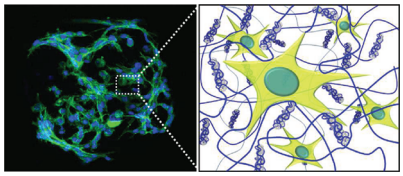
Bringing in Reinforcements: Carbon Nanotubes for Tissue Engineering

Various tissue engineering applications have used synthetic substitutes to recreate the natural extracellular matrix (ECM), a network of proteins and polysaccharide-based nanofibers that support cells and provide signaling cues during development. While many studies have sought to define the interactions between cells and the ECM on two-dimensional substrates, this environment does not successfully mimic the three-dimensional (3D) environment present *in vivo*. Consequently, developing a 3D synthetic ECM that accurately represents the ECM of real tissues is an important goal of biomedical research. Some researchers have looked to hydrogels for this capability, seeking to capitalize on their high water content and controllable biodegradability. However, highly cross-linking these materials to match the mechanical properties of tissues such as brain, muscle, or bone has been shown to limit cell activity.

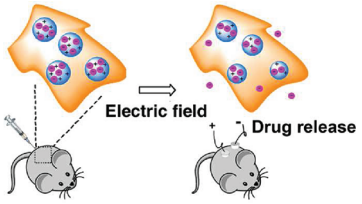
Looking for a new way to reinforce hydrogels, Shin *et al.* (DOI: 10.1021/nn203711s) developed a novel method to incorporate carbon nanotubes (CNTs), which have long been recognized for their superior mechanical properties. To make CNTs more biologically friendly, the researchers first coated them with a layer of gelatin methacrylate (GelMA), a biocompatible relative of gelatin. GelMA also acted as a surfactant, allowing CNTs to disperse in cell culture media. The researchers then incorporated the GelMA-coated CNTs into a prepolymer GelMA hydrogel solution, cross-linking the solution under UV light. Tests showed that the CNT-reinforced hydrogel successfully encapsulated cells, with more than 90% cellular viability over 48 h and significant proliferation. These artificial ECMs showed mechanical properties similar to native tissues such as muscle and bone. The authors suggest that CNT–GelMA hydrogels could have promising applications in tissue engineering and drug discovery.



Spark of Genius: Releasing Drugs from Electric-Field-Sensitive Nanoparticles

Controlled or long-term drug release is a desirable quality for a number of commonly used drugs, such as targeted chemotherapy for cancer or pharmaceuticals that require daily injections. Consequently, many researchers have sought to develop "smart" biomaterials for drug delivery that respond to various stimuli, such as heat, pH, light, enzymes, and magnetic fields. Many drug delivery vehicles of these types have been successfully employed in the laboratory setting. However, because activating these materials typically requires large or specialized equipment, they are thus far impractical for home use.

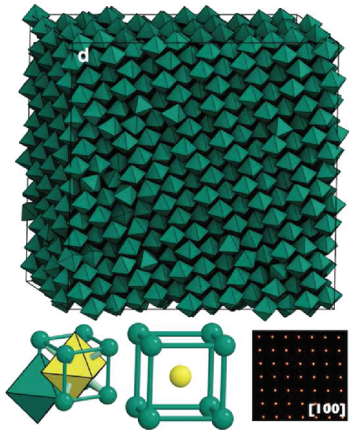
Seeking a new paradigm for smart drug delivery, Ge *et al.* (DOI: 10.1021/nn203430m) encapsulated drug particles in polypyrrole, an electric-field-responsive polymer. The researchers loaded model compounds fluorescein and daunorubicin into micelles, then encapsulated these micelles into polypyrrole nanoparticles. In solution, a low voltage over several seconds successfully released these drugs from their capsules, with more compound released with higher voltage pulses. With a single low-voltage pulse per day over seven days, the researchers demonstrated successful long-term release. No drug was released without applying an electric field, indicating excellent control over drug delivery. After enclosing the drug-containing nanoparticles in a temperature-sensitive, biocompatible polymer that remains liquid at room temperature but gels at body temperature, the researchers injected the hydrogel into mice. Applying a low-voltage electric field onto the injection site also successfully stimulated drug release, demonstrating that drug release can be controlled spatially as well as temporally. The researchers note that their new electric-field- and temperature-sensitive drug delivery vehicle might be useful for a variety of pharmaceutical applications.



Bringing Truncated Tetrahedra Together

Entropic forces can drive hard particles to form crystals and liquid crystals. Forming more complex phases, however, such as colloidal crystals, has required two-component mixtures and attractive interactions. Finding new and different ways to assemble novel and complex superstructures more easily is an important prerequisite for future applications of nanoparticles and colloids.

To understand the factors involved in particle self-assembly, Damasceno *et al.* (DOI: 10.1021/nn204012y) examined the roles of individual nanoparticle shape. Using tetrahedra, a shape now synthesizable at the nanoscale, the researchers used Monte Carlo simulations of assemblies and packing structures as the particles' corners were increasingly and symmetrically truncated until the shapes became octahedra. These simulations show that all the truncated tetrahedra pack efficiently, with maximum packing densities of 82% or higher, even better than the 74% maximum packing density of spheres. As the corners of the tetrahedra were increasingly sheared off and the shapes progressed from regular tetrahedra to octahedra, several atomic crystal isostructures emerged, including diamond, β-tin, and high-pressure lithium. This last structure has 16 particles per unit cell, the highest number reported for hard particles in the literature. Neighboring particles always packed face-to-face, with at least partial registry. This face-to-face alignment suggests directionality of the entropic forces, increasing contact between neighbors through interfacial interactions. Additionally, the researchers found that the self-assembled structures always differed from the densest packing structures, suggesting that dense packing behavior may not be useful for predicting self-assembly outcomes. The authors suggest that these findings shed new light on entropic forces in polyhedra.



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The Sunny Potential of Solar Paint

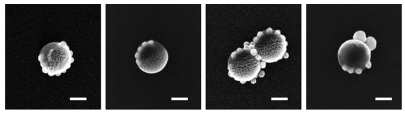
To meet consumers' demand for renewable energy, investigators continue to focus on developing more efficient solar cells that are easy and inexpensive to manufacture. The small size and high absorption cross section of semiconductor quantum dots, often combining metal chalcogenide semiconductors as sensitizers and large band gap semiconductors as acceptors, make it possible to capture nearly all incident sunlight in the visible region with just a thin layer. However, creating solar cells with these materials typically requires several sequential deposition steps, annealing, and one to two days processing time—a complicated, time-consuming method that drives up the cost of the resulting device.

Seeking a simpler way to produce extremely thin absorber solar cells, Genovese *et al.* (DOI: 10.1021/nn204381g) developed a solar paint that can be applied directly to conducting glass electrodes. The researchers tested two different methods of preparing the paint, either mixing CdS, CdSe, or both with TiO_2 in a solvent, or coating TiO_2 with either metal chalcogenide using a sequential ionic layer adsorption and reaction (SILAR) method. After incorporating the resulting thick, yellow pastes into photoelectrochemical cells, the researchers found that solar paints made by simple mixing of CdS and TiO_2 powders could deliver power conversion efficiencies of about 0.8%. This efficiency could be raised to more than 1% by using the SILAR method to combine CdS, CdSe, and TiO_2. Preparing the photoelectrode with solar paint took less than an hour. The authors suggest that solar paint could be a key element in next-generation solar cells.

DNA: Janus Nanoparticles' Better Half

As scientists have become more skilled at crafting various nanoparticles, combining these particles into increasingly complex nanostructures has attracted greater attention. However, despite the interesting anisotropic potential of asymmetric nanostructures, the vast majority of these nanostructures have been symmetrical. That asymmetric nanoclusters have remained relatively unexplored is likely a function of the challenging nature of developing these structures, with spatial and chemical controls in previous methods limiting their type and yield. Having a facile means to develop asymmetric nanostructures will be pivotal to their use in future applications.

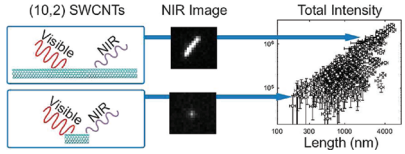
In a step toward that goal, Xing *et al.* (DOI: 10.1021/nn2042797) used DNA base pairing to form asymmetric nanostructures, using Janus nanoparticles (JNP) as a platform. The researchers first developed JNP, so named for the double-faced Roman god of beginnings and transitions, by coating one-half of individual 160 nm diameter polystyrene nanoparticles with Au. They then decorated the Au half with thiolated DNA linkers. After attaching complementary DNA on smaller Au nanospheres, the researchers created asymmetric nanoclusters by allowing the DNA strands on the JNP to base pair with those on the Au nanospheres. Further experiments showed that this attachment was reversible by introducing into solution an invasive DNA strand that outcompeted the original DNA linker. By attaching Au nanospheres of five different sizes ranging from 15 to 80 nm or, alternatively, attaching DNA linkers and corresponding Au nanospheres to the polystyrene side, the investigators demonstrated the versatility of the technique. The authors suggest that this approach to creating asymmetric nanoclusters could be promising for photonic, electronic, or biomedical applications.



How Nanotubes Get Their Glow

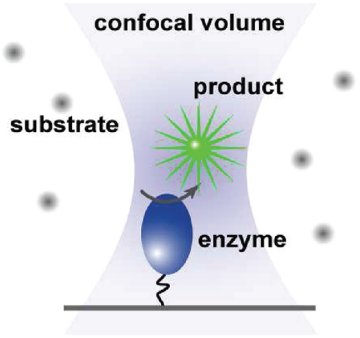
For nearly a decade, researchers have been aware that semiconducting single-walled carbon nanotubes (SWCNTs) fluoresce after exposure to near-infrared light, spurring a range of basic and applied research. However, nanotube photophysics research has been hindered by the polydispersity of bulk SWCNTs, with substantial variations in length, (*n*,*m*) structures (a measure of different diameters and roll-up angles), and imperfections. While (*n*,*m*) structure variations have been well studied in relation to spectral transition wavelengths and fluorescence action cross sections, scientists still know little about how individual SWCNT lengths and imperfections affect fluorescence. Understanding these qualities will be important not only for basic science but also for making sense of spectrometric measurements of bulk SWCNT samples.

To understand these qualities, Cherukuri *et al.* (DOI: 10.1021/nn2043516) undertook a systematic study of more than 400 individual (10,2) SWCNTs in unsorted liquid suspensions. The researchers measured the spatially integrated emission intensity, then correlated the intensity with length measurements taken either from direct imaging for longer nanotubes or from diffusion coefficients calculated through analysis of the SWCNTs' Brownian motion trajectory for shorter nanotubes. Results showed that fluorescence varied greatly even among nanotubes of the same length, presumably as a function of the defect density present along each structure. Those that showed the brightest fluorescence had total emission proportional to length, suggesting constant absorption cross section per carbon atom and a nearly constant fluorescence quantum yield. Though these results shed light on SWCNTs' intrinsic properties, the authors suggest that further research is necessary to investigate what extrinsic effects are responsible for wide variations in quantum yield.



Peering at Single Enzymes

Single enzyme studies are the only way to create a truly representative kinetic model of the catalytic reaction. Previous research into the kinetic sequence of individual enzymatic turnovers has suggested that enzymes' catalytic activity is not constant over time, with different conformations of the same enzyme leading to different rate constants. If the rate constant for the rate-limiting step varies with time, a phenomenon known as dynamic disorder arises. Although some researchers have suggested that dynamic disorder is a general quality of all enzymes, it could be an artifact of the short residence times of the fluorescent product molecules generated to study individual enzymatic reactions. These artifacts might be further amplified by the data analysis procedures typically used in these experiments, which involve binning data, then applying a threshold that separates short, high-intensity on-states from off-states.

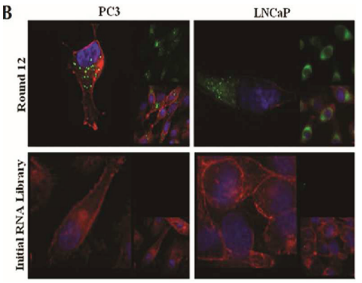


To define single enzymatic activity better and to evaluate dynamic disorder, Terentyeva *et al.* (DOI: 10.1021/nn203669r) compared the usual enzymatic turnover analysis to a different method that identifies intensity change points. Using simulated data, the researchers found that the signal-to-noise ratio and the overall fluorescence intensity significantly affect the analysis, leading to artifacts in each data analysis method. For experimental data in which the signal and background levels and the duration of on-states are unknown, the researchers found that the change point analysis method appears to be more accurate. Data from fluorescence experiments on the enzyme α-chymotrypsin showed no evidence of dynamic disorder. The authors suggest that previous studies indicating that all enzymes display dynamic disorder may have been plagued by data analysis artifacts.

An Apt(amer) Way To Get Drugs into Cancer Cells

Targeted therapies using nanoparticles are a lofty goal for treating cancer, potentially providing enhanced efficacy and fewer side effects. Researchers continue to look for ways to increase nanoparticle cellular uptake, such as modifying surface topography and charge and attaching targeting ligands. However, these methods have significant limitations. For example, only a limited number of antigens have been discovered for cancer cell recognition, and many of these help with cell binding but not internalization.

Seeking a different way to increase cell uptake of targeted therapies, Xiao *et al.* (DOI: 10.1021/nn204165v) tested nanoparticles attached to aptamers—single-stranded oligonucleotides that fold into three-dimensional conformations with the potential to bind strongly and specifically to cells. The researchers incubated normal prostate and nonprostate cells with a large library of RNA aptamers (Apts) modified with 2′-O-methyl functional groups, which prevents nuclease degradation inside cells. Pulling remaining aptamers out of the supernatant, presumably those that were not taken up by cells, the researchers then incubated these with two lines of prostate cancer cells, PC3 or LNCaP. After several rounds of washing and reincubation, the cells were lysed to remove internalized Apts. Further experiments showed that cloned exact sequences and other shortened sequences of these selected Apts were successfully bound and internalized by the prostate cancer cells, most likely through membrane proteins. After attaching these Apts to nanoparticles, the researchers found that whole conjugates were taken up by cells, with significantly enhanced cell death when the nanoparticles were loaded with the cancer drug docetaxel. The authors suggest that Apts could be a new targeted weapon against a variety of oncologic diseases.



Very Cool: Converting Graphene to Carbon Nanotubes at 500 °C

Carbon nanotubes (CNTs) and graphene continue to be highly studied carbon allotropes. Through combining these materials, researchers have envisioned a variety of applications, such as chemical sensors, electrodes, and solar cells. Controlling the growth of nanotubes is pivotal to their specific applications. To that end, Au nanoparticles are often used as catalysts and have successfully produced nanotubes in numerous experiments. However, these experiments are normally performed at relatively high temperatures, such as 800 to 1000 °C. No experiments thus far have grown CNTs on Au nanoparticles at lower temperatures.

Looking for a better way to grow carbon nanotubes, Dervishi *et al.* (DOI: 10.1021/nn203836q) show success with a new method that catalytically converts graphene decorated with Au nanoparticles into CNTs without the need for an additional hydrocarbon source. Starting with commercially prepared graphene sheets, the researchers deposited Au nanoparticles of ~6 to 12 nm in diameter on their surfaces. Placing the decorated sheets in a radio frequency chemical vapor deposition (RF-CVD) reactor and using Ar as a carrier gas, the researchers carried out reactions between 500 and 600 °C. Scanning electron microscopy and transmission electron microscopy images showed a high yield of random networks of CNTs with diameters between 10 and 20 nm, in line with the size of the Au nanoparticles. Further experiments with acetylene as the carrier gas showed similar results. No CNTs formed without the presence of Au nanoparticles, pointing to the pivotal nature of this catalyst. The authors suggest that catalytically converting graphene to CNTs with Au nanoparticles represents a viable way to form CNTs at relatively low temperature.