to design better superconducting materials.



Treating Traumatic Brain Injury with Nanoparticles

The brain's high metabolic needs are typically satisfied even under varying blood pressure by the phenomenon known as autoregulation: Low blood pressure causes brain vasculature to dilate, and high blood pressure causes it to constrict. However, after traumatic brain injury (TBI), autoregulation can become dysfunctional, with patients often developing hypotension even after treatment to increase blood pressure. Autoregulatory dysfunction has been shown to be a major determinant of how well patients recover after brain injuries. Although it is unclear how this system becomes damaged in TBI, research has shown that elevated levels of reactive oxygen species (ROS) in the vasculature following trauma appear to play a role.

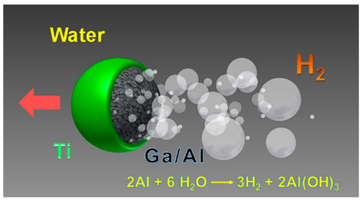


Seeking a way to combat the spike in ROS, and consequently the decreased brain blood flow sometimes observed after traumatic brain injury, Bitner *et al.* (DOI: 10.1021/nn302615f) turned to polyethylene glycol-functionalized hydrophilic carbon clusters (PEG-HCCs). *In vitro* tests showed that these nontoxic carbon particles were rapidly internalized by murine brain endothelial cells and decreased oxidative stress in a dose-dependent manner, saving the majority of cells even at high doses of toxin exposure. Further examination showed that the PEG-HCCs acted as selective antioxidants, quenching superoxide without affecting levels of nitric oxide, an essential compound for blood vessel dilation and autoregulation. Testing PEG-HCCs next in a rat model of TBI with hypotension, the researchers found that animals that received the particles experienced rapidly restored cerebral blood flow during resuscitation, compared to animals that received just the vehicle. The authors suggest that PEG-HCCs could offer a promising way to improve patient outcomes in cases of traumatic brain injuries.

Tiny Motors Run in Water

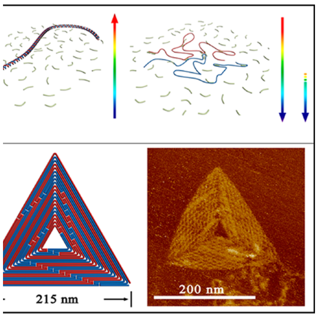
Microscale and nanoscale synthetic objects with controllable motion have been the focus of research efforts over the past several years due to their wide-ranging potential applications, including drug delivery and environmental remediation. These tiny movers have taken a variety of forms, including catalytic nanowires, spherical Janus micromotors, and tubular microengines. However, most have relied on hydrogen peroxide as a fuel source, a requirement that limits their practical applications in many venues. Ideally, micro- and nanomotors would harvest energy from the materials that surround them, such as blood plasma for those geared toward drug delivery, preventing the need for additional fuels.

In a new study, Gao *et al.* (DOI: 10.1021/nn303309z) move a step closer to this goal, developing a new micromotor that runs in water. The researchers pressed Al particles into liquid Ga, creating an Al−Ga alloy that prevented a passivation layer from forming on the Al surface. They then coated half the particle surface with Ti. When these micromotors were immersed in water, the reaction between Al and water generated hydrogen bubbles, which propelled the particles toward the Ti-coated side. In ultrapure water, these 20 μm particles moved at a clip of about 150 body lengths per second for short time periods. The investigators were able to increase this time period to several minutes by varying the pH and salt content of the media, although motor efficiency was reduced. The authors note that these micromotors, which also show potential for propulsion in biologically relevant media, could hold significant promise for medical and other applications.



Double Strands Bring DNA Origami above the Fold

DNA origami has been used for several years as a way to create nanoscale structures with custom construction and surfaces that can easily be further modified. This technique has typically involved folding a long piece of single-stranded DNA (ssDNA) into a designated shape held in place by several shorter DNA oligonucleotides “staples.” While DNA origami has demonstrated versatility in creating a variety of two-dimensional and three-dimensional shapes, the complexity, size, and diversity of synthesized structures has been limited by the length of ssDNA templates.



In a new effort toward creating larger and more complex DNA origami structures, Yang *et al.* (DOI: 10.1021/nn302896c) took advantage of double-stranded DNA (dsDNA), a material with a virtually limitless natural supply with well-developed manufacturing methods for creating strands with very long lengths. Unlike previous reports that described DNA origami structures that used dsDNA scaffolds, this new attempt did not completely pull the DNA into separate strands; rather, it required some cooperation between the two strands to form a unified structure. After digesting DNA from a λ phage into fragments, the researchers heated selected fragments to denature them, then added an excess of staples. Heating the mixture again, then slowly cooling it, the strands folded along a path precisely designed to be asymmetric, which prevented the complete convergence of the two strands. Using this method, the researchers created maze-like boxes and triangles, expanding these efforts to more complicated interconnected boxes and larger triangles. The authors suggest that even larger, more complex structures could be synthesized with further improvements to this technique.