

5-01

Block Copolymer Directed Self-Assembly of Drug Nanoparticles

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Nanoparticle formulations of drugs, printing inks, sun screens, and other hydrophobic organic compounds have distinct advantages in bioavailability, color intensity, and aesthetics, for example. Common requirements of these applications are control of particle size and surface functionality. Commonly used techniques for the production of nanoparticles include salting out, solvent-evaporation, and emulsification-based methods. However, these methods have serious limitations, including long processing times, process scale-up, low nanoparticle drug loading, and lack of controlled nanoparticle size. In order to overcome these limitations, we describe, an easily scalable Flash Nano Precipitation process to produce stable, high concentration, and high drug loading nanoparticles using amphiphilic diblock copolymers. Uniform particles with tunable sizes from 50-500 nm can be prepared. The rules controlling particle formation will be presented using block copolymers as the structure-directing species. The process requires control of three time scales: micromixing times to initiate nucleation, nucleation and growth times for the drug compound, and block copolymer micellization times.

5-02

Enzymatic Cleavage of Surface-Immobilized Substrates: Effect of Substrate Adsorbed-Layer Age

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Proteolytic enzymes are common components of automatic dishwashing and laundry formulations used to remove protein stains. However, understanding is lacking of their adsorption and kinetic behavior at surface-bound proteins. Using optical waveguide lightmode spectroscopy (OWLS), we study the proteolysis kinetics of subtilisin on surface-immobilized protein substrates including ovalbumin, BSA and beta-casein. We focus specifically on the age of the surface-immobilized protein by measuring the transient protein-layer mass and thickness after 4 and 22 hours of protein adsorption. The rate of proteolysis increases linearly with enzyme concentration for both the 4- and 22-hr adsorbed protein substrate. Surface cleavage rates are compared to the corresponding bulk proteolysis rates, as gauged by fluorometry with FITC-labeled proteins. We argue that structure changes of the proteins upon adsorption influence the proteolysis rates. Longer aging times permit continuing protein unfolding and interfacial rearrangement that further decreases the cleavage rate. This hypothesis is supported by companion interfacial-elasticity measurements for the same proteins adsorbed at the air/water interface as a function of aging time. A simple Langmuir-Michaelis-Menton kinetic model is proposed to describe the kinetics of the simultaneous enzyme adsorption and substrate cleavage of the surface-immobilized protein layers.

5-03

Liquid Core - Polymer Shell Particles

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Core-shell particles (microcapsules), dispersed in water, with liquid cores and polymer shells of controlled thickness and morphology, are excellent candidates for the controlled release of "active" molecules, such as pharmaceuticals, agrochemicals, perfumes, flavors, dyes, inks, etc. Various methodologies have been reported for making such capsules. In this paper we will discuss a novel method for the preparation and characterization of a variety of different microcapsules, including ones with oil cores and others with aqueous cores, depending on the nature of the active material to be released. The general method used for their preparation is based on *internal* phase separation of the polymer wall from the droplets of either an oil/water emulsion or a water/oil emulsion depending on the nature of the internal phase required. For the aqueous core particles, the external oil phase is replaced (after shell formation) by an aqueous phase. Control of the various interfacial tensions is critical in obtaining particles with a shell (rather than an "acorn" structure"). The size of the microcapsules, and the polymer wall thickness and permeability can be readily controlled using this method. Characterization of the microcapsules is mainly based on light scattering, optical microscopy and SEM (of the broken microcapsules).

Some data will be presented for release rates and amounts of model active materials, and how this is affected by changes in the various system parameters, such as the size of the liquid core, the polymer shell thickness, and the nature of the polymer shell.

5-04

Effects of Surface Properties on Droplet Formation Inside a Microfluidic Device

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Micro-fluidic devices offer a unique method of creating and controlling droplets on small length scales. A microfluidic device is used to study the effects of surface properties on droplet formation of a 2-phase flow system. Four phase diagrams are generated to compare the dynamics of the 2 immiscible fluid system (silicone oil and water) inside microchannels with different surface properties. Results show that the channel surface plays an important role in determining the flow patterns and the droplet formation of the 2-phase fluid system. The surface effect on the droplet deposition inside microchannels will also be discussed.

5-05

Delivery of Food Antimicrobials In Micellar Surfactant Systems

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Foodborne illness continues to be a problem in the US. Effective and simple processor-level control measures for foodborne pathogens are urgently needed. Naturally occurring food antimicrobials offer a convenient mean to improve the safety of the US food supply. While these compounds have shown to inhibit or kill foodborne pathogens in model microbiological systems, their widespread use has been limited by general lack of activity and low solubilities. We suggest that lack of activity of food antimicrobials can be overcome by encapsulating antimicrobials in delivery systems that are capable of targeting pathogens while decreasing interaction with interfering food components. We report recent results on the use and efficiency of micellar surfactant systems as delivery vehicles for lipophilic food antimicrobials. The encapsulation mechanism and inhibitory efficacy of phytophenol antimicrobials eugenol and carvacrol in two food surfactants, Surfynol 465 and 485 was investigated. Combinations of surfactant/phytophenol antimicrobials yielded greatly improved activity in model microbiological systems with Eugenol-Surfynol 465 having the highest observed activity and successfully inhibiting *Escherichia coli* O157:H7 and *Listeria monocytogenes*. Testing in model food system (skim, 2% and whole milk) indicated that activity while slightly lower than in model microbiological system was maintained in skim and 2% milk, but activity in whole milk was reduced. Reduction of activity is explained in terms of de-micellization and adsorption of surfactant monomers at milk fat droplet interfaces. Results are promising in that development of novel antimicrobial delivery systems offers a potentially simple and affordable solution to improve the safety of fresh and processed food products.

5-06

Formation Mechanism and Properties of Colloidal Nanoparticles used in Lubricant Additive Formulations

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Additives are used in lubricant systems to minimise destructive processes in the engine (*e.g.* wear and corrosion) and to confer beneficial properties (*e.g.* more uniformed viscosity with temperature and improved fuel economy). Overbased detergents are an integral element of such additive systems, and consist of surfactant stabilised inorganic nanoparticles (comprising calcium carbonate). Such “overbased” additives represent “model” hard-sphere systems with narrow polydispersity and mean core radius in the range 2 – 5 nm. They have been characterised by a range of techniques including small-angle neutron scattering (SANS). Overbased detergents are used in lubrication packages to neutralise acid species introduced into the lubricant through acidic blow-by gases. In addition, the detergent helps maintain piston cleanliness.

The production of stable nanoparticles (with tailored properties) is an area of current research interest, with potential for a wide range of future applications. For many such systems, a major

challenge is the production of particles with consistent quality (and low polydispersity) on a large scale. Overbased detergents are produced on a multi-tonne scale, with a constant particle size and low degree of polydispersity. The mechanism by which such nanoparticles are formed has recently been investigated by small angle neutron scattering and evidence will be presented that suggests the particle formation mechanism is via nucleation-growth (and not the previously reported micellar route). A similar synthesis mechanism may have potential for other inorganic nanoparticles.

In addition, characterisation of the properties of such detergent particles (*e.g.* core and surfactant shell sizes by SANS) will also be presented.

5-07

The Synthesis of FePt Nanoparticles by Two-Liquid Mixing Method

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FePt nanoparticles have been synthesized continuously by mixing two precursor liquids: ferric acetylacetonate, $\text{Fe}(\text{acac})_3$, and platinum acetylacetonate, $\text{Pt}(\text{acac})_2$ in ethyleneglycol solution with dispersing agents. The reduction reaction of the mixed Fe and Pt ions to the FePt metal alloys in the reaction cell at a high temperature were aided by irradiating the high power of ultrasound continuously. The obtained FePt particle size was found by TEM photograph to be around 3~4 nm showing monodisperse and nonagglomerating. The rate of production of the FePt nanoparticles was more than 30g per hour. The composition of Fe and Pt elements in FePt nanoparticles determined by ICP analysis was changed arbitrarily by controlling the flow rate of two precursor liquids. The ferromagnetic property of FePt nanoparticles was obtained by the annealing because as grown sample shows the nature of super-paramagnetic properties. The annealing condition was to keep the FePt nanoparticles at a high temperature for 30 min in an atmosphere of 15% of H_2 and 85% of Ar. The magnetic hysteresis loops of FePt nanoparticles were obtained by SQUID measurements. The highest room temperature coercivity ~up to 10 kOe was observed in $\text{Fe}_{53}\text{Pt}_{47}$ sample.

The addition of Ag atoms to FePt nanoparticles in the nanoparticles synthesis lowered the annealing temperature of the sample as low as below 350°C. The magnetic properties of the FePtAg and FePt nanoparticles were compared by the measurements of SQUID and XMCD.

5-08

Mesoscale Simulation of Colloids and Surfactants in Consumer Products

FIONA CASE, Case Scientific

Many soft or fluid consumer products, such as foods, paint, detergents, personal care products, and cosmetics, contain nanometer to micron size fluid structures. These structures (such as micelles, vesicles, emulsions and lamella) are formed by the spontaneous self-assembly of natural or

synthetic surfactants or block copolymers. In many cases complex mixtures of different surfactants and polymers are required to create the desired structure and performance.

These complex materials are challenging to characterize. Even with the latest developments in light microscopy the fluid structures can be orders of magnitude too small to be observed. Illumination with smaller wavelength radiation (such as x-rays or neutrons) solves the size problem, but results can only be interpreted unambiguously for simplified model systems. Adding to this challenge is the fact that product performance depends not on the static or equilibrium structure of the material, but on its dynamic behavior. When detergent cleans, or soap foams, or a fragrance releases, or margarine spreads, it is the way that the nanometer to micron sized fluid structures change in response to external stimuli that determines performance.

How can we predict the dynamic nanometer to micron scale structure of a particular mixture of surfactants, polymers, oils and additives – of a particular formula? And how can we predict its response to external stimuli - agitation, dilution, or the introduction of a dirty surface? If we could do this, and we could also identify the link between physical properties and consumer perceivable performance (another significant challenge!), we could prescribe the perfect formula for any application.

Computer simulation may provide part of the solution by predicting the structure and dynamic behavior of materials. There are a number of different types of simulation. Atomistic scale simulation methods are quite well established. They can reliably predict the shape of individual molecules or relatively small clusters of molecules. Using a super-computer, such as IBM's Blue Gene/L prototype, the structures of lipid membranes and membrane proteins can even be predicted. These methods can provide insight into part of the problem (the behavior of small fluid structures, over the short periods of time). The much larger scale mixing and flow of materials can be predicted using methods such as computational fluid dynamics, this is another part of the solution. But CFD alone cannot predict the effects of varying molecular structure on the performance of a material (for example of changing the type of surfactants in a complex mixture). Mesoscale modeling techniques, such as dissipative particle dynamics and mean-field theories, have proved capable of modeling a critical length scale for complex fluids – capable of predicting the self assembly of structures from nanometers to microns in size. This presentation will provide an overview of different computational approaches, focusing on mesoscale modeling and its potential application to predict properties of personal care products such as liquid soaps and detergents. We will also look to the future, and to the development of new approaches that combine the different length scales in one simulation. These new methods may finally allow us to predict the behavior of the fascinating, complex, dynamic materials that are modern consumer products.

5-09

Fluorescent Silica Colloids for Detection of Absorption of Various Skin Care Products

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Recently we have synthesized a new type of very bright nanoporous silica colloids. Organic lasing dye is encapsulated inside of closed pores, which prevents its leakage. Silica particles are

chemically inert and rather biocompatible. It makes them a good candidate for tracing of various substances, in particular, skin-care products. To demonstrate this, we mix the silica particles with two types of moisturizers broadly used in cosmetics, Vaseline and glycerin. We demonstrate that the amount and location of the moisturizers on human skin can now be easily detected with UV light source. The absolute radiance measurements show a good correlation with amount of the moisturizers measured by collecting-by-scratching tests. The presented method can be effectively used for a fast non-contact detection of location of the skin-care products, its spread with time, and absorption by skin.

5-10

Colloidal Nanoparticles in Consumer Products

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Colloidal nanoparticles have found many applications in a broad range of technologies and in the processing of various materials including foods, cosmetics, paints, and drug delivery systems. In addition, due to their ability to assemble in bulk and at interfaces they are widely used as a precursor for advanced nanostructured materials. In consumer products, colloidal nanoparticles are either naturally present, formed during the processing, or intentionally added to tailor certain functional properties of the product. In this presentation, we will discuss the fundamental approaches to control product functionality like composition, structure, stability, taste and appearance.