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Monday, February 27, 2012 8:00AM - 11:00AM –
Session A51 DCMP DFD: Colloids I: Beyond Hard Spheres Boston Convention Center 154

8:00AM A51.00001 Photonic Droplets Containing Transparent Aqueous Colloidal Suspensions with Optimal Scattering Properties

JIN-GYU PARK, SOFIA MAGKIRIADOU, Department of Physics, Harvard University, YOUNG-SEOK KIM, Korea Electronics Technology Institute, VINOTHAN MANOHARAN, Department of Physics, Harvard University, HARVARD UNIVERSITY TEAM, KOREA ELECTRONICS TECHNOLOGY INSTITUTE COLLABORATION — In recent years, there has been a growing interest in quasi-ordered structures that generate non-iridescent colors. Such structures have only short-range order and are isotropic, making colors invariant with viewing angle under natural lighting conditions. Our recent simulation suggests that colloidal particles with independently controlled diameter and scattering cross section can realize the structural colors with angular independence. In this presentation, we are exploiting depletion-induced assembly of colloidal particles to create isotropic structures in a milimeter-scale droplet. As a model colloidal particle, we have designed and synthesized core-shell particles with a large, low refractive index shell and a small, high refractive index core. The remarkable feature of these particles is that the total cross section for the entire core-shell particle is nearly the same as that of the core particle alone. By varying the characteristic length scales of the sub-units of such 'photonic' droplet we aim to tune wavelength selectivity and enhance color contrast and viewing angle.

8:12AM A51.00002 Curvature-Induced Capillary Interaction between Spherical Particles at a Liquid Interface[1]

NESRIN SENBIL, CHUAN ZENG, BENNY DAVIDOVITCH, ANTHONY D. DINSMORE, University of Massachusetts Amherst — Capillary interactions among particles adsorbed at a fluid interface are important in a variety of natural and technological systems but still pose many mysteries. Capillary interactions induced by buoyancy, referred to as the"Cheerios "effect, have been studied for years. Here, we experimentally investigate how anisotropic interfacial shape affects capillary forces among millimeter-sized spheres. The Cheerios model predicts that particles with densities that are higher and lower compared to the fluids adsorbed at an initially flat interface will repel. Our experiments, however, clearly show that they can attract one another at the short range. We explain our results with a model, in which each sphere creates an anisotropic curvature at the position of the other sphere. To satisfy the constant contact-angle boundary condition, the interface is deformed with quadrupolar symmetry around each sphere. This quadrupolar deformation creates a short-ranged, attractive capillary force. The range of size and density ratios at which we observe a dominant short-range attraction is consistent with the model. Our results show how interfacial shape may be used to direct the assembly of interfacial particles.

[1] Funded by the NSF-supported MRSEC on Polymer at UMASS(DMR-0820506)and NSF CBET-0967620.

8:24AM A51.00003 Using Micron-Sized Ellipsoids as a New Tool for Microrheology

DAVID C. KILGORE, KENNETH W. DESMOND, ERIC R. WEEKS, Emory University — Microrheology is a well-established technique, and in its simplest form it allows you to measure the viscosity of a fluid by examining the diffusion of microspheres, provided the diameter of the microspheres is known. We are developing a similar technique using ellipsoids, where the viscosity can be calculated without prior knowledge of the length and width of the ellipsoid. The asymmetry of ellipsoids provides a distinct advantage, allowing for the diffusion to be decomposed into two translational motions and one rotational motion. For each of these diffusive motions, we can measure a diffusion constant and relate the constant to the three unknowns: the length and width of the ellipsoid, and the viscosity. By measuring the three diffusion constants, we can determine the three unknowns. To verify this technique, we produce ellipsoids in the lab and suspend them in a viscous solution for three-dimensional imaging of the diffusion with a confocal microscope. We are able to get good agreement between the microrheological measurements and macroscopic viscosity measurements.

8:36AM A51.00004 Non-capillary binding of colloidal particles to liquid interfaces

DAVID KAZ, UC Berkeley, RYAN MCGORTY, UC San Fransisco, VINOTHAN MANOHARAN, Harvard University — We observe colloidal polystyrene particles binding reversibly to an oil-water interface through the combination of a repulsive electrostatic force and an attractive van der Waals force. Previously studied interactions of an aqueous colloidal particle and a liquid interface have generally fallen into two categories: 1) electrostatic repulsion indicated by the dependence on salt and 2) capillary adsorption where surface tension brings the particle in contact with both phases and is indicated by practically irreversible binding. With our technique of pushing individual colloidal particles towards a planar oil-water interface and observing their motion in three-dimensions with holographic microscopy we have observed both interactions. However, our observations indicate that under certain conditions the electrostatic repulsion, which is due to repulsive image charges, is weak enough for a particle to experience a van der Waals attraction while strong enough to prevent a particle from penetrating the interface and becoming bound through capillary action. We observe individual particles transition between repulsive and attractive interactions with the interface suggesting that these colloidal particles have a heterogeneous surface charge.

8:48AM A51.00005 Memory effects in soap film arrangements

NICOLAS VANDEWALLE, STEPHANE DORBOLO, GEOFFROY LUMAY, JULIEN SCHOCKMEL, MARTIAL NOIRHOMME, GRASP, Institute of Physics B5a, University of Liege, B4000 Liege — We report experiments on soap film configurations in a triangular prism for which the shape factor can be changed continuously. Two stable configurations can be observed for a range of the shape factor h. A hysteretic behaviour is found, due to the occurence of another local minima in the free energy. Experiments demonstrate that soap films can be trapped in a particular configuration being different from a global surface minimization. This metastability can be evidenced from a geometrical model based on idealized structures. Depending on the configuration, providing clues on the structural relaxations taking place into 3D foams, such as T1 rearrangements. The composition of the liquid is also investigated leading to dynamical picture of the transition. (Phys. Rev. E 83, 021403 (2011))

9:00AM A51.00006 Droplet-based microfluidics and the dynamics of emulsions

JEAN-CHRISTOPHE BARET, QUENTIN BROSSEAU, BENOIT SEMIN, XIAOPENG QU, Max-Planck Institute for Dynamics and Self-Organization, DROPLETS, MEMBRANES AND INTERFACES TEAM — Emulsions are complex fluids already involved for a long time in a wide-range of industrial processes, such as, for example, food, cosmetics or materials synthesis [1]. More recently, applications of emulsions have been extended to new fields like biotechnology or biochemistry where the compartmentalization of compounds in emulsion droplets is used to parallelise (bio-) chemical reactions [2]. Interestingly, these applications pinpoint to fundamental questions dealing with surfactant dynamics, dynamic surface tension, hydrodynamic interactions and electrohydrodynamics. Droplet-based microfluidics is a very powerful tool to quantitatively study the dynamics of emulsions at the single droplet level or even at the single interface level: well-controlled emulsions are produced and manipulated using hydrodynamics, electrical forces, optical actuation and combination of these effects. We will describe here how droplet-based microfluidics is used to extract quantitative informations on the physical-chemistry of emulsions for a better understanding and control of the dynamics of these systems [3].

[1] J. Bibette et al. Rep. Prog. Phys., 62, 969-1033 (1999)
[2] A. Theberge et al., Angewandte Chemie Int. Ed. 49, 5846 (2010)
[3] J.-C. Baret et al., Langmuir, 25, 6088 (2009)

9:12AM A51.00007 Pseudo-Steady Liquid Transport in Aqueous Foams during Filling of a Container

, MICHAEL CONROY[1], RAMAGOPAL ANANTH[2], Naval Research Laboratory — Various applications of aqueous foams involve filling a container or a column (e.g., fractionation), where the foam is formed and processed. However, existing studies in the literature do not treat the filling stage and only describe liquid transport within a static foam bed. We developed a theory that predicts liquid loss from the foam and the liquid distribution within its interior during the filling and post-filling stages. During the filling stage, the theory predicts that the foam reaches a pseudo-steady state characterized by a time-independent drainage rate and liquid fraction. The pseudo-steady-state liquid fraction appears above a thin, liquid-saturated boundary layer that exists at the bottom of the foam bed. During the post-filling stage, the theory predicts that the drainage rate decreases with time, similar to static foams beds studied by others. The theory compares well with our previously reported volume-averaged macroscopic model and drainage measurements for dry (high-expansion) foams. We will show that drainage during the filling stage is significant when the fill time is comparable to the intrinsic drainage time scale of the foam.

[1]This work was performed while M. W. Conroy was a NRC Postdoctoral Associate at NRL.
[2]Author to whom correspondence should be addressed: ramagopal.ananth@nrl.navy.mil

9:24AM A51.00008 Coarsening of Two Dimensional Foams on a Curved Surface

, ADAM ROTH, University of Pennsylvania, CHRIS JONES, Cornell University, DOUG DURIAN, University of Pennsylvania — We report on foam coarsening and statistics of bubble distributions in a closed, two dimensional, hemispheric cell of constant curvature. Using this cell it is possible to observe individual bubbles and measure their coarsening rates. Our results are consistent with the modification to von Neumann's law predicted by Avron and Levine. We observed the relative frequencies of bubbles with a given number of sides and found a shortage of bubbles with few sides as compared to a flat two dimensional cell. We also measured the value of $m(n)$, the average number of sides of an n sided bubble, and found general agreement with the Aboav-Weaire law, although there was greater deviation than for a flat cell.

9:36AM A51.00009 Analysis of emulsion stability in acrylic dispersions[1]

, SURESH AHUJA, Retired — Emulsions either micro or nano permit transport or solubilization of hydrophobic substances within a water-based phase. Different methods have been introduced at laboratory and industrial scales: mechanical stirring, high-pressure homogenization, or ultrasonics. In digital imaging, toners may be formed by aggregating a colorant with a latex polymer formed by batch or semi-continuous emulsion polymerization. Latex emulsions are prepared by making a monomer emulsion with monomer like Beta-carboxy ethyl acrylate (β-CEA) and stirring at high speed with an anionic surfactant like branched sodium dodecyl benzene sulfonates , aqueous solution until an emulsion is formed. Initiator for emulsion polymerization is 2-2'- azobis isobutyramide dehydrate with chain transfer agent are used to make the latex. If the latex emulsion is unstable, the resulting latexes produce a toner with larger particle size, broader particle size distribution with relatively higher latex sedimentation, and broader molecular weight distribution. Oswald ripening and coalescence cause droplet size to increase and can result in destabilization of emulsions. Shear thinning and elasticity of emulsions are applied to determine emulsion stability.

[1]Xerox Corporation

9:48AM A51.00010 ABSTRACT WITHDRAWN —

10:00AM A51.00011 Dynamics of charged particles in nonpolar solvent in response to an electric field

, TINA LIN, DAVID WEITZ, Harvard University — In nonpolar solvent, surfactant molecules aggregate to form charge-stabilizing reverse micelles. This enables surface charging of colloidal particles suspended in nonpolar solvent. We investigate the dynamics of such charged particles in response to an externally applied electric field. By combining microfluidics and confocal microscopy, we directly visualize the transport of particles between two parallel electrodes. We use direct visualization to measure the electrophoretic mobility of each particle and determine the effect of added surfactant on the measured mobility. In addition, we find that the presence of surfactant has a significant effect on the transport dynamics of the charged particles.

10:12AM A51.00012 Controlling Aggregation in Non-Polar Asphaltene Suspensions Through Electrostatics

, SARA HASHMI, ABBAS FIROOZABADI, Yale University — Asphaltenes, the most aromatic and largest molecular weight components of petroleum fluids, can undergo a liquid-liquid phase transition in conditions including highly non-polar environments. Phase separation begins with molecular association and proceeds to and through the colloidal length-scale until complete sedimentation or deposition. Non-ionic polymeric dispersants can stabilize asphaltenes at the colloidal scale in non-polar suspensions. We perform a variety of experiments which suggest that stabilization occurs by adsorption of dispersant onto the asphaltenes, truncating the progress of precipitation. In particular, dynamic light scattering (DLS) and phase-analysis light scattering (PALS) measurements indicate that electrostatic repulsion is responsible for stabilizing asphaltene colloids against further aggregation. Aggregation time increases exponentially with dispersant concentration, as expected for particles interacting through a combination of attractive dispersion forces and repulsive electrostatics. However, contrary to current understandings of electrostatic stabilization in non-polar systems, the charges in colloidal asphaltene suspensions seem to arise from the asphaltene colloids themselves rather than from dispersant micelles.

10:24AM A51.00013 The Electric Double Layer Structure Around Charged Spherical Interfaces[1]

, ZHENWEI YAO, MARK BOWICK, XU MA, Syracuse University — We derive a formally simple approximate analytical solution to the Poisson-Boltzmann equation for the spherical system via a geometric mapping. Its regime of applicability in the parameter space of the spherical radius and the surface potential is determined, and its superiority over the linearized solution is demonstrated. In addition, the influence of nonuniform surface potential on the electric double layer structure is studied for large spheres in the weak potential limit.

[1]This work was supported by the National Science Foundation grant DMR-0808812 and by funds from Syracuse University

10:36AM A51.00014 ABSTRACT WITHDRAWN —

10:48AM A51.00015 First experimental determination of permanent and induced electric dipolar moments of colloidal cellulose nanocrystals dispersed in apolar solvents[1] , BRUNO FRKA-PETESIC, BRUNO JEAN, LAURENT HEUX, CERMAV-CNRS — Scientists and industrialists show a growing interest for cellulose nanocrystals (CNCs) since these rod-like nanoparticles display excellent mechanical properties that make them perfect candidates for the design of high performance biobased composites. Furthermore, CNCs can be obtained as colloidal suspensions in apolar solvents that form chiral nematic (cholesteric) liquid crystals. Our aim is to obtain homogeneous unidimensionnal structures to enhance the optical and/or mechanical properties of CNCs-based architectures at a macroscopic scale. Using electric fields, CNCs suspensions from either cotton or tunicate were succesfully oriented in the direction of an electric field, in both AC and DC configurations. To probe the electric field induced orientation of the CNCs, a birefringence experimental set-up has been developped. While applying short electric DC field pulses, static and transient birefringence has been measured in diluted isotropic suspensions. From these measurements, we determined both the permanent and induced electric dipolar moments of the CNCs, whose effects appeared to be of the same order of magnitude. The results are discussed regarding to the CNC type and the apolar solvent used.

[1]This work was supported by ANR-08-NANO-P235 BIOSELF

Monday, February 27, 2012 11:15AM - 2:15PM –
Session B42 DBIO DFD: Focus Session: BioChip Physics-Detection and Transport 156C

11:15AM B42.00001 On-chip Metamaterials for Ultra-sensitive Spectroscopy and Identification of Biomolecules , HATICE ALTUG, Boston University — Infrared absorption spectroscopy is a unique tool for identifying and characterizing molecular bonds. For most organic and inorganic molecules (such as proteins, chemical toxins and gases), vibrational and rotational modes are spectroscopically accessible within the mid-infrared (mid-IR; 3-20 μm) regime of the electromagnetic spectrum. Characteristic vibrational modes are associated with unique IR absorption spectral bands that are bond-specific. Because of that, the IR wavelength range is also known as "finger print" region. However, because of the Beer-Lambert law, its sensitivity has been limited to perform analytical/functional studies on small samples often available from biological specimens. In this talk we will describe how we use plasmonic metametrials to overcome these challenges. We will introduce tailoring of the resonances to selectively address fingerprint signatures of proteins. We will also describe novel designs and fabrication methods to exploit extreme near-field enhancements in small gaps for vibrational signal enhancements.

In collaboration with In collaboration with Ronen Adato, Serap Aksu, Alp Artar, Arif Cetin, and Boston University.

11:51AM B42.00002 Ultrasensitive Plasmonic Biosensors for Direct Detection of Biomarker Proteins with The Naked Eye , AHMET ALI YANIK, Harvard University Medical Schoold and Massachusetts General Hospital, JOHN CONNOR, Boston University Medical School, GENNADY SHVETS, University of Texas, Austin, HATICE ALTUG, Boston University Electrical and Computer Engineering — We introduce an ultrasensitive label free biodetection technique based on asymmetric plasmonic Fano resonances. Our sensors bring a number of advantages: (i) ultrasensitive detection limits surpassing gold standard Kretschmann configuration plasmon sensors, (ii) detection of biomarker molecules with "the naked eye", (iii) massive multiplexing capabilities. By exploiting extraordinary light transmission phenomena through high quality factor sub-radiant dark modes, we experimentally demonstrate record high figures of merits for intrinsic detection limits surpassing the gold standard BiaCore devices. Our experiments show an order of magnitude improved device performances over the state of art metamaterial and other plasmonic biosensors. Steep dispersion of the plasmonic Fano resonance profiles in engineered plasmonic sensors exhibit dramatic light intensity changes to the slightest perturbations within their local environment. As a spectacular demonstration, we show direct detection of a single monolayer of biomolecules with naked eye using these Fano resonances and the associated Wood's anomalies. The demonstrated sensing platform offers point-of-care diagnostics in resource poor settings by eliminating the need for fluorescent labeling and optical detection instrumentation (such camera, spectrometer, etc.).

12:03PM B42.00003 High-Throughput On-Chip Diagnostic System for Circulating Tumor Cells , JAEHOON CHUNG, HUILIN SHAO, RALPH WEISSLEDER, HAKHO LEE, Center for Systems Biology, Massachusetts General Hospital — We have developed a novel, low-cost and high-throughput microfluidic device for detection and molecular analysis of circulating tumor cells (CTCs). The operation is based upon a size-selective cell separation, which was enabled by a weir-style physical barrier with a gap in the fluidic channel. The new system is a versatile CTC analysis platform with many advantages. First, it supports extremely high throughput operation, since the use of weir structure reduces fluidic resistance and enables flow-through separation ($>$ 20,000-fold CTC enrichment from whole blood at the flow rate of 10 mL/h). Second, the CTC-chip facilitates visual verification and enumeration of CTCs during/after operation. By implementing microwell-shaped structures on the physical barrier, CTCs can be individually captured at sites for single-cell resolution analyses. Furthermore, the captured cells could be profiled in situ by introducing antibodies or small molecular probes. The chip thus assumes not only high detection sensitivity but also molecular specificity for CTC identification. Finally, the CTC-chip can retrieve captured CTCs. By reversing the flow direction, the cells can be dislodged from their capture sites and collected for downstream investigation.

12:15PM B42.00004 Mass transport to suspended waveguide biosensors , JASON GAMBA, CHAITANYA MURTHY, ANDREA ARMANI, University of Southern California — The response of a biosensor is controlled both by the kinetics of analyte adsorption as well as the mass transport to the device. Improving the affinity between a target molecule and the functionalized sensor can pose significant challenges in terms of biochemistry and surface chemistry. The careful design of sample flow systems presents a more convenient route for decreasing the time required for a measurement Using finite element methods, we model mass transport to a novel integrated photonic biosensor suspended within a microfluidic channel in an effort to understand how boundary layer flow patterns may be engineered to improve the transient response of the device. By monitoring the surface concentration of bound analyte over a range of inlet concentrations and vertical positions within the channel, we compare the behavior of suspended devices to that of planar sensors located on the floor of the channel. Thinner boundary layers and increased effective sensing area lead to consistently faster transient responses for the suspended sensor, with optimal performance resulting from the symmetric placement of the sensor with respect to the channel height.

12:27PM B42.00005 Weighing single cells in two fluids: measuring mass, volume and density , FRANCISCO FEIJÓ DELGADO, WILLIAM GROVER, NATHAN CERMAK, ANDREA BRYAN, SCOTT MANALIS, Massachusetts Institute of Technology — The Suspended Microchannel Resonator (SMR) is a highly sensitive cantilever-based mass sensor shown to be capable of weighing the buoyant mass of living single cells. We have engineered SMR-based microfluidic systems to achieve consecutive weighing of single cells in two different fluids, with controlled exposure times. By choosing fluids of two different densities, the paired buoyant mass measurements are used to characterize single-cell volume, mass and density. With density precision of 0.001 g.cm^{-3}, we explore the application of our techniques to samples ranging from bacterial to mammalian cells and show that cellular density is a tightly regulated biological property within populations, up to 100-fold more so than the other size parameters.

12:39PM B42.00006 Label-free screening of niche-to-niche variation in satellite stem cells using functionalized pores, MATTHEW R. CHAPMAN, Biophysics Graduate Group, UC Berkeley, KARTHIK BALAKRISHNAN, Dept. Mechanical Engineering, UC Berkeley, MICHAEL J. CONBOY, Dept. Bioengineering, UC Berkeley, SWOMITRA MOHANTY, Dept. Mechanical Engineering, UC Berkeley, ERIC JABART, Dept. Bioengineering, UC Berkeley, HAIYAN HUANG, Dept. Statistics, UC Berkeley, JAMES HACK, Dept. Mechanical Engineering, UC Berkeley, IRINA M. CONBOY, Dept. Bioengineering, UC Berkeley, LYDIA L. SOHN, Dept. Mechanical Engineering, UC Berkeley — Combinations of surface markers are currently used to identify muscle satellite cells. Using pores functionalized with specific antibodies and measuring the transit time of cells passing through these pores, we discovered remarkable heterogeneity in the expression of these markers in muscle (satellite) stem cells that reside in different single myofibers. Microniche-specific variation in stem cells of the same organ has not been previously described, as bulk analysis does not discriminate between separate myofibers or even separate hind-leg muscle groups. We found a significant population of Sca-1+ satellite cells that form myotubes, thereby demonstrating the myogenic potential of Sca-1+ cells, which are currently excluded in bulk sorting. Finally, using our label-free pore screening technique, we have been able to quantify directly surface expression of Notch1 without activation of the Notch pathway. We show for the first time Notch1-expression heterogeneity in unactivated satellite cells. The discovery of fiber-to-fiber variations prompts new research into the reasons for such diversity in muscle stem cells.

12:51PM B42.00007 Demonstration and analysis of the harmonic dithering technique for a high-sensitivity silicon waveguide biosensor, KANGBAEK KIM, ROBERT M. PAFCHECK, THOMAS L. KOCH, Lehigh University — A label-free biosensor readout technique is demonstrated based on a silicon-on-insulator ring resonators and a harmonic dithering technique using a distributed feedback (DFB) laser and a lock-in amplifier. The 400 μm ring resonator is integrated with a microfluidic sample delivery channel formed with Polydimethylsiloxane (PDMS). Dithering the frequency of the DFB laser across the Lorentzian lineshape of the drop port at high frequency eliminates 1/f noise, and broadband noise is reduced by narrow-band detection with the lock-in amplifier. Biosensor system noise is analyzed and compared with more conventional readout methods, and in our case is dominated by thermal noise of the receiver, shot noise, and relative intensity noise (RIN) of the DFB laser. Because the readout automatically latches onto the drop port and does not require a complex scanning process, this methodology may provide a pathway for high-sensitivity, real-time, and low-cost biosensing.

1:03PM B42.00008 Label-free detection of DNA on silicon surfaces using Brewster angle straddle interferometry (BASI), XIAO WANG, University of Rochester School of Medicine and Dentistry, Department of Biochemistry and Biophysics, 601 Elmwood Ave., Box 712, Rochester, NY, 14642, LEWIS ROTHBERG, University of Rochester, Department of Chemistry, Rochester, NY 14627 — Label-free sensing of biomolecular interactions is of great importance for drug screening and a variety of clinical assays. Ultrasensitive detection of dsDNA on silicon substrates can be achieved using our new label-free sensing method - Brewster angle straddle interferometry (BASI) which exploits the removal of destructive interference to detect binding of target molecules on a silicon surface functionalized by probe molecules. By exploiting the fact that reflections of p-polarization undergo 180 degree phase shifts above the Brewster angle and none below it, we are able to use unprocessed silicon substrates with native oxide serving as the interference layer. Destructive interference in the geometry we use results in reflectivities $\sim$ 0.01%. Reflectivity from the chip is a quantitative measure of the amount of bound target molecules and can be imaged in real time in microarray format. We demonstrate detection of DNA intercalation on pyrene modified surfaces. The substrates are shown to exhibit excellent binding toward dsDNAs. This work provides an avenue for understanding the binding specificity of small molecule-DNA interactions that can be potentially helpful in developing anticancer agents.

1:15PM B42.00009 Real-time molecular detection using a nanoscale porous silicon waveguide biosensor, XING WEI, JEREMY MARES, SHARON WEISS, Vanderbilt University — A grating-coupled porous silicon waveguide with an integrated PDMS flow cell is demonstrated as a platform for real-time detection of chemical and biological molecules. This sensor platform not only allows for quantification of molecular binding events, but also provides a means to improve understanding of diffusion and binding mechanisms in constricted nanoscale geometries. The large internal surface area of porous silicon enables the capture of molecules inside the waveguide, which causes a large perturbation of the guided mode field and improves detection sensitivity by more than one order of magnitude as compared to evanescent wave-based detection methods. Molecular binding events in the waveguide are monitored by real-time angle-resolved reflectance measurements. Diffusion, adsorption and desorption coefficients of different sized chemical linker and nucleic acid molecules are determined based on the rate of change of the measured resonance angle. Both the magnitude of the waveguide resonance angle shift and kinetic parameters are observed to depend on molecule size. Experimental results are shown to be in good agreement with calculations based on rigorous coupled wave analysis and finite element simulation.

1:27PM B42.00010 On-chip Magnetic Separation and Cell Encapsulation in Droplets, A. CHEN, T. BYVANK, A. BHARDE, B.L. MILLER, J.J. CHALMERS, R. SOORYAKUMAR, The Ohio State University, W.-J. CHANG, University of Wisconsin-Milwaukee, R. BASHIR, University of Illinois at Urbana-Champaign — The demand for high-throughput single cell assays is gaining importance because of the heterogeneity of many cell suspensions, even after significant initial sorting. These suspensions may display cell-to-cell variability at the gene expression level that could impact single cell functional genomics, cancer, stem-cell research and drug screening. The on-chip monitoring of individual cells in an isolated environment could prevent cross-contamination, provide high recovery yield and ability to study biological traits at a single cell level These advantages of on-chip biological experiments contrast to conventional methods, which require bulk samples that provide only averaged information on cell metabolism. We report on a device that integrates microfluidic technology with a magnetic tweezers array to combine the functionality of separation and encapsulation of objects such as immunomagnetically labeled cells or magnetic beads into pico-liter droplets on the same chip. The ability to control the separation throughput that is independent of the hydrodynamic droplet generation rate allows the encapsulation efficiency to be optimized. The device can potentially be integrated with on-chip labeling and/or bio-detection to become a powerful single-cell analysis device.

1:39PM B42.00011 Chip-based magnetic cytometer for high-throughput cellular profiling in unprocessed biological samples, DAVID ISSADORE, JAEHOON CHUNG, HUILIN SHAO, MONTY LIONG, RALPH WEISSLEDER, HAKHO LEE, Massachusetts General Hospital / Harvard Medical School — Quantitative, high-throughput measurement of biomarkers in individual cells is a cornerstone of biomedical research, but prohibitive size, cost, and requisite sample processing have kept this technology from being more widely adapted in the clinic. We have developed a miniaturized magnetic cytometer (μMCM), a hybrid semiconductor / microfluidic chip, to rapidly measure the magnetic moments of individual immunomagnetically tagged cells. The use of magnetic detection enables measurements to be done on native specimens, thus decreasing the loss of rare cells and removing the need for expensive sample processing equipment. Benefiting from the high speed and sensitivity of semiconductor technology, the μMCM offers high-throughput operation (upwards of 10^7 cells/sec) with a detection resolution of $\sim$2000 magnetic nanoparticles/cell. The clinical utility of the μMCM was demonstrated by detecting scant tumor cells (20 cells) in whole blood and by molecularly profiling cells from solid tumor to monitor longitudinal drug efficacy.

1:51PM B42.00012 Miniature magnetic resonance system for robust and portable diagnostics[1]

, CHANGWOOK MIN, DAVID ISSADORE, JAEHOON CHUNG, HUILIN SHAO, MONTY LIONG, Massachusetts General Hospital, RALPH WEISSLEDER, Massachusetts General Hospital/Harvard Medical School, HAKHO LEE, Massachusetts General Hospital — We have recently developed a new diagnostic platform, microNMR(μNMR), specifically designed for clinical applications This new μNMR system performs rapid, accurate, and robust measurements of cells, proteins and small molecules in point-of-care settings. The system utilizes magnetic nanoparticles (MNPs) to amplify the analytical signals in NMR detection. When molecularly-specific MNPs identify their targets, the particles induce large, amplified changes in the transverse relaxation of water protons by producing local magnetic fields. A major challenge in achieving reliable NMR detection is the fluctuation of NMR frequency ($f0$) with temperature, which originates from the the temperature-dependent drift of the magnetic field. To overcome the challenge, we have implemented a new, automated feedback controller that keeps track of $f0$ and reconfigures measurement settings. The mechanism enables robust μNMR measurements in realistic clinical environments (4-50 °C). Moreover, the μNMR interfaces with mobile devices for its operation, maximizing the portability of μNMR. The clinical utility of the new μNMR system is demonstrated by detecting and molecularly profiling cancer cells from patient samples.

[1]This work is supported in part by National Institutes of Health Grants 2R01-EB004626, HHSN268201000044C, U54-CA119349, and T32-CA79443.

2:03PM B42.00013 Paper Inside? - New Thinking for Biochip and Other Applications

, ANDREW STECKL, University of Cincinnati — The drive to improve the performance and reduce the cost of electronic, photonic and fluidic devices is starting to focus on the use of materials that are exotic for these applications but actually readily available in other fields. In this talk the use of paper in biochip and other applications will be reviewed. Paper is a very attractive material for many device applications: very low cost, available in almost any size, versatile surface finishes, portable and flexible. From an environmental point of view, paper is a renewable resource and is readily disposable (incineration, biodegradable). Applications of paper-based electronics currently being considered or investigated include biochips, sensors, communication circuits, batteries, smart packaging, displays. The potential advantages of paper-based devices are in many cases very compelling. For example, biochips fabricated on paper can use the capillary properties of paper to operate without the need of external power sources, greatly simplifying the design and reducing the cost. For e-reader devices, in addition to flexibility, the ideal solution for providing the look-and-feel of ink on paper is to have *e-paper on paper*.

Monday, February 27, 2012 2:30PM - 5:30PM –

Session D51 DCMP DFD: Liquid Crystals: Chromonics and Nematics Boston Convention Center 154

2:30PM D51.00001 Lyotropic chromonic liquid crystals in the biphasic region

, XUXIA YAO, Georgia Institute of Technology, ALEJANDRO REY, McGill University, JUNG PARK, MOHAN SRINIVASARAO, Georgia Institute of Technology — Lyotropic chromonic liquid crystals have a wide coexistence temperature range where the isotropic and nematic phases are in equilibrium. Negative tactoids (isotropic droplets in the nematic medium) or positive tactoids (nematic droplets in the isotropic medium) form and grow as the nuclei of the new phases in the biphasic region. We studied the growth of tactoids as a function of temperature, the prolate shape of tactoids as well as their thermal fluctuation, based on which the viscoelastic properties of chromonic liquid crystals were obtained.

2:42PM D51.00002 Order Parameter measurements of Chromonic Liquid Crystal Benzopurpurin 4B using polarized Raman scattering[1]

, KARTHIK NAYANI, JUNG OK PARK, MOHAN SRINIVASARAO, Georgia Institute of Technology — Benzopurpurin 4B (BPP4B), a commonly used textile dye, is known to form chromonic liquid crystal phases in aqueous solutions at fairly low concentrations (<0.5 wt%) in comparison with other chromonic liquid crystals. Also the aggregation properties and the structure of the aggregates in aqueous solutions of BPP4B are not well understood. Recently McKitterick et al. reported a study on the aggregation and phase behavior of BPP4B in water.[2] Further understanding of the behavior of BPP4B in aqueous solutions can be gained by studying how the order parameter of its liquid crystalline phase varies with some relevant parameters. Planar monodomains of BPP4B were obtained using a flat rectangular capillary. Thermal evolution of the order parameter of these aligned monodomains was carried out using polarized Raman scattering measurements. Further, the concentration dependence and the effect of salt on the order parameter were studied. The variation of the order parameter with the above parameters was correlated to the structure of the aggregates using the UV-Vis absorption data.

[1]This study was partially supported by NSF (DMR-0706235) and PSE fellowship (Georgia Institute of Technology).

[2]C. B. McKitterick, N. L. Erb-Satullo, N. D. LaRacuente, A. J. Dickson, P. J. Collings. *J. Phys. Chem. B.* **2010**. 114, 1888.

2:54PM D51.00003 Textural transformations in lyotropic chromonic liquid crystals under confinement[1]

, ALIREZA SHAMS, Department of Chemical Engineering, McGill University, Montreal, Quebec H3A 2B2, Canada, XUXIA YAO, School of Materials Science and Engineering, Georgia Institute of Technology, Atlanta, GA 30332, USA, ALEJANDRO D. REY[2], Department of Chemical Engineering, McGill University, Montreal, Quebec H3A 2B2, Canada, JUNG OK PARK[3], School of Materials Science and Engineering, Georgia Institute of Technology, Atlanta, GA 30332, USA, MOHAN SRINIVASARAO[4], School of Chemistry and Biochemistry, Georgia Institute of Technology, Atlanta, GA 30332, USA — Lyotropic chromonic liquid crystals under capillary confinement display textural transformations between planar radial and planar polar modes, in which a $+1$ disclination branches into two $+1/2$ lines. The texture transformation is characterized by the nature and kinematics of the branch point, the aperture angle, and the shape of the lines. This work presents and validates a model of these four phenomena, which yield the viscoelastic moduli of these novel mesophases.

[1]This work is partially supported by a grant from the U.S. Office of Basic Energy Sciences, Department of Energy; grant DE-SC0001412 and McGill Engineering Doctorate Award.

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[4]School of Materials Science and Engineering and Center for Advanced Research on Optical Microscopy, Georgia Institute of Technology, Atlanta, GA 30332, USA

3:06PM D51.00004 Molecular Aggregation in Disodium Cromoglycate[1] , GAUTAM SINGH, D. AGRA-KOOIJMAN, Kent State University, P.J. COLLINGS, Swarthmore College, SATYENDRA KUMAR, Kent State University — Details of molecular aggregation in the mesophases of the anti-asthmatic drug disodium cromoglycate (DSCG) have been studied using x-ray synchrotron scattering. The results show two reflections, one at wide angles corresponding to $\pi - \pi$ stacking (3.32 Å) of molecules, and the other at small angles which is perpendicular to the direction of molecular stacking and corresponds to the distance between the molecular aggregates. The latter varies from 35 - 41 Å in the nematic (N) phase and 27 – 32 Å in the columnar (M) phase. The temperature evolution of the stack height, positional order correlations in the lateral direction, and orientation order parameter were determined in the N, M, and biphasic regions. The structure of the N and M phases and the nature of the molecular aggregation, together with their dependence on temperature and concentration, will be presented.

[1]Work supported by NSF grant DMR-0806991.

3:18PM D51.00005 Flexopolydispersity of Nematic Liquid Crystals[1] , YUE SHI, DONG CHEN, Department of Physics and Liquid Crystal Material Research Center, University of Colorado-Boulder, RIZWAN MAHMOOD, Department of Physics, Slippery Rock University, NOEL CLARK, Department of Physics and Liquid Crystal Material Research Center, University of Colorado-Boulder — Flexopolydispersity is the coupling of gradients in the director field $\mathbf{n}(\mathbf{r})$ of a nematic phase made from a polydisperse mixture of anisotropic particles in solution to the spatial change in variables describing the local mean particle shape, size, and concentration: In solutions of sufficiently polydisperse plates this coupling can lead to a nematic phase with a "blue-phase" like array of $+1$ defect lines. Such a structure has been observed in the lyotropic nematic phase of solutions of graphene oxide sheets.

[1]Supported by NSF MRSEC Grant DMR-0820579.

3:30PM D51.00006 Nematic order in toroidal and higher-genus droplets[1] , EKAPOP PAIRAM, JAYA LAKSHMI, ALBERTO FERNANDEZ-NIEVES, Georgia Institute of Technology, GEORGIA TECH TEAM — We generate toroidal and higher-genus droplets filled with nematic liquid crystal which are stabilized inside viscoelastic fluid with a non-zero yield stress. The work presented here is the preliminary observations of our experiments.

[1]Georgia Institute of Technology, NSF Career

3:42PM D51.00007 Seeing and Sculpting Nematic Liquid Crystal Textures with the Thom construction , BRYAN CHEN, University of Pennsylvania, GARETH ALEXANDER, University of Warwick — Nematic liquid crystals are the foundation for modern display technology and also exhibit topological defects that can readily be seen under a microscope. Recently, experimentalists have been able to create and control several new families of interesting defect textures, including reconfigurably knotted defect lines around colloids (Ljubljana) and the "toron," a pair of hedgehogs bound together with a ring of double-twist between them (CU Boulder). We apply the Thom construction from algebraic topology to visualize 3 dimensional molecular orientation fields as certain colored surfaces in the sample. These surfaces turn out to be a generalization to 3 dimensions of the dark brushes seen in Schlieren textures of two-dimensional samples of nematics. Manipulations of these surfaces correspond to deformations of the nematic orientation fields, giving a hands-on way to classify liquid crystal textures which is also easily computable from data and robust to noise.

3:54PM D51.00008 Patterned Liquid Crystal Droplets , JAKUB KOLACZ, ANDREW KONYA, Kent State University Liquid Crystal Institute, JULIO AVILA, California State University, FENG WANG, QI-HUO WEI, Kent State University Liquid Crystal Institute — Geometrical confinement has a significant influence on the structure and properties of liquid crystals. Prior research in this area is mainly on polymer-dispersed liquid crystals and liquid crystals in porous media where the liquid crystal droplets are usually non-uniform in size. Here we use microfabrication techniques to pattern liquid crystals into droplets of different geometrical shapes and sizes, and study the liquid crystal ordering in these liquid crystal droplets. The experimental observations will be compared with simulation results.

4:06PM D51.00009 The mechanism of controlling liquid crystal surface pretilt angle on plasma beam sputtered films[1] , RU-PIN PAN, National Chiao Tung University, MENG-CHIOU HUANG, Institute of Atomic and Molecular Sciences, Academia Sinica, WEI-TA WU, CHENG-WEI LAI, HSIN-YING WU, National Chiao Tung University — In liquid crystal (LC) devices, the surface alignment is essential. The polyimide (PI) film is commonly used to make LC molecules parallel to the surface. A rubbing process is usually applied to choose a particular direction on the surface. A pretilt angle is also induced, which is useful but usually very small. In previous works, we have found out that the sputtered ion-oxide films can give a homeotropic alignment to LC, i,e, the LC molecules are perpendicular to the surface. In this work, we combine these two effects by sputtering the ion-oxide particles onto the PI coated glasses. By adjusting the sputtering conditions, the LC alignment are controlled. A wide range of pretilt angles have been achieved, while the rubbing process is no longer required. A thorough study by varying the sputtering conditions, such as voltage, current, and time duration, and observing the pretilt angles is carried out. The sputtered surfaces are examined with scanning electron microscope to see the coverage. By considering the charge distribution and electric field within the sputter, a quantitative model is then developed, which explains how the sputtering conditions affect the pretilt angles almost perfectly.

[1]Supported by National Science Council, ROC, under grand number 96-2221-E-009-131-MY3 and Academia Sinica AS-98-TP-A10.

4:18PM D51.00010 Transient Splitting of Conoscopic Isogyres of a Uniaxial Nematic[1] , YOUNG-KI KIM, BOHDAN SENUK, LUANA TORTORA, Liquid Crystal Institute and Chemical Physics Interdisciplinary Program, Kent State University, Kent, OH, USA, SAMUEL SPRUNT, Physics Department, Kent State University, Kent, OH, USA, MATTHIAS LEHMANN, Institute of Chemistry, Chemnitz University of Technology, Chemnitz, Germany, OLEG D. LAVRENTOVICH, Liquid Crystal Institute and Chemical Physics Interdisciplinary Program, Kent State University, Kent, OH, USA — The phase identification is often based on conoscopic observations of homeotropic cells: A uniaxial nematic produces a pattern with crossed isogyres, while the biaxial nematic shows a split of isogyres. We demonstrate that the splitting of isogyres occurs even when the material remains in the uniaxial nematic phase. In particular, in the bent core material J35, splitting of isogyres is caused by change of the temperature. The effect is transient and the isogyres return to a uniaxial (crossed) configuration after a certain time that depends on sample thickness, temperature, and rate of temperature change; the time varies from a few seconds to tens of hours. The transient splitting is caused by the temperature-induced material flow that triggers a (uniaxial) director tilt in the cell. The flows and the director tilt are demonstrated by the CARS microscopy and fluorescent confocal polarizing microscopy (FCPM). This transient effect is general and can be observed even in E7 and 5CB. The effect should be considered in textural identifications of potential biaxial nematic materials.

[1]The work was supported by DOE grant DE-FG02-06ER46331 and by SEC.

4:30PM D51.00011 A comparison between "cybotactic" groups in bent-core and rod-like nematic liquid crystals , SAONTI CHAKRABORTY, NICHOLAS DIORIO, WILL CARR, JAMES GLEESON, ANTAL JAKLI, SAMUEL SPRUNT, Kent State University — It is becoming increasingly clear that short-range smectic-CP order is the basis for some of the unusual macroscopic properties of bent-core nematic (BCN) liquid crystals. By analyzing small angle X-ray diffraction patterns taken on a bent-core and a chemically related calamitic (rod-like) nematic, we have attempted to clarify the nature of the "cybotactic groups" (or molecular clusters) contributing to this short-range order in BCNs, and to distinguish their signature from the scattering due to smectic fluctuations normally observed above a nematic to smectic transition. We find that persistent, finite-sized, tilted smectic clusters, with short, temperature-independent correlation lengths, account for the scattering observed from the BCN, while the calamitic material provides a remarkably clear example of temperature-dependent fluctuations in smectic order observed even far above a smectic-C phase. Supported by NSF DMR-0964765

4:42PM D51.00012 Optimizing liquid crystalline properties for bio-sensing at aqueous interfaces[1] , WILDER IGLESIAS, Kent State University, NICHOLAS L. ABBOTT, University of Wisconsin, ELIZABETH K. MANN, ANTAL JÁKLI, Kent State University — Recent studies show that surfactant or phospholipid assemblies can be monitored at interfaces between aqueous solutions and thermotropic liquid crystals. The capability of these liquid crystals to change birefringence with the reordering induced by the decorated surface allows to study and characterize dynamical phenomena happening at the interfaces. In this work we tune the surface anchoring and the viscoelastic properties of the liquid crystal mesogens in order to increase sensitivity and optimize the response to events at the surface.

[1]This Work was supported by NSF DMR-0907055.

4:54PM D51.00013 Competing Ordering Processes at Liquid Crystal Surfaces Laden with Semifluorinated Alkane Molecules , XUNDA FENG, Max Planck Institute for Dynamics and Self-Organization, Am Faßberg 17, D-37077 Göttingen, Germany, AHMED MOURRAN, MARTIN MOELLER, DWI an der RWTH Aachen e.V. and Institute for Technical and Macromolecular Chemistry, RWTH Aachen, Forckenbeckstr. 50, D-52056 Aachen, Germany, CHRISTIAN BAHR, Max Planck Institute for Dynamics and Self-Organization, Am Faßberg 17, D-37077 Göttingen, Germany — Ellipsometric measurements elucidate the interplay between the surface order at the isotropic liquid crystal/air interface and a structural phase transition in a Gibbs film on the same interface. Gibbs films formed by the semifluorinated alkane C18H37–C12F25 exhibit a sharp transition from a dilute state at higher temperatures to a dense state at lower temperatures. The transition temperature can be tuned by controlling the C18H37–C12F25 concentration in the bulk liquid crystal phase. When the transition takes place in the temperature range in which a molecular thin smectic or nematic film exists at the isotropic liquid crystal/air interface, the smectic surface order is destroyed while the nematic surface order is affected by a change of the orientation of the liquid crystal molecules. The ellipsometric data indicate that both behaviors result from a change of the anchoring condition of the liquid crystal molecules in contact with the Gibbs film.

5:06PM D51.00014 Revealing the inner arrangement of cholesteric liquid crystals confined in polymeric electrospun fibers[1] , GIUSY SCALIA, Seoul National University, EVA ENZ, MLU Halle-Wittenberg, VERA LA FERRARA, ORONZO CALÓ, ENEA C.R. Portici, JAN LAGERWALL, Seoul National University — Cholesteric liquid crystals, like other types of LCs, can be confined inside polymeric fibers by coaxial electrospinning. In this way the interesting optical properties of cholesterics could be transferred to very long fibers that can form flexible or rigid mats according to the outer sheath material. Selective reflection was easily detected from polymeric fibers with cholesteric LC core. Despite the uniformity of the external morphology of the fibers, evaluated by SEM, defects in the optical texture could be observed in some locations as well as differences in the wavelength of the reflected light. The reason for such differences needs to be clarified in order to achieve a uniform, controlled optical texture. The understanding was achieved by direct observation of the cross section of the LC-filled fibers by cutting and sectioning the fibers by Focused Ion Beam (FIB). This revealed differences in dimensions of the inner cavity correlating them to the observed wavelengths of the selectively reflected light, but also changes in shape, in some parts with strongly varying width that accounts for the defect lines observed. We could also visualize the effect of flow instability of the jet during spinning, inducing the formation of chains of LC droplets.

[1]Research supported by grants from the AICT (SNU, Korea) and NRF (Korea)

5:18PM D51.00015 Macroscopic torsional strain and induced molecular conformational deracemization , RAJRATAN BASU, JOEL PENDERY, ROLFE PETSCHEK, Case Western Reserve University, ROBERT LEMIEUX, Queen's University, CHARLES ROSENBLATT, Case Western Reserve University — A macroscopic helical twist is imposed on an achiral nematic liquid crystal by controlling the azimuthal alignment directions at the two substrates. On application of an electric field the director rotates in the substrate plane. This electroclinic effect, which requires the presence of chirality, is strongest at the two substrates and increases with increasing imposed twist distortion. We present a simple model involving a tradeoff among bulk elastic energy, surface anchoring energy, and deracemization entropy that suggests the large equilibrium director rotation at the surfaces induces a deracemization of chiral conformations in the molecules, quantitatively consistent with experiment.

Monday, February 27, 2012 2:30PM - 5:30PM – Session D53 GSNP DFD: Focus Session: Jamming – Nonlinear Acoustics and Vibrational Response 153B

2:30PM D53.00001 Vibrational Modes in Colloidal Crystals , KE CHEN, TIM STILL, Department of Physics and Astronomy, University of Pennsylvania, KEVIN APTOWICZ, Deparment of Physics, West Chester University, ARJUN YODH, Department of Physics and Astronomy, University of Pennsylvania — We investigate vibrational modes in quasi-two-dimensional colloidal crystals using video microscopy and displacement covariance matrix analysis. Debye scaling in the phonon density of states and the dispersion curve for two-dimensional hexagonal crystals are recovered for both mono-layer and double layer colloidal crystals. Using "soft spots" analysis, low-frequency quasi-localized phonon modes, which were found to coincide with fragile regions in glasses [1] appear to be spatially correlated with structural defects in colloidal crystals. Thus, "soft spots" may be a useful general identifier for defects in both crystalline and amorphous solids. This work is supported by NSF DMR 0804881, MRSEC DMR11-20901, and by NASA NNX08AO0G.

[1] K. Chen et al, Phys. Rev. Lett. 107, 108301 (2011)

2:42PM D53.00002 Acoustic measurement of a granular density of state , ELI OWENS, KAREN DANIELS, North Carolina State University — Measurements of the vibrational density of states $D(\omega)$ in glasses reveal that an excess number of low-frequency modes is associated with a loss of mechanical rigidity. An excess number of such modes has also been observed in both simulations of idealized granular materials near the jamming point, and in experiments on colloids. We experimentally investigate similar features in a jammed, quasi-two-dimensional granular material. We mimic thermal fluctuations using an electromagnetic driver to inject acoustic white noise, while piezoelectric sensors embedded inside a subset of the particles provide measurements of single-particle velocities. By analogy with conventional thermal techniques, we calculate a $D(\omega)$-like quantity via the spectrum of the velocity autocorrelation function. We measure $D(\omega)$ as a function of the confining pressure and find that the peak in the density of states shifts to higher frequency with system pressure. At low pressure, disordered systems have more low frequency modes than do hexagonally-packed systems.

2:54PM D53.00003 Elastic weakening of a dense granular medium by acoustic fluidization , XIAOPING JIA, JEROME LAURENT, Université Paris-Est, SIET WILDENBERG, MARTIN VAN HECKE, Universiteit Leiden, LPMDI TEAM, ONNES LAB TEAM — Elastic waves propagating through a dense granular pack provide a unique probe of the elastic properties and internal dissipation of the medium [1], and also allow investigating the irreversible rearrangement of the contact network at large vibration amplitude. In this talk, we describe two distinct types of nonlinearity, i.e. hertzian and frictional, at the grain contact by sound amplitude and velocity measurements, respectively, under different confining pressure [2]. Beyond certain wave amplitude, the sound-matter interaction becomes irreversible, leaving the medium in a weakened and slightly compacted state. A slow recovery of the initial elastic modulus is observed after acoustic perturbation, revealing the plastic creep growth of microcontacts. The cross-correlation function of configuration-specific acoustic speckles highlights the relationship between the macroscopic elastic weakening and the local change of the contact networks, induced by strong sound vibration, in the absence of appreciable grain motion. We show that the softening of elastic modulus is much more pronounced with the shear wave (up to 20%) than with the compressional wave (to 10%).

[1] Th. Brunet, X. Jia and P. Mills, Phys. Rev. Lett **101**, 138001 (2008)
[2] Th. Brunet, X. Jia and P. Johnson, Geophys. Res. Lett **35**, L19308 (2008); X. Jia, Th. Brunet and J. Laurent, Phys. Rev. E **00**, 000300(R) (2011)

3:06PM D53.00004 Nonharmonicity in vibrated granular solids , CARL SCHRECK, Yale University — We have shown that granular packings composed of frictionless particles with repulsive contact interactions are strongly nonharmonic. When infinitesimally perturbed along linear response eigenmodes of the static packing, energy leaks from the original mode of vibration to a continuum of frequencies due solely to contact breaking even when the system is under significant compression. Further, vibrated packings possess well-defined equilibrium positions that are different than those of the unperturbed packing. The vibrational density of states obtained using the displacement matrix and velocity autocorrelation function methods exhibit an increase in the number of low-frequency modes over that obtained from linear response of the static packing. The form of the density of states in vibrated granular packings is reminiscent of the low-frequency behavior of the vibrational density of states in fluid systems. We also investigate the effects of inter-particle friction, dissipation, particle shape, and degree of positional order on the density of states and thermal transport properties in driven granular packings.

3:42PM D53.00005 Irreversible Incremental Behavior in a Granular Material[1] , LUIGI LA RAGIONE, Cornell University, VANESSA MAGNANIMO, MSM, CTW, University of Twente, 7500EA Enschede (NL), JAMES JENKINS, Cornell University, HERNAN MAKSE, City College New York — We test the elasticity of dense, isotropic, compressed aggregates of frictional spheres using cyclic increments of shear and volume strain in a numerical simulation. For both types of increments, we measure irreversibility in relative displacements and contact forces that is stronger for the increments in shear. The strength of the irreversibility increases as the average number of contacts per particle (the coordination number) decreases. This irreversibility may be associated with the opening of contacts in an increment of loading, pointed out in a recent paper of Schreck et al. (PRL, 2011); such contact opening could lead to irreversible rearrangement of the contact network when the increment is relaxed.

[1] Office of Naval Research, Global

3:54PM D53.00006 Experimental Measurements of Force Propagation in Vibrated Photoelastic Disks[1] , ALINE HUBARD, MARK SHATTUCK, CUNY Graduate Center and the Benjamin Levich Institute and Physics Department of The City College of New York — We measure and analyze the propagation forces in vibrated disks under constant pressure with different amplitudes and frequencies. We use photoelastic particles to visualize the stress within each particle using a high-speed video camera. From the images we can extract the time dependent force at each contact to determine how force propagates through the contact network. Using mono-disperse particles we focus on force propagation during the phase transition from an ordered solid-like state to a disordered fluid-like state as we change the vibration amplitude. With bi-disperse particles we compare with the transition to a disordered solid-like state.

[1] Supported by NSF PREM (DMR-0934206).

4:06PM D53.00007 Nonlinear acoustics of glass bead packings at vanishing static pressures[1] , VINCENT TOURNAT, LAUM, CNRS, Universite du Maine, Le Mans, France, VITALYI GUSEV, LPEC, CNRS, Universite du Maine, Le Mans, France — We present here a set of recent results obtained in three experimental configurations: linear and nonlinear acoustic probing of a granular slab at different compacities, surface acoustic waves in granular layers submitted to gravity, resonances of a granular layer with an in-depth elasticity gradient. We succeeded to overcome the experimental issues associated to the dramatic increase of acoustic wave attenuation when the confining pressure diminishes. Interpretations reveal that the manifestations of nonlinear effects (self-demodulation, nonlinear resonance, second harmonic or subharmonic generation...) allow to isolate the different types of nonlinearities involved (Hertz, clapping, stick-slip, hysteresis...). Also, some discrepancies are observed for the extracted linear elastic parameters scaling laws as a function of vanishing pressure (lower than 100 Pa typically) between the different developed experimental configurations and the theoretical predictions. Explanations for these discrepancies are given. We show than under some conditions, it is necessary to take into account the coupling of grain motion with that of the saturating air. Application of these results to the probing of granular layers under destabilization will be presented.

[1] This work is supported by ANR contract "Stabingram" ANR-2010-BLAN-0927-03.

4:18PM D53.00008 Acoustic Echoes in Model Glasses , JUSTIN BURTON, SIDNEY NAGEL, The University of Chicago — At low temperatures, glasses and crystals behave in qualitatively different ways. In particular, glasses have a great many more low-energy excitations that have traditionally been explained in terms of a distribution of dilute, two-level quantum states that are created by clusters of particles tunneling between two nearly degenerate ground states. Strong evidence for this model has come from the saturation effects and acoustic echoes [1] observed in these excitations. We show that, in contrast to conventional wisdom, the quasi-localized, strongly anharmonic, normal modes of jammed systems [2] can produce acoustic echoes due to the shift in the mode frequency with increasing amplitude. We observe this both in jammed packings of spherical particles with finite-range, Hertzian repulsions, and in model glasses interacting with a Lennard-Jones potential. In contrast to pulse echoes in two-level systems, a distinguishing feature of these "anharmonic echoes" is the appearance of multiple echoes after two excitation pulses, a feature also observed in experiments [1].

[1] B. Golding and J. E. Graebner. Phys. Rev. Lett. **37**, 852 (1976).
[2] N. Xu, V. Vitelli, A. J. Liu, and S. R. Nagel. Europhys. Lett. **90**, 56001 (2010).

4:30PM D53.00009 Extreme Physics and Rearrangements near Jamming , MARTIN VAN HECKE, Leiden University, ZORANA ZERAVCIC, Harvard University, ALEX SIEMENS, JOHANNES SIMON, DANIEL GEELEN, Leiden University — Near jamming, linear response becomes irrelevant. I briefly discuss how this gives rise to a range of intrinsically nonlinear, even extreme, phenomena. Moreover, reversibility also breaks down, and I will discuss the nature of rearrangements near jamming.

4:42PM D53.00010 Formation, Propagation, and Attenuation of Shocks Waves in Jammed Matter , LEOPOLDO GOMEZ, Leiden University - Universidad Nacional del Sur - CONICET, VINCENZO VITELLI, Leiden University — We study the formation and propagation of fully non-linear waves in jammed granular media. Close to the jamming point, an arbitrary initial distortion of the media will induce the formation of non-linear finite amplitude waves. There are two regimes in the evolution of these waves. At early times non-linear interactions dominate the propagation, leading to a temporal evolution strongly dependent on the initial distortion. At long times the propagation is characterized by a new universal regime, dominated by hydrodynamical attenuation. Here the non-linear waves evolve in a self-similar fashion, characterized by a power law attenuation whose exponent is weakly dependent on the initial pressure of the system.

4:54PM D53.00011 Jamming of soft spheres at finite temperature : a granular experiment , CORENTIN COULAIS, CEA Saclay, OLIVIER DAUCHOT, ESPCI, ROBERT BEHRINGER, Duke University, GIT - SPEC - CEA SACLAY TEAM, ESPCI TEAM[1], GIT-SPEC-CEA SACLAY / BEHRINGER'S GROUP AT DUKE COLLABORATION — At large packing fraction, disordered packings of particles with repulsive contact interactions jam into a rigid state where they withstand finite shear stresses before yielding. For frictionless particles and at zero temperature, the jamming transition coincides with the onset of iso-staticity and many geometrical and mechanical properties scale with the distance to the jamming point. What are the vestige of jamming at finite temperature and how jamming impacts the thermodynamics of glasses remain open issues. We address these questions experimentally by investigating the dynamics of both the density field and the force network of an horizontally shaken bi-disperse packing of photo-elastic disks. The average number of contact clearly displays an abrupt transition which we interpret as the jamming transition. Besides, dynamical heterogeneities are observed and their amplitude exhibits a maximum, which, in turn, signs a dynamical transition. We discuss in detail the interplay between these two transitions and how they depend on the particle softness and amplitude of the horizontal vibration.

[1]The Team is in Saclay and Olivier Dauchot has recently move to ESPCI

5:06PM D53.00012 Density of vibrational modes in partially crystalline granular packings[1] , THIBAULT BERTRAND, Yale University, Dpt of Mechanical Engineering, CARL F. SCHRECK, Yale University, Dpt of Physics, MARK SHATTUCK, Benjamin Levich Institute and Physics Department, The City College of the City University of New York, COREY S. O'HERN, Yale University, Dpt of Mechanical Engineering, O'HERN GROUP, YALE UNIVERSITY TEAM — Numerous numerical results have shown that systems of monodisperse frictionless disks crystallize readily and that disordered mechanically stable packings are rarely obtained. We numerically investigate the dependence of the cluster size distribution on system size and quench rate. We also investigate the effect of crystallization on the vibrational response outside the linear response regime. We study changes in the density of vibrational modes due to changes in the average crystallite size and perturbation amplitude in partially crystalline granular packings. In particular we determine how the number of contacts (above the isostatic value) affects anharmonic response in granular packings.

[1]Acknowledgement: NSF CBET-0967262, CBET-0968013

5:18PM D53.00013 Studying the low-frequency quasilocalized modes in disordered colloidal systems , LEI XU, PENG TAN, Physic Dept., The Chinese University of Hong Kong, NING XU, Physic Dept., The University of Science and Technology of China, ANDREW SCHOFIELD, Physic Dept., University of Edinburgh — In disordered colloidal systems, we experimentally measure the normal modes with covariance matrix method, and clarify the origin of low-frequency quasilocalization at single-particle level. We observe important features from both jamming and glass simulations: there is a plateau in the density of states which is suppressed upon ompression, as predicted by jamming; within the same systems, we also find that the low-frequency quasilocalization originates from the coupling between large vibrations of defective structures and transverse excitations, consistent with recent glass simulation. The coexistence of these features demonstrates an experimental link between jamming and glass. Extensive simulations further show that such structural origin of quasilocalization is universally valid for various temperatures and volume fractions.

Tuesday, February 28, 2012 8:00AM - 11:00AM –

Session H20 GSNP DFD: Invited Session: Hydrodynamics and Microstructure: From Single Self-Propelled Particles to Active Soft Matter 253C

8:00AM H20.00001 Swimming & Propulsion in Viscoelastic Media[1] , PAULO ARRATIA, University of Pennsylvania — Many microorganisms have evolved within complex fluids, which include soil, intestinal fluid, and mucus. The material properties or rheology of such fluids can strongly affect an organism's swimming behavior. A major challenge is to understand the mechanism of propulsion in media that exhibit both solid- and fluid-like behavior, such as viscoelastic fluids. In this talk, we present experiments that explore the swimming behavior of biological organisms and artificial particles in viscoelastic media. The organism is the nematode *Caenorhabditis elegans*, a roundworm widely used for biological research that swims by generating traveling waves along its body. Overall, we find that fluid elasticity hinders self-propulsion compared to Newtonian fluids due to the enhanced resistance to flow near hyperbolic points for viscoelastic fluids. As fluid elasticity increases, the nematode's propulsion speed decreases. These results are consistent with recent theoretical models for undulating sheets and cylinders. In order to gain further understanding on propulsion in viscoelastic media, we perform experiments with simple reciprocal artificial 'swimmers' (magnetic dumbbell particles) in polymeric and micellar solutions. We find that self-propulsion is possible in viscoelastic media even if the motion is reciprocal.

[1]This work is supported by NSF-CAREER-0954084.

8:36AM H20.00002 Assembly and dynamics of synthetic cilia[1] , TIM SANCHEZ, Brandeis University, Physics Department — From motility of simple protists to determining the handedness of complex vertebrates, highly conserved eukaryotic cilia and flagella are essential for the reproduction and survival of many biological organisms. Despite extensive studies, the exact mechanism by which individual components coordinate to produce ciliary beating patterns remains unknown. We describe a novel approach towards studying ciliary beating. Instead of deconstructing a fully functional organelle from the top-down, we describe a process by which synthetic cilia-like structures are assembled from the bottom-up. We find that simple mixtures of microtubules, kinesin clusters, and a bundling agent produce spontaneous oscillations in MT bundles, suggesting that self-organized beating may be a generic feature of internally driven bundles. Furthermore, bundles in close proximity spontaneously coordinate their beating to generate metachronal traveling waves, reminiscent of the waves seen in ciliary fields. These findings and future refinements of the system can potentially provide insights into general design principles required for engineering synthetic cilia as well as understanding the biological analogues.

[1]Support from Keck and MRSEC (NSF)

9:12AM H20.00003 Polar patterns in active fluids[1] , M. CRISTINA MARCHETTI, Physics Department & Syracuse Biomaterials Institute, Syracuse University — Active fluids are a new class of soft materials composed of interacting units that consume energy and collectively generate motion and mechanical stress. Examples include bacterial suspensions, mixtures of cytoskeletal filaments and motor proteins, and migrating epithelial cell layers. Due to their elongated shape, active particles can exhibit orientational order at high concentration and have been likened to "living liquid crystals", with either nematic or polar symmetry. In this talk I will discuss the spatio-temporal dynamics of continuum models of active fluids in two dimensions, focusing on the case of a system with polar symmetry as relevant to bacterial suspensions. Upon increasing activity, the active fluid displays increasingly complex patterns, including traveling bands, traveling vortices and chaotic behavior. The nonlinear hydrodynamic equations can be mapped onto a diffusion-reaction-convection model, highlighting the connection between the complex dynamics of active system and that of excitable systems.

[1]This work was carried out with Luca Giomi and supported by the NSF through grants DMR-0806511 and DMR-1004789.

9:48AM H20.00004 Swimming of Paramecium in confined channels , SUNGHWAN JUNG, Virginia Tech — Many living organisms in nature have developed a few different swimming modes, presumably derived from hydrodynamic advantage. Paramecium is a ciliated protozoan covered by thousands of cilia with a few nanometers in diameter and tens of micro-meters in length and is able to exhibit both ballistic and meandering motions. First, we characterize ballistic swimming behaviors of ciliated microorganisms in glass capillaries of different diameters and explain the trajectories they trace out.We develop a theoretical model of an undulating sheet with a pressure gradient and discuss how it affects the swimming speed. Secondly, investigation into meandering swimmings within rectangular PDMS channels of dimension smaller than Paramecium length. We find that Paramecium executes a body-bend (an elastic buckling) using the cilia while it meanders. By considering an elastic beam model, we estimate and show the universal profile of forces it exerts on the walls. Finally, we discuss a few other locomotion of Paramecium in other extreme environments like gel.

10:24AM H20.00005 Helical swimming in viscoelastic and porous media , BIN LIU, School of Engineering, Brown University — Many bacteria swim by rotating helical flagella. These cells often live in polymer suspensions, which are viscoelastic. Recently there have been several theoretical and experimental studies showing that viscoelasticity can either enhance or suppress propulsion, depending on the details of the microswimmer. To help clarify this situation, we study experimentally the motility of the flagellum using a scaled-up model system - a motorized helical coil that rotates along its axial direction. A free-swimming speed is obtained when the net force on the helix is zero. When the helix is immersed in a viscoelastic (Boger) fluid, we find an increase in the force-free swimming speed as compared with the Newtonian case. The enhancement is maximized at a Deborah number of approximately one, and the magnitude depends not only on the elasticity of the fluid but also on the geometry of the helix. In the second part of my talk, I will discuss how spatial confinements, such as a porous medium, affect the flagellated swimming. For clarity, the porous media are modeled as cylindrical cavities with solid walls. A modified boundary element method allows us to investigate a situation that the helical flagella are very close to the wall, with high spatial resolution and relatively low computational cost. To our surprise, at fixed power consumption, a highly coiled flagellum swims faster in narrower confinements, while an elongated flagellum swims faster in a cavity with a wider opening. We try understanding these effects with simple physical pictures.

Tuesday, February 28, 2012 8:00AM - 11:00AM –
Session H51 DCMP DFD: Colloids II: Crystals and Phase Transitions Boston Convention Center 154

8:00AM H51.00001 Effects of vacancies and interstitials on the phonon modes in a 2D colloidal crystal[1] , LICHAO YU, SUNGCHEOL KIM, Brown University, DI YIN, Wuhan University and Brown University, ALEXANDROS PERTSINIDIS, Sloan-Kettering Institute, New York, XINSHENG LING, Brown University — We report a study of the effects of vacancies and interstitials on the phonon modes in a 2D colloidal crystal. By applying the equi-partition theorem, we extract the dispersion relation of the lattice vibrations in a two-dimensional colloidal crystal using real-time video microscopy. We find that both longitudinal and transverse modes in the spectrum are softened by the existence of vacancies and interstitials.

[1]This work was supported by a grant from NSF-DMR.

8:12AM H51.00002 Normal modes of various colloidal crystals[1] , FENG WANG, YI PENG, ZIREN WANG, YILONG HAN, Department of Physics, Hong Kong University of Science and Technology, Clear Water Bay, Hong Kong, China, SOFT MATTER AND VIDEO MICROSCOPY LAB TEAM — We measured the vibrational normal modes from particle displacements in various microgel colloidal crystals including monolayers, multi-layer thin films, three-dimensional normal and superheated crystals by video microscopy. Their density of states all agree with the Debye's theory in the low-frequency regime, but the fluctuation of the frequency is similar to that of the eigenvalues of random matrices: the distributions of the frequency spacings between successive normal modes are the Wigner surmise, the spectral rigidities are logarithmic, and the distributions of vibrational amplitudes in the majority of modes are Gaussian. In addition, the first a few low-frequency modes are plane waves and dominate the thermal vibration, and the majority of modes are delocalized.

[1]This work was supported by Hong Kong GRF Grants No. 601208 and No. 601911.

8:24AM H51.00003 Microscopic observation of dynamics and structure in microgel suspensions[1] , MELAKU MULUNEH, Harvard University, JORIS SPRAKEL, Wageningen University, The Netherlands, HANS WYSS, Eindhoven University of Technology, The Netherlands, JOHAN MATTSSON, University of Leeds, UK, DAVID WEITZ, Harvard University — We use 3D confocal microscopy to understand the packing dynamics and structure of fluorescently labeled p(NIPAm-co-AAc) microgel colloidal particles. Such systems respond to changes in temperature, pH, and polymer content by changing size, morphology, and interaction behavior. We conduct experiments to understand this behavior in detail: our results show that the dynamics are dominated by attraction driven crystallization and concentration at low pH and concentration only at high pH. Crystal nucleation occurs homogeneously in the suspensions and does not appear to be restricted to geometric boundaries. The growth of crystals is nucleation-limited and can complete on the order of hours. Structural analysis of the crystals formed indicates that the stacking style is insensitive to charge, concentration, size, and stiffness of the particles and remains FCC.

[1]This work is supported by the Harvard MRSEC (DMR-0820484), and the NSF (DMR-1006546)

8:36AM H51.00004 Homogeneous Melting of 3D Superheated Colloidal Crystals[1] , ZIREN WANG, FENG WANG, YI PENG, YILONG HAN, Department of Physics, Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong, SOFT MATTER & VIDEO MICROSCOPY LAB TEAM — We locally superheated the interior of thermal-sensitive microgel colloidal crystals and measured the homogenous melting by video microscopy. The nucleation was typically started from a local strong-vibrating region instead of precursor defects. We found that the nucleation time $t \sim (\phi - \phi_m)^{-2}$ and critical nucleus size $r^* \sim (\phi - \phi_m)^{-1}$ as predicted by the classical nucleation theory, while the observed non-spherical critical nuclei and the merging of subcritical nuclei are beyond the classical nucleation theory. At the superheated limit where the incubation time vanishes, the Lindemann parameter approaches 0.18 which just equals to that at the liquid-solid interface. Beyond the superheated limit, the melting becomes like a spinodal decomposition rather than a nucleation process.

[1]This work was supported by Hong Kong SAR GRF Grants No. 601208 & 601911.

8:48AM H51.00005 Polyhedral assembled colloids (PACs); a new family of colloids with facets , NOBUHIRO YANAI, JING YAN, QIAN CHEN, STEVE GRANICK, University of Illinois at Urbana Champaign — We introduce a new class of colloids with polyhedral morphology that self-assemble into well-defined clusters and crystals by means of directional attraction between facets. These micron-sized particles are prepared by controlled crystallization of metal ions and organic bridging ligands in solution. They are characterized by distinct polyhedral morphology, rhombic dodecahedra in this work. Unlike spheres that isotropically interact along a curved surface, rhombic dodecahedra particles in suspension associate in a directional facet-to-facet fashion, forming clusters whose elemental units are orderly not only in interparticle distance but also mutual orientation. Furthermore, by changing the particle concentration during the self-assembly, we observe two types of hexagonal arrangement of these rhombic dodecahedra.

9:00AM H51.00006 Measuring every particle's size in a confocal microscopy experiment , ERIC WEEKS, Physics Dept., Emory University, REI KURITA, Institute of Industrial Science, University of Tokyo — We have developed a technique to estimate the radius of every particle observed in a confocal microscopy experiment. From simulations, we verify that the particle radii are estimated to high accuracy in a variety of samples: dense colloidal suspensions, colloidal gels, and binary samples. This method allows us to determine *in situ* the particle size distribution. Furthermore, this method lets us find relationships between individual particle size and dynamical behaviors. First, crystal nucleation occurs in regions that are locally more monodisperse. Second, in dense samples, particle mobility is well correlated with the local volume fraction, defined as the true particle volume divided by the particle's Voronoi volume.

9:12AM H51.00007 Vibrational Phonon Modes of Two-Dimensional Soft-Particle Colloidal Crystals with Hard-Particle Dopants[1] , MATTHEW GRATALE, PETER YUNKER, KE CHEN, Department of Physics and Astronomy, University of Pennsylvania, KEVIN APTOWICZ, Department of Physics, West Chester University, ARJUN YODH, Department of Physics and Astronomy, University of Pennsylvania — We study the phonon modes of two-dimensional colloidal crystals consisting of random distributions of "soft" NIPA microgel particles and "hard" polystyrene particle dopants. Thus, the effective springs connecting nearest-neighbors are very stiff, very soft, or of intermediate stiffness, corresponding to three possible inter-particle potentials present in the crystals. We employ video microscopy to derive the phonon modes of corresponding "shadow" crystals with the same geometric configuration and interactions as the experimental colloidal system, but absent damping [1,2,3]. Long wavelength, Debye-like behavior is found at low frequencies, regardless of the number of hard polystyrene particles present in the crystal. Hard particles are primary participants at high frequencies, while soft spheres are primary participants at intermediate frequencies. [1] Chen *et al.*, PRL **105**, 025501 (2010). [2] Kaya *et al.*, Science **329**, 656 (2010). [3] Ghosh *et al.* PRL **104**, 248305 (2010).

[1]This work is supported by NSF grant DMR-0804881, Penn MRSEC grant DMR11-20901, and NASA grant NNX08AO0G

9:24AM H51.00008 Direct observation of the nucleation in colloidal solid-solid transitions[1] , YI PENG, FENG WANG, ZIREN WANG, YILONG HAN, Department of Physics, Hong Kong University of Science and Technology, Clear Water Bay, Hong Kong, China — We studied the solid-solid transitions between square and triangular lattices in thermal sensitive microgel colloidal thin films by video microscopy. A novel two-step nucleation process was observed in a locally heated single crystalline domain: typically a $\sim$60-particle liquid nucleus was first from the square lattice and then rapidly transformed to a solid nucleus with triangular lattice. Such a post-critical triangular-lattice nucleus grew linearly and induced grain boundaries around it. Nuclei were triggered by the merging of stronger vibrating areas instead of precursor defects. The critical nucleus size was measured from the mean first passage time of the nucleus size.

[1]This work was supported by GRF grants 601208 and 601911.

9:36AM H51.00009 Colloidal gas-liquid transition: tuning nucleation and growth by Critical Casimir forces , DUC NGUYEN, PhD, PETER SCHALL, Dr — The nucleation and growth of the liquid phase has been well studied in simulations, but direct experimental observations remain challenging. Here we present a detailed study of the colloidal gas-liquid transition induced by Critical Casimir forces that allow direct control over particle interactions via temperature-dependent solvent fluctuations. We show that with the direct control over particle interactions we can "freeze" a dilute colloidal gas into a dense colloidal liquid. By using dynamic light scattering to follow the evolution of liquid aggregates we observe three clearly distinct regimes: nucleation, interface limited- and diffusion limited growth. We elucidate these regimes directly in real space by using confocal microscopy. In the nucleation regime, we determine the Gibbs free energy, interfacial tension and chemical potential of the liquid aggregates directly from their size distribution. In the growth regime, we can directly follow the attachment of particles, and the collapse of liquid aggregates to large drops. Our critical Casimir colloidal system allows us to control all stages of nucleation and growth with temperature, thereby providing unprecedented insight into this gas-liquid transition.

9:48AM H51.00010 Temperature control of colloidal phases by Critical Casimir forces – a simulation study , MINH TRIET DANG, VAN DUC NGUYEN, Van der Waals-Zeeman Institute, University of Amsterdam, Netherlands, ANA VILA VERDE, PETER BOLHUIS, Van't Hoff Institute for Molecular Science, University of Amsterdam, Netherlands, PETER SCHALL, Van der Waals-Zeeman Institute, University of Amsterdam, Netherlands, VAN DER WAALS-ZEEMAN INSTITUTE, UNIVERSITY OF AMSTERDAM, NETHERLANDS COLLABORATION, VAN'T HOFF INSTITUTE FOR MOLECULAR SCIENCE, UNIVERSITY OF AMSTERDAM, NETHERLANDS COLLABORATION — Critical Casimir forces arising from the confinement of critical solvent fluctuations between the surfaces of colloidal particles have recently been shown a promising route to control colloidal assembly. Such forces are strongly temperature dependent, and thus allow for direct temperature control of colloidal interactions. However, colloidal phase transitions controlled by this highly temperature-dependent potential are still poorly understood. Here, we report Monte Carlo simulations of critical Casimir-driven colloidal phase behavior using input potentials directly measured in experiments. We map the gas-liquid coexistence region using Gibbs ensemble simulations and the solid-fluid coexistence boundaries using Gibbs-Duhem integration, and determine the gas-liquid critical point by applying scaling theory. The constructed gas-liquid-solid phase diagram agrees quantitatively with that observed in experiments. Remarkably, the simulated gas-liquid coexistence curve exhibits 3D Ising scaling despite the strong temperature dependence of the pair potentials.

10:00AM H51.00011 Colloidal aggregation in microgravity by critical Casimir forces[1] , SANDRA VEEN, PETER SCHALL, OLEG ANTONIUK, Van der Waals Zeeman Institute - University of Amsterdam, MARCO POTENZA, MATTEO ALAIMO, University of Milan, STEFANO MAZZONI, European Space Agency, GERARD WEGDAM, Van der Waals Zeeman Institute - University of Amsterdam, VAN DER WAALS ZEEMAN INSTITUTE - UNIVERSITY OF AMSTERDAM COLLABORATION, OPTICS AND MICROGRAVITY RESEARCH LABORATORY - UNIVERSITY OF MILAN COLLABORATION, PHYSICAL SCIENCE UNIT HUMAN SPACEFLIGHT AND OPERATIONS - EUROPEAN SPACE AGENCY COLLABORATION — We study aggregation and crystal growth of spherical Teflon colloids in binary liquid mixtures in microgravity by the critical Casimir effect. The critical Casimir effect induces interactions between colloids due to the confinement of bulk fluctuations (density or concentration) near the critical point of liquids. The strength and range of the interaction depends on the length scale of these fluctuations which increase as one approaches the critical point. The interaction potential can thus be tuned with temperature. We follow the growth of structures in real time with Near Field Scattering. Measurements are performed in microgravity in order to study pure diffusion limited aggregation, without disturbance by sedimentation or flow.

[1]NWO/NSO/ESA

10:12AM H51.00012 Light transport through soft colloidal glasses , SOFIA MAGKIRIADOU, Harvard Physics Department, Cambridge, MA, USA, JIN-GYU PARK, School of Engineering and Applied Sciences, Harvard University, Cambridge, MA, USA, YOUNG-SEOK KIM, Korea Electronics Technology Institute, S.Korea, GI-RA YI, Department of Engineering Chemistry, Chungbuk National University, S. Korea, VINOTHAN N. MANOHARAN, School of Engineering and Applied Sciences, Harvard University, Cambridge, MA, USA — We have developed a novel colloidal system for the fundamental study of light propagation through disordered media. Our colloids contain core-shell particles with scattering cores and transparent shells which are self-assembled into amorphous, glassy configurations. The core-shell structure of the particles allows us to independently control two key parameters for light propagation: their scattering cross-section, which is determined by the cores, and their spacing, which is determined by the shells. Thus, our system is ideally suited for the study and manipulation of the optical properties of disordered materials. In particular, we aim to investigate how photonic stop bands arise in disordered media and how near-field coupling between scatterers affects light transport. We intend to use this knowledge to make amorphous colloids with various angularly-independent structural colors.

10:24AM H51.00013 3D Dynamic Light Scattering of Microgel Suspensions , JOHN HYATT[1], ALBERTO FERNANDEZ-NIEVES[2], Georgia Institute of Technology, GEORGIA TECH TEAM — We use 3D cross-correlated dynamic light scattering to investigate suspensions of microgels. We will discuss some of the theory behind this technique and present results from size- and pH-tunable pNIPAM microgels cross-linked with PEG and copolymerized with acrylic acid.

[1]Graduate student in Georgia Tech Soft Condensed Matter Laboratory.
[2]PI of Georgia Tech Soft Condensed Matter Laboratory.

10:36AM H51.00014 Using colloidal packings as templates for structuring drugs , JAMES WILKING, Harvard University, ANDRÉ STUDART, ETH, SEBASTIAN KOLTZENBURG, BASF, RODRIGO GUERRA, ESTHER AMSTAD, Harvard University, JENS RIEGER, BASF, DAVID WEITZ, Harvard University — Many pharmaceutical compounds are poorly soluble in water; this is problematic because most pharmaceuticals are delivered orally and must dissolve in the gastrointestinal fluid in order to be taken up by the body. We introduce a simple method for increasing the dissolution rates of poorly water-soluble organic actives. We demonstrate that by structuring the compounds within the interconnected, nanoscale pore space of a colloidal packing we create composites which rapidly disintegrate in water, exposing the nanostructured organic active and leading to improved dissolution rates.

10:48AM H51.00015 Spin coating of superparamagnetic colloids with applied magnetic fields[1] , WENCESLAO GONZÁLEZ-VIÑAS, MOORTHI PICHUMANI, University of Navarra — We report experimental results on the behavior of dilute superparamagnetic colloids under shear stresses (using a commercial spin-coater and varying its rate of rotation) with applied magnetic fields. For the case of zero field, we compare the results obtained for different kind of particles (non-magnetic [1] vs PS based [2] vs silica based [3]) and solvents by analyzing the dried deposits obtained from the spin coating. All the data collapse in a single curve, when the appropriate scaling for the film thickness is performed. This agreement allows us to define a reference to measure the relative change in viscosity, when a magnetic field is applied during the spin coating. Thus, we show the magnetorheological properties of colloidal dispersions. These results shed light into the aggregation and clustering dynamics for colloids under external fields with shear and provide a new method to study the rheological properties of colloids.

[1] M. Giuliani et al. "Dynamics of crystal structure formation in spin-coated colloidal films" J. Phys. Chem. Lett. 1(9), 1481 (2010)
[2] M. Pichumani et al. "Spin-coating of dilute magnetic colloids in a magnetic field" Magnetohydrodynamics, 47(2), 191 (2011)
[3] M. Pichumani et al. In preparation

[1]This work is partly supported by the Spanish Government Contract No. FIS2008-01126. M.P. acknowledges the financial support from the "Asociación de Amigos de la Universidad de Navarra"

Tuesday, February 28, 2012 8:00AM - 11:00AM –
Session H52 GSNP DFD: Focus Session: Extreme Mechanics - Rods 153C

8:00AM H52.00001 Dynamic curling of a naturally curved Elastica[1] , BASILE AUDOLY, Institut Jean le Rond d Alembert, University Paris 6 and CNRS — We consider the motion of a naturally curved Elastica that has been flattened onto a hard surface. When it is released from one end, the Elastica lifts off the surface and curls dynamically into a moving spiral. The motion is governed by inertia, bending and geometric nonlinearity. At long times, the dynamics follows a self-similar regime: the size of the spiral grows like the cubic root of time, while the velocity of the front reaches a constant value. The asymptotic velocity is derived analytically, and compared to numerical simulations and to experiments.

[1]Joint work with Andrew Callan-Jones and Pierre-Thomas Brun

8:36AM H52.00002 The Mechanics of Curly Hair , JAMES MILLER, Massachusetts Institute of Technology, ARNAUD LAZARUS, BREANNA BERRY, MIT, BASILE AUDOLY, Institut d'Alembert (University Paris 6), PEDRO REIS, MIT — We explore the oft-neglected role of intrinsic natural curvature on the mechanics of elastic rods. Our testbed, a hanging hair, is a deceivingly simple system that exhibits complex mechanics and geometrically nonlinear behavior. Through a combination of precision desktop-scale experiments, numerical simulations, and theoretical analysis, we seek physical insight into the nontrivial configurations adopted by a naturally curved elastic rod that is suspended under its own weight. In particular, we aim to gain predictive understanding of the transition from planar to non-planar solutions as well as the localization of torsion in the non-planar configurations. The experimentally observed behavior of our custom-fabricated naturally curved rods is captured well by simulations and is rationalized through scaling arguments.

8:48AM H52.00003 The Shape of a Ponytail and the Statistical Physics of Hair Fiber Bundles

, RAYMOND E. GOLDSTEIN, University of Cambridge, PATRICK B. WARREN, Unilever R&D Port Sunlight, ROBIN C. BALL, University of Warwick — From Leonardo to the Brothers Grimm our fascination with hair has endured in art and science. Yet, a quantitative understanding of the shapes of a hair bundles has been lacking. Here we combine experiment and theory to propose an answer to the most basic question: What is the shape of a ponytail? A model for the shape of hair bundles is developed from the perspective of statistical physics, treating individual fibers as elastic filaments with random intrinsic curvatures. The combined effects of bending elasticity, gravity, and bundle compressibility are recast as a differential equation for the envelope of a bundle, in which the compressibility enters through an "equation of state." From this, we identify the balance of forces in various regions of the ponytail, extract the equation of state from analysis of ponytail shapes, and relate the observed pressure to the measured random curvatures of individual hairs.

9:00AM H52.00004 Following the equilibria of slender elastic rods

, ARNAUD LAZARUS, JAMES MILLER, PEDRO REIS, Massachusetts Institute of Technology — We present a novel continuation method to characterize and quantify the equilibria of elastic rods under large geometrically nonlinear displacements and rotations. To describe the kinematics we exploit the synthetic power and computational efficiency of quaternions. The energetics of bending, stretching and torsion are all taken into account to derive the equilibrium equations which we solve using an asymptotic numerical continuation method. This provides access to the full set of analytical equilibrium branches (stable and unstable), a.k.a bifurcation diagrams. This is in contrast with the individual solution points attained by classic energy minimization or predictor-corrector techniques. We challenge our numerics for the specific problem of an extremely twisted naturally curved rod and perform a detailed comparison against a precision desktop-scale experiments. The quantification of the underlying 3D buckling instabilities and the characterization of the resulting complex configurations are in excellent agreement between numerics and experiments.

9:12AM H52.00005 The elasticity of magnetic chains: From self-buckling to self-assembly

, DOMINIC VELLA, EMMANUEL DU PONTAVICE, CAMERON HALL, ALAIN GORIELY, OCCAM, University of Oxford — Spherical neodymium magnets have become a popular toy in recent years. In this talk, we present the results of some experimental and theoretical investigations into the peculiar elastic-like behaviour exhibited by chains of these magnetic spheres. We show how the dipole-dipole interactions between spheres penalise deformation, and we find that the form of this penalty is different for a long chain compared to a short chain. Finally, we investigate the dynamic self-assembly of these chains into cylindrical structures.

9:24AM H52.00006 Spontaneous and Deterministic Three-dimensional Curling of Pre-strained Elastomeric Strips: From Hemi-helix to Helix

, JIANGSHUI HUANG, JIA LIU, BENEDIKT KROLL, KATIA BERTOLDI, ZHIGANG SUO, DAVID CLARKE, Harvard University — A variety of three dimensional curls are produced by a simple generic process consisting of pre-straining one elastomeric strip, joining it to another and then releasing the bi-strip. The hemi-helix, one kind of three dimensional curls, consists of multiple, alternating helical sections of half wavelength in opposite chiralities and separated by perversions. The hemi-helix wavelength and the number of perversions are determined by the strip cross-section, the constitutive behavior of the elastomer and the value of the pre-strain. Topologically, the perversions also separate regions of the helix deforming principally by bending from those where twisting dominates. Changing the prestrain and the ratio between the thickness and the width induce a phase separation of hemi-helical structure, helical structure and hybrid structure which have similarities to coiled polymer molecules and plant tendrils.

9:36AM H52.00007 Snakes Out of the Plane[1]

, ANDREW MCCORMICK, BRUCE A. YOUNG, L. MAHADEVAN, Harvard University — We develop a new computational model of elastic rods, taking into account shear and full rotational dynamics, as well as friction, adhesion, and collision. This model is used to study the movement of snakes in different environments. By applying different muscular activation patterns to the snake, we observe many different patterns of motion, from planar undulation to sudden strikes. Many of the most interesting behaviors involve the snake rising out of the horizontal plane in the vertical direction. Such behaviors include a sand snake sidewinding over the hot desert sand and a cobra rearing up into a defensive striking position. Experimental videos of live snakes are analyzed and compared with computational results. We identify and explain a new form of movement previously unobserved: "collateral locomotion."

[1]A.M. acknowledges support from the NDSEG program.

9:48AM H52.00008 Analysis of the fluid mechanical sewing machine

, PIERRE-THOMAS BRUN, Institut Jean le Rond dAlembert/Lab. FAST, UPMC, Univ Paris-Sud, CNRS, BASILE AUDOLY, Institut Jean le Rond dAlembert, UPMC, CNRS, NEIL RIBE, Lab FAST, UPMC, Univ Paris-Sud, CNRS — A thin thread of viscous fluid falling onto a moving belt generates a surprising variety of patterns, similar to the stitch patterns produced by a traditional sewing machine. By simulating the dynamics of the viscous thread numerically, we can reproduce these patterns and their bifurcations. The results lead us to propose a new classification of the stitch patterns within a unified framework, based on the Fourier spectra of the motion of the point of contact of the thread with the belt. The frequencies of the longitudinal and transverse components of the contact point motion are locked in most cases to simple ratios of the frequency Ω_c of steady coiling on a surface at rest (i.e., the limit of zero belt speed). In particular, the "alternating loops" pattern involves the first five multiples of $\Omega_c/3$. The dynamics of the patterns can be described by matching the upper (linear) and the lower (non-linear) portions of the thread. Following this path we propose a toy model that successfully reproduces the observed transitions from the steady dragged configuration to sinusoidal meanders, alternating loops, and the translated coiling pattern as the belt speed is varied.

10:00AM H52.00009 Microfabrication of a spider-silk analogue through the liquid rope coiling instability[1]

, FREDERICK P. GOSSELIN, DANIEL THERRIAULT, MARTIN LEVESQUE, Ecole Polytechnique de Montreal — Spider capture silk outperforms most synthetic materials in terms of specific toughness. We developed a technique to fabricate tough microstructured fibers inspired by the molecular structure of the spider silk protein. To fabricate microfibers (with diameter $\sim 30\mu m$) with various mechanical properties, we yield the control of their exact geometry to the liquid rope coiling instability. This instability causes a thread of honey to wiggle as it buckles when hitting a surface. Similarly, we flow a filament of viscous polymer solution towards a substrate moving perpendicularly at a slower velocity than the filament flows. The filament buckles repetitively giving rise to periodic meanders and stitch patterns. As the solvent evaporates, the filament solidifies into a fiber with a geometry bestowed by the instability. Microtraction tests performed on fibers show interesting links between the mechanical properties and the instability patterns. Some coiling patterns give rise to high toughness due to the sacrificial bonds created when the viscous filament loops over itself and fuse. The sacrificial bonds in the microstructured fiber play an analogous role to that of the hydrogen bonds present in the molecular structure of the silk protein which give its toughness to spider silk.

[1]We acknowledge the funding from FQRNT, NSERC and CFI.

10:12AM H52.00010 Buckling Instability and Stress Propagation in Rods with Elastic Support

, ZI CHEN, Biomedical Engineering, Washington Univ. in St. Louis, WANLIANG SHAN, Mechanical & Aerospace Engineering, Princeton Univ., ANKITA GUMASTE, Neuroscience & Behavioral Biology, Emory Univ., WINSTON SOBOYEJO, Mechanical & Aerospace Engineering, Princeton Univ., CLIFFORD BRANGWYNNE, Chemical & Biological Engineering, Princeton Univ. — The cytoskeleton of living cells is a composite material consisting of a network of biopolymers including f-actin and microtubules (MTs). MTs are able to bear significant compressive loads in cells as a result of reinforced short wavelength buckling, due to the surrounding actin network. However, the length scale of compressive force propagation, even for macroscopic rods, remains poorly understood. Here we propose a minimal theory that incorporates elastic restoring forces from the surrounding network, elucidating the compressive force-dependence of the buckled rod shape. We identify a threshold length as the effective distance stresses can propagate in such network, and show that the decay length is tunable by modifying the longitudinal mechanical coupling coefficients. We test these predictions with experiments in macroscopic rods, and show that the degree of mechanical coupling directly controls the penetration depth of buckling, in agreement with theoretical and numerical predictions. Our results suggest that the length scale over which mechanical signals are transduced in cells may be actively controlled, and could provide design principles for novel types of fiber composite materials based on biomimetic control of the longitudinal coupling coefficients.

10:24AM H52.00011 Undulatory buckling of a rod constrained by an elastic matrix

, JIA LIU, TIANXIANG SU, Harvard University, OSCAR LOPEZ-PAMIES, UIUC, PEDRO REIS, MIT, KATIA BERTOLDI, Harvard University — Elastic instabilities of rods constrained by an elastic matrix and subjected to axial compression have long been recognized as essential for structural applications in the context of failure mitigation and, more recently, towards exploitation of functionality. Relevant fields for this class of problems include drilling, biomedical instrumentation and root growth in plants. We explore the two possible scenarios observed when, above a threshold load, compression is applied to a rod constrained by a matrix: i) the rod can develop a planar oscillatory solution (sinusoidal buckling) or ii) it can take the configuration of a helix (helical buckling). We identify the principal parameters of this system, perform a systematic parametric study and rationalize the phase diagram through a hybrid of theoretical and numerical analyses. Particular attention is devoted to the effect of the mechanical properties of the constraining matrix which is found to have a critical influence on this buckling scenario.

10:36AM H52.00012 Slack, stress, and noisy structures in inertial strings

, JAMES HANNA, CHRISTIAN SANTANGELO, Department of Physics, University of Massachusetts - Amherst — Strings and chains are inextensible filaments with negligible bending and twist resistance. Local arc length conservation is enforced by the stress, a Lagrange multiplier field screened by curvature. Uniform stress fields are generated by a wide class of inertial motions that includes travelling waves of curvature and torsion, while gradients in stress result in more complicated dynamics. We will discuss a theoretical example inspired by experimental and numerical observations of the growth of an arch in a straightening chain, involving the amplification, rectification, and advection of slack.

10:48AM H52.00013 Sinusoidal to helical buckling of an elastic rod under a cylindrical constraint

, TIANXIANG SU, Harvard University, JAMES MILLER, ARNAUD LAZARUS, Massachusetts Institute of Technology, NATHAN WICKS, JAHIR PABON, Schlumberger-Doll Research, KATIA BERTOLDI, Harvard University, PEDRO REIS, Massachusetts Institute of Technology — We investigate the buckling and post-buckling behavior of an elastic rod loaded under cylindrical constraint. Our precision desktop-scale experiments comprise of axially compressing a hyper-elastic rod inside a transparent acrylic pipe. These experiments are also modeled using a discrete elastic rod simulation that includes frictional effects. Under imposed displacement, the initially straight rod first buckles into a sinusoidal mode and eventually undergoes a secondary instability into a helical buckling regime. The buckling and post-buckling behavior is found to be highly dependent on the systems' geometry, in particularly the aspect ratio of the rod to pipe diameter. We quantify the wavelength and pitch of the periodic patterns through direct digital imaging and record the reaction forces at both ends of the pipe. The observed behavior is rationalized through scaling arguments and captured by numerical simulations.

Tuesday, February 28, 2012 11:15AM - 2:15PM –
Session J41 DFD: Vortex Dynamics, Turbulence and Geophysical Flows 156B

11:15AM J41.00001 Two point correlations between velocity sums and differences in turbulence

, NICHOLAS ROTILE, GREG VOTH, SUSANTHA WIJESINGHE, Wesleyan University — In turbulent flows, the universality of small scales has been a subject of ongoing investigation. Recent work has explored the degree to which small scales are independent of large scales by measuring correlations between velocity differences over a distance r (whose variance is dominated by scales near r) and velocity sums over the same distance (whose variance is dominated by large scales). Some correlations between velocity differences and sums are required by the Navier-Stokes equations (Hosokawa, Prog. Theor. Phys. Lett., 118:169, 2007.) This talk will focus on experimental measurements of correlations between velocity sums and velocity differences in a turbulent flow between oscillating grids. We find that these correlations provide an accurate way to measure the energy dissipation rate that complements existing methods based on the third order structure functions. The correlations which are required by Navier-Stokes dynamics do not appear to violate the assumption of independence between the large and small scales, however there are other correlations in our measurements that show clear dependence of the small scales on the large scales.

11:27AM J41.00002 Variance of scalar fluctuations using backwards relative dispersion in turbulent channel flows

, CHIRANTH SRINIVASAN, DIMITRIOS PAPAVASSILIOU, The University of Oklahoma — Temperature fluctuations at a location in a turbulent flow field are brought about by the arrival of particle pairs with different scalar concentrations. Studying backwards relative dispersion can be an alternative way to describe the local variance in scalar fluctuation. This work uses a numerical approach that couples a direct numerical simulation with the tracking of scalar markers to obtain scalar statistics in an infinitely long turbulent channel flow. Focusing on the anisotropic direction perpendicular to the channel walls, the two-particle correlation coefficients are used to determine a Lagrangian material time scale as a function of distance from the wall. Introducing a model that follows Durbin's theory [1], the variance of the temperature fluctuation is calculated by assuming that particle pairs that arrive at a particular location carry with them the mean temperature acquired at the location they were at a previous time. This earlier location is determined by utilizing the Lagrangian backwards timescale. Results obtained from this model are tested at two different Reynolds numbers (at $\mathrm{Re}_\tau = 150$ and 300) and for each *Re* case at several different Prandtl numbers (from 0.1 to 1,000). **References** [1] Durbin, P.A., J. Fluid Mech., 100, 279-302, 1980

11:39AM J41.00003 Measuring anisotropy as a function of scale in turbulence using 3D particle tracking

, SUSANTHA WIJESINGHE, GREG VOTH, Department of Physics, Wesleyan University, Middletown, CT 06459 — We report the first full 3D experimental measurements of anisotropy as a function of scale in turbulence. From 3D particle tracks obtained with stereoscpic high speed video, we measure the Eulerian structure functions and decompose them into irreducible representation of SO(3) rotation group. This method allows us to quantify the anisotropy in different sectors, specified by j and m of the spherical harmonics $Y_{jm}(\theta, \phi)$, at all scales in the flow. We study a turbulent flow between two oscillating grids in an octagonal tank filled with $1100\ l$ of water with $R_\lambda = 265$. An image compression system processes high-speed video from four cameras in real-time allowing us to acquire huge data sets required for full 3D measurement of anisotropy as a function of scale. Careful selection of a sample of measurements with isotropic orientations is necessary to ensure that anisotropy of the measurement system does not affect the measured anisotropy of the flow. Increasing j sectors show faster decay of anisotropy as scale decreases, consistent with the idea that the small scales should become isotropic at very high Reynolds number. However, conditioning the measured anisotropy on the instantaneous velocity reveals that characterization of anisotropy in an inhom

11:51AM J41.00004 Rotation rate of rods in turbulent flow , SHIMA PARSA, GREG VOTH, Wesleyan University

— We present the first time resolved experimental measurements of the motion of small rod-like particles in turbulent flow. The orientation and position of rods are measured using Lagrangian particle tracking with images from multiple high speed cameras in a flow between two oscillating grids. We work at low particle density so rod-rod interaction can be ignored. The probability distribution of the rotation rate of the rods has extended tails indicating the presence of rare events with large rotation rate. Rods rotation rate is determined by the velocity gradients of the flow, so measurements of the rotation rate provide indirect access to statistics of the velocity gradient of the flow as well as the energy dissipation rate. However, tracer rods preferentially sample the flow since their orientation becomes correlated with the local axes of the velocity gradient tensor. The result is that the typical rotation rate of rods is much smaller than it would be if they were randomly oriented.

12:03PM J41.00005 Statistics of Macroturbulence from Flow Equations[1] , BRAD MARSTON, THOMAS IADECOLA, WANMING QI, Brown University

— Probability distribution functions of stochastically-driven and frictionally-damped fluids are governed by a linear framework that resembles quantum many-body theory. Besides the Fokker-Planck approach, there is a closely related Hopf functional method[2]; in both formalisms, zero modes of linear operators describe the stationary non-equilibrium statistics. To access the statistics, we generalize the flow equation approach[3] (also known as the method of continuous unitary transformations[4]) to find the zero mode. We test the approach using a prototypical model of geophysical and astrophysical flows on a rotating sphere that spontaneously organizes into a coherent jet. Good agreement is found with low-order equal-time statistics accumulated by direct numerical simulation, the traditional method. Different choices for the generators of the continuous transformations, and for closure approximations of the operator algebra, are discussed.

[1]Supported in part by NSF DMR-0605619.
[2]Ookie Ma and J. B. Marston, J. Stat. Phys. Th. Exp. P10007 (2005).
[3]F. Wegner, Ann. Phys. **3**, 77 (1994).
[4]S. D. Glazek and K. G. Wilson, Phys. Rev. D **48**, 5863 (1993); Phys. Rev. D **49**, 4214 (1994).

12:15PM J41.00006 Motion of a Thread in Compressible Turbulence , RORY CERBUS, WALTER GOLDBURG, Department of Physics and Astronomy, University of Pittsburgh

— Particles that float on a turbulent tank of water form a system that is compressible in the two dimensions on which they move. Here we study, with an overhead camera, the snake-like motion of a 10 μm thread that floats on the surface. The thread, of length much greater than the integral scale L_I of the underlying turbulence, cannot respond to the small-scale turbulent motions at the surface; its Young's modulus is too large. As a result, the mean curvature of the thread is of the order $1/L_I$. Measured properties include velocity structure functions of the thread $S_n(r)$ (including the third moment), the local curvature along the thread (a random variable), and "Richardson diffusion" of pairs of points along the thread separated by distances r. Supported by NSF Grant DMR 0604477 and the Okinawa Institute of Science Technology.

12:27PM J41.00007 Statistical Equilibria of Turbulence on Surfaces of Different Symmetry[1] , WANMING QI, BRAD MARSTON, Brown University

— We test the validity of statistical descriptions of freely decaying 2D turbulence by performing direct numerical simulations (DNS) of the Euler equation with hyperviscosity on a square torus and on a sphere. DNS shows, at long times, a dipolar coherent structure in the vorticity field on the torus but a quadrapole on the sphere[2]. A truncated Miller-Robert-Sommeria theory[3] can explain the difference. The theory conserves up to the second-order Casimir, while also respecting conservation laws that reflect the symmetry of the domain. We further show that it is equivalent to the phenomenological minimum-enstrophy principle by generalizing the work by Naso et al.[4] to the sphere. To explain finer structures of the coherent states seen in DNS, especially the phenomenon of confinement, we investigate the perturbative inclusion of the higher Casimir constraints.

[1]Supported in part by NSF DMR-0605619.
[2]J. Y-K. Cho and L. Polvani, Phys. Fluids **8**, 1531 (1996).
[3]A. J. Majda and X. Wang, *Nonlinear Dynamics and Statistical Theories for Basic Geophysical Flows* (Cambridge University Press, 2006).
[4]A. Naso, P. H. Chavanis, and B. Dubrulle, Eur. Phys. J. B **77**, 284 (2010).

12:39PM J41.00008 Design and Evolution of Shaped Vortices , DUSTIN KLECKNER, WILLIAM T.M. IRVINE, University of Chicago

— We present a novel method for generating vortex lines of arbitrary shapes. We then image their dynamics using a high speed scanning technique which provides three-dimensional information at up to 500 volumes per second. We create a variety of configurations and study the effect of geometry on their evolution.

12:51PM J41.00009 Insights into vortex merger using the core growth model , FANGXU JING, Georgia Institute of Technology, EVA KANSO, PAUL NEWTON, University of Southern California

— We revisit the two vortex merger problem (both symmetric and asymmetric) for the Navier-Stokes equations using the core growth model for vorticity evolution coupled with the passive particle field and an appropriately chosen time-dependent rotating reference frame. Using the combined tools of analyzing the topology of the streamline patterns along with careful tracking of passive fields, we highlight the key features of the stages of evolution of vortex merger, pinpointing deficiencies in the low-dimensional model with respect to similar experimental/numerical studies. The model, however, reveals a far richer and delicate sequence of topological bifurcations than has previously been discussed in the literature for this problem, and at the same time points the way towards a method of improving the model.

1:03PM J41.00010 Entrainment of solid particles by energetic flow events , MANOUSOS VALYRAKIS, Virginia Tech

— The focus of this research study is to investigate the utility and applicability of a recently proposed criterion for the prediction of incipient entrainment of sediment particles. Recently introduced theoretical frameworks and stochastic approaches are presented. At near incipient flow conditions the magnitude of energetic flow events follows a power law distribution, over a wide range of frequencies, similar to many other geophysical phenomena. This implies that highly energetic flow structures, which have a good potential of impinging on an exposed particle and displacing it downstream, occur less frequently. This is in agreement with the intermittent and episodic character of particle entrainment observed from mobile particle flume experiments at low flow stages. Further, analysis of synchronous time series of particle entrainment and local instantaneous flow upstream of it, allows for extraction and characterization of the scales and magnitudes that are relevant to the displacement of individual particles. In addition to having a sound theoretical basis, the modeling approach is shown to perform well in accurately defining the condition of incipient motion and various levels of probability of particle entrainment.

1:15PM J41.00011 Modeling and dynamics of sand bed vortex ripples , JUSTIN KAO, ABIGAIL KOSS, TAYLOR PERRON, Massachusetts Institute of Technology

— Vortex ripples arise through the instability of a flat sand bed under oscillatory water flow, for example due to wave action at a beach or continental shelf. Fully developed vortex ripples display complex interactions through the mutual influence of fluid flow and bed topography on each other, via sediment transport. We discuss a mechanistic model of ripple dynamics in which the hydrodynamic influence is linearized, and show that this reduced model nonetheless captures many of the ripple dynamics observed in experiments. Cross-sectional profiles of experimentally generated ripples constrain the modeled sediment flux and provide support for our approximations.

1:27PM J41.00012 The statistics of wind driven ocean currents , YOSEF YOSEF, GOLAN BEL, Dept. of Solar Energy and Environmental Physics, Ben-Gurion University of the Negev — Ocean currents play an important role is the climate system, yet the properties and origin of their statistics is not fully understood. Using the Ekman layer model we show that the statistical properties of the depth integrated surface currents are associated with the temporal correlations of the wind driving the surface currents—when the temporal correlations of the wind are long the probability distribution of the current magnitude is proportional to that of the wind stress. When the temporal correlations of the wind is short the current approaches zero where each component of the current follows a Gaussian distribution such the current magnitude follows the Rayleigh distribution. Using two idealized cases we show that in between these two limits the second (and higher) moment of the current magnitude reaches a maximal value. The results are validated using an oceanic general circulation model.

1:39PM J41.00013 Modulation of Atlantic tropical cyclones by El Nino - Southern Oscillation , CONSTANTIN ANDRONACHE, Boston College — North Atlantic tropical cyclones (TC) usually form in the northern hemisphere summer and fall with a maximum of activity in September. El Nino–Southern Oscillation (ENSO) has been shown to impact seasonal levels of Atlantic basin TC activity. ENSO is the strongest year to year climate fluctuation on Earth. It originates in the tropical Pacific through coupled ocean-atmosphere interactions mediated by surface wind stress and sea surface temperature (SST) variations. Understanding the effects of ENSO on the seasonal variations of TC activity has important practical consequences for seasonal forecast of hurricanes in North Atlantic. In this study we use the NOAA Extended Reconstructed Sea Surface Temperature, the TC counts in North Atlantic, and the NCEP/NCAR reanalysis data to investigate the relationship between significant ENSO events and TC activity during the hurricane season. Model calculations show that forecasted ENSO SSTA can be used as predictors of TC in North Atlantic region. Such results are illustrated in the context of current efforts to understand climate predictability relevant to North Atlantic tropical storms.

1:51PM J41.00014 Fingers and Toes in Miscible Viscous Flows , RADHA RAMACHANDRAN, IRMGARD BISCHOFBERGER, SIDNEY NAGEL, University of Chicago — The displacement of a more viscous fluid by a less viscous one in a porous medium produces complex fingering patterns. To study this phenomenon a Hele-Shaw geometry is used in which the gap-averaged equations for flow between two parallel plates has the same form as Darcy's law for flow in porous media. Our experiments use a radial Hele-Shaw cell as well as a two dimensional porous medium of densely packed granular beads between two circular glass plates, to study viscous fingering in miscible fluids. For immiscible fluids it is known that the most-unstable wavelength for interface growth depends on surface tension, viscosity difference, velocity and plate spacing. In contrast, we find that for *miscible fluids* the large-scale structure (i.e., the ratio of finger length to overall size of the pattern) is set entirely by the viscosity ratio rather than the viscosity difference of the two fluids. We further investigate the role played by other dimensionless parameters in determining the fine structure and evolution of these fingering patterns in the two geometries.

2:03PM J41.00015 Thermal plumes in locally heated vertical soap films , NICOLAS ADAMI, STÉPHANE DORBOLO, HERVÉ CAPS, Université de Liège, GRASP TEAM — A vertical soap film is maintained by injection of a soap solution from the top. The film is then locally heated. Thermal plumes may be observed to rise in the film, depending on the magnitude of the heating and injected flows. The nearly-2D nature of the system allows to visualize the motion of the plumes using an infrared camera. A model is proposed to describe the growth, emergence, and stationarity of the plumes in the film by taking into account both magnitudes of the heating ΔT and injected flow Q. Oscillatory behaviors of both the full-grown plumes size and direction with respect to the vertical direction may also be observed. Particular soap film thickness dynamics shows to be the origin of those phenomena.

Tuesday, February 28, 2012 11:15AM - 2:15PM – Session J43 GSNP DFD: Invited Session: Stochastic Geometry and Conformal Invariance in Non-Equilibrium and Disordered Systems 157AB

11:15AM J43.00001 Stochastic geometry of turbulence , GREGORY FALKOVICH, Weizmann Institute of Science — Geometric statistics open the window into the most fundamental aspect of turbulence flows, their symmetries, both broken and emerging. On one hand, the study of the stochastic geometry of multi-point configurations reveals the statistical conservation laws which are responsible for the breakdown of scale invariance in direct turbulence cascades. On the other hand, the numerical and experimental studies of inverse cascade reveal that some families of isolines can be mapped to a Brownian walk (i.e. belong to the so-called SLE class) and are thus not only scale invariant but conformally invariant. That means that some aspects of turbulence statistics can be probably described by a conformal field theory. The talk is a review of broken and emerging symmetries in turbulence statistics.

11:51AM J43.00002 Stochastic geometry in disordered systems, applications to quantum Hall transitions , ILYA GRUZBERG, The University of Chicago — A spectacular success in the study of random fractal clusters and their boundaries in statistical mechanics systems at or near criticality using Schramm-Loewner Evolutions (SLE) naturally calls for extensions in various directions. Can this success be repeated for disordered and/or non-equilibrium systems? Naively, when one thinks about disordered systems and their average correlation functions one of the very basic assumptions of SLE, the so called domain Markov property, is lost. Also, in some lattice models of Anderson transitions (the network models) there are no natural clusters to consider. Nevertheless, in this talk I will argue that one can apply the so called conformal restriction, a notion of stochastic conformal geometry closely related to SLE, to study the integer quantum Hall transition and its variants. I will focus on the Chalker-Coddington network model and will demonstrate that its average transport properties can be mapped to a classical problem where the basic objects are geometric shapes (loosely speaking, the current paths) that obey an important restriction property. At the transition point this allows to use the theory of conformal restriction to derive exact expressions for point contact conductances in the presence of various non-trivial boundary conditions.

12:27PM J43.00003 Efficient SLE algorithms and numerical pitfalls of the method[1] , TOM KENNEDY, Departments of Mathematics and Physics, University of Arizona — We consider a physical experiment or a numerical simulation of a physical phenomena that produces a random family of two-dimensional curves. We would like to know if there is a conformal invariance underlying this stochastic geometry. The Schramm-Loewner evolution (SLE) is a conformally invariant stochastic process which depends on a single parameter κ. For different values of κ it is known to describe the scaling limit of many conformally invariant 2d systems, e.g, percolation, the Ising model, self-avoiding walks and many more. So it is a natural candidate for describing the stochastic geometry of other physical systems. The classical Loewner equation provides a correspondence between curves in the plane and "driving functions," and SLE is obtained by taking the driving function to be a Brownian motion. Given a collection of random curves in the plane one would like to determine if the curves come from an SLE process for some value of κ. One method is to compute the driving processes of the curves and test if they are a Brownian motion. We discuss algorithms for doing this efficiently and some of the pitfalls in this approach.

[1]research supported by NSF grant DMS-0758649

1:03PM J43.00004 Search for Conformal Invariance in Two-dimensional Compressible Turbulence , - STEFANUS, University of Pittsburgh — We present a viable way of experimentally testing for conformal invariance at the surface of a turbulent fluid. The theory being tested here is related to the behavior of random curves on a plane and is associated with the work of Loewner, Schramm and others. It is usually referred to as Schramm-Loewner evolution (SLE). The scalar random variables that are put to this test are the vorticity and the divergence of the surface flow. Both of these variables display certain characteristics of Brownian motion, but the divergence field does not exhibit the Gaussian behavior required by SLE.

1:39PM J43.00005 Schramm-Loewner (SLE) analysis of quasi two-dimensional turbulent flows , SIMON THALABARD, SPEC/IRAMI/CEA Saclay — Quasi two-dimensional turbulence can be observed in several cases: for example, in the laboratory using liquid soap films, or as the result of a strong imposed rotation as obtained in three-dimensional large direct numerical simulations. We study and contrast SLE properties of such flows, in the former case in the inverse cascade of energy to large scale, and in the latter in the direct cascade of energy to small scales in the presence of a fully-helical forcing. We thus examine the geometric properties of these quasi 2D regimes in the context of stochastic geometry, as was done for the 2D inverse cascade by Bernard et al. (2006). We show that in both cases the data is compatible with self-similarity and with SLE behaviors, whose different diffusivities can be heuristically determined.

Tuesday, February 28, 2012 11:15AM - 2:03PM –

Session J51 DCMP DFD: Liquid Crystals: Smectic, Ferroelectric, Nanocomposites and DNA

Boston Conference Center 154

11:15AM J51.00001 Two-Dimensional Microfluidics: Hydrodynamic Interactions in Ultra-Thin Smectic Liquid Crystal Films[1] , ZOOM NGUYEN, AARON GOLDFAIN, CHEOL PARK, JOE MACLENNAN, MATT GLASER, NOEL CLARK, Physics, University of Colorado at Boulder, LCMRC TEAM — Hydrodynamics is important in nature and has a wide range of applications in science and industry. Most studies of fluid dynamics have been carried out in 3D systems, but there is an increasing interest in the hydrodynamics in confined geometries. Smectics can form ultra-thin, stable fluid films of uniform but readily variable thickness, a structure which enables the quantitative study of 2D hydrodynamics. Hydrodynamic interactions in 2D extend much further across the fluid than in 3D, and all the dynamics is confined to a well-defined plane, facilitating clean, high-contrast and high-resolution experiments. Here, we explore the hydrodynamic interactions of disk-like smectic islands with other islands and with a straight film boundary acting as a 1D wall. High speed video microscopy confirms that the translational diffusion of an island is anisotropic in the vicinity of another island or the wall, and this anisotropy persists even at large separations many times the island radius.

[1]This work was supported by NASA Grant NAG-NNX07AE48G, and by NSF MRSEC Grant DMR-0820579

11:27AM J51.00002 Two-Dimensional Microfluidics: hydrodynamics of drops and interfaces in flowing smectic liquid crystal channels[1] , ZHIYUAN QI, ZOOM NGUYEN, CHEOL PARK, JOE MACLENNAN, MATT MACLENNAN, NOEL CLARK, Physics, University of Colorado at Boulder, LC TEAM — The quantization of film thickness in freely suspended fluid smectic liquid crystal film enables the study of the hydrodynamics of drops and interfaces in 2D. We report microfluidic experiments, in which we observe the hydrodynamics of 2D drops flowing in channels. Using high-speed video microscopy, we track the shape of 2D drops and interfaces, visualizing the deterministic lateral displacement-based separation and pinched flow separation phenomena previously observed only in 3D. Finally, we demonstrate techniques for 2D drop generation and sorting, which will be used for 2D microfluidic applications.

[1]Work supported by NSF MRSEC Grant DMR- 0820579 and NASA Grant NAG No. NNX07AE48G

11:39AM J51.00003 Smectic liquid crystal cells with a "dirty" substrate , QUAN ZHANG, LEO RADZIHOVSKY, Department of Physics, University of Colorado, Boulder, CO 80309 — I will describe our recent studies of smectic liquid crystal cells with a "dirty" substrate. Acting as quenched disorder, such substrate heterogeneity destabilizes long-range smectic order on the surface and in the bulk for arbitrarily weak randomness. We analyze the statistics of the corresponding distortions, their decay into the bulk, topological defects and the role of nonlinear smectic elasticity. We will discuss our predictions in the context of recent experiments on ferroelectric smectic-C liquid crystals.

11:51AM J51.00004 Structural Reorganization of 4 - Cyano - 4' - octyloxybiphenyl (8OCB) revealed by Fast Scanning Calorimetry[1] , DONGSHAN ZHOU, JING JIANG, ZHIJIE HUANG, WEI JIANG, GI XUE, Nanjing University, DONGSHAN ZHOU TEAM — 4-Cyano-4'-octyloxybiphenyl (8OCB) is a liquid crystal with a few crystalline polymorphic modifications, of which the square plate form is the most elusive. Square plate form was reported to be only solution grown at low temperature and transformed to metastable parallelepiped form immediately even at -20 OC. With the chip calorimeter, we got the smectic glass of 8OCB when it was quenched from the melt with cooling rate of 20, 000 K/s. In the subsequent reheating with rates ranged from 2,000 K/s to 7,000 K/s, we could find two melting peaks located at 310K and 320K, respectively. Under faster heating, the peak at 310K became dominating, while the peak at 320K weakening. At heating rate of 8000 K/s, there was only melting peak of 310K. If further increased the heating rate, the melting peak at 310K would become smaller again because the crystal growth was suppressed until basically invisible at heating rate of about 20,000 K/s. This work shows that the square plate form is the dominating form when grown from the smectic glass, but it starts transforming to the parallelepiped form at heating slower than 8000 K/s. At heating slower than 1000 K/s, the transformation is completed and there is no chance to capture the square plate form.

[1]This work is financially supported by the National Basic Research Program of China (973 Program, 2012CB821500) and National Natural Science Foundation of China (No: 20874045, 21027006).

12:03PM J51.00005 A Biaxial Banana Liquid Crystal Phase with Short-range Layer Ordering[1] , YONGQIANG SHEN, TAO GONG, DONG CHEN, RENFAN SHAO, CHENHUI ZHU, MATTHEW GLASER, JOSEPH MACLENNAN, DAVID WALBA, NOEL CLARK, Liquid Crystal Materials Research Center, University of Colorado at Boulder — W623, a single-tail, bent-core molecule with a polar termination on one end and a siloxane-terminated tail on the other, exhibits a ferroelectric, orthorhombic, fluid smectic liquid crystal phase, the SmAP$_F$. Powder x-ray diffraction (XRD) measurements reveal an exotic structural transition on cooling from the SmAP$_F$ to a SmX phase, in which resolution-limited fluid smectic layering reflections give way to four much broader peaks, indicating short-range layer ordering. This behavior points to the kind of internal frustration that gives rise to our recently discovered helical nanofilament phases. We have performed two-dimensional XRD on aligned samples and discovered that one of the four peaks is from the in-plane order. Freeze-fracture transmission electron microscope (FFTEM) measurements confirm that there is two-dimensional short-range order in the SmX phase, with one periodicity in the layer plane and another normal to the layers. The in-plane periodicity can be measured directly from the packing of fibrils to be about 8 nm, consistent with the in-plane x-ray reflection peak. We will present depolarized transmission light microscopy, high-resolution XRD, and FFTEM studies of pure W623, and of mixtures of W623 with the calamitic liquid crystal 8CB.

[1]This work is supported by NSF MRSEC Grant DMR-0820579 and by NSF Grant DMR-1008300.

12:15PM J51.00006 A Bent – Shape Leaning Smectic Liquid Crystal Material , CUIYU ZHANG, NICK DIORIO, Kent State University, S. RADHIKA, B.K. SADASHIVA, Raman Research Institute, ANTAL JAKLI, Kent State University — Liquid crystals of bent-shape molecules theoretically can form four types of fluid smectic layer structures: (a) A polar smectic phase (called SmAP) where both molecular plane and the line connecting the end of average molecules (director) are perpendicular to the layer normal; (b) A double tilted chiral polar structure; (c) A single tilted phase (SmCP) where only the molecular plane is tilted with respect to the layer normal. The fourth possibility, where the director is tilted with respect to the layer normal, the "leaning" SmLP phase, has never been verified experimentally. Here we present the first bent-core material that forms a SmLP structure, thus proving the reality of all theoretically predicted bent-core smectic phases.

12:27PM J51.00007 Effective Conductivity due to Continuous Polarization Reorientation in Fluid Ferroelectrics[1] , JOSEPH MACLENNAN, YONGQIANG SHEN, TAO GONG, RENFAN SHAO, EVA KORBLOVA, DAVID WALBA, NOEL CLARK, Liquid Crystal Materials Research Center, University of Colorado at Boulder — In crystal ferroelectrics, the macroscopic polarization density **P** is stabilized to a set of discrete orientations by the underlying lattice, and ferroelectricity characterized by field-induced switching of **P** between these stable states. Fluid ferroelectrics exhibit **P** with no energy barriers to its reorientation. As a result, **P** can respond to applied electric field in a continuous fashion. We show here that, due to the reorientation of **P**, an otherwise insulating fluid ferroelectric behaves electrically as a resistive medium, with conductivity in the semiconducting range. Measurements of cell dynamics are reported for the SmAP$_F$ material W623, a bent-core liquid crystal (LC) with large macroscopic polarization that we find to exhibit nearly ideal field-induced block polarization reorientation. We have investigated theoretically the dynamic behavior of block polarization in the SmAP$_F$ phase, finding that a reorienting LC polarization block behaves electrically as a resistor. Experimental studies of W623 confirm this behavior, revealing the low resistance of the block-reorienting LC and the corresponding characteristic flat-topped step in the current response.

[1]This work is supported by NSF MRSEC Grant DMR-0820579 and by NSF Grant DMR-1008300.

12:39PM J51.00008 Microscopic origins of first-order SmA-SmC phase behavior and electro optics in de Vries smectic liquid crystals[1] , Z. KOST-SMITH, M.A. GLASER, P.D. BEALE, N.A. CLARK, Dept. of Physics, University of Colorado — Many de Vries liquid crystals exhibit a first-order SmA-SmC phase transition. The original de Vries hollow cone model, in which molecules in the SmA phase are tilted with respect to the layer normal but are uniformly distributed in azimuthal orientation, ϕ, has been used successfully to model many properties of de Vries materials, but the microscopic origins of first-order behavior remain obscure. We describe a microscopic mechanism for first-order behavior in de Vries smectics based on the hollow cone model, embodied in a generalized planar spin model where effective interactions between tilted molecules in the smectic layer planes are represented by a nearest-neighbor pair potential, $u(\phi_{ij})$, with a minimum of variable width around $\phi_{ij} = \phi_i - \phi_j = 0$. Using mean-field theory and Monte Carlo simulation, we find that the SmA-SmC transition is second order for a relatively broad minimum in the potential, and becomes first-order as the minimum narrows. This reflects the expected behavior due to excluded volume interactions in a tilted smectic, in which increasing cone angle leads to a more steeply varying effective azimuthal potential. This model naturally explains the observed first-order behavior in the framework of a hollow cone model.

[1]This work was supported by NSF MRSEC Grant DMR-0820579 and NSF Grant DMR-1008300

12:51PM J51.00009 Morphology and Dynamics of Liquid Crystalline Molecules Confined in Nano-pores , MALGORZATA JASIURKOWSKA, WILHELM KOSSACK, ROXANA ENE, CIPRIAN IACOB, WYCLIFFE KIPNUSU, PERIKLIS PAPADOPOULOS, JOSHUA SANGORO, University of Leipzig, Germany, MARIA MASSALSKA-ARODZ, Polish Academy of Sciences, Krakow, Poland, FRIEDRICH KREMER, University of Leipzig, Germany, UNIVERSITY OF LEIPZIG, GERMANY TEAM, POLISH ACADEMY OF SCIENCES, KRAKOW, POLAND COLLABORATION — Broadband dielectric and Infrared spectroscopy are combined to study the molecular dynamics of the liquid crystalline compounds belong isothiocyanatobiphenyl homologous series (abbreviated as nBT) confined in pores of mean diameters from 4 nm to 10.5 nm. In bulk, the studied substances show only one liquid crystalline phase: the SmE phase with orthorhombic arrangement within the molecular layers. In contrast to well-known bulk dielectric properties of nBTs, confinement leads to modification of the molecular dynamics. Two relaxation processes are detected. The slower process corresponds to molecular reorientation around short axis and it is faster in pores than in bulk. The second process is attributed to a librational motion of the molecules close to the walls. Both processes exhibit an Arrhenius-type temperature dependence. Detailed analysis of the temperature dependent infrared spectra indicates the different impact of confinement on the rigid and flexible molecular units of nBTs. Transition Moment Orientational Analysis is employed to explore the orientational order of molecules in pores.

1:03PM J51.00010 Temperature Dependence of Smectic Liquid Crystals Mixed With Magnetic Nanoparticles[1] , JEFFERSON W. TAYLOR, University of Maryland - College Park, LYNN K. KURIHARA, Naval Research Laboratories, LUZ J. MARTINEZ-MIRANDA, University of Maryland - College Park — We investigate the properties of bulk liquid crystal mixed with a magnetic nanoparticle (CoFe) as a function of temperature. We compare our results to those of a heat capacity measurement of Cordoyiannis et al.[2] and compare the way the smectic as a function of temperature the way the nematic behaves. We study how the liquid crystal reorganizes in the presence of the functionalized nanoparticles as a function of temperature and compare it to how it behaves at room temperature.[3] The X-rays give rise to three or four peaks whose evolution in temperature varies depending on their origin. In particular the second peak does not seem to vary much with temperature, and can be associated with the first several molecular layers attached to the nanoparticles.

[1]This work was supported by NSF-DMR-0906344.

[2]George Cordoyiannis, Lynn K. Kurihara, Luz J. Martinez-Miranda, Christ Glorieux, and Jan Thoen, Phys. Rev. E **79**, 011702 (2009)

[3]L. J. Martínez-Miranda, and Lynn Kurihara, J. Appl. Phys, **105**, p. 084305 (2009).

1:15PM J51.00011 The Role of ZnO Particle Size, Shape and Concentration on Liquid Crystal Order and Current-Voltage Properties for Potential Photovoltaic Applications[1] , LUZ J. MARTINEZ-MIRANDA, JANELLE BRANCH[2], ROBERT THOMPSON, JEFFERSON W. TAYLOR, LOURDES SALAMANCA-RIBA, University of Maryland - College Park — We investigate the role order plays in the transfer of charges in ZnO nanoparticle - octylcyanobiphenyl (8CB) liquid crystal system for photovoltaic applications as well as the role the nominally 7x5x5nm^3 or 20x5x5nm^3 ZnO nanoparticles play in improving that order. Our results for the 5nm nanoparticles show an improvement in the alignment of the liquid crystal with increasing weight percentage of ZnO nanoparticles[1]. Our results for the 7x5x5 nm^3 sample show that the current is larger than the current obtained for the 5 nm samples. We find that order is improved for concentrations close to 35% wt ZnO for both the 7x5x5 nm^3 and 20x5x5 nm^3. We have analyzed the X-ray scans for both the 7x5x5 and the 20x5x5 nm^3 samples. The signal corresponding to the liquid crystal aligned parallel to the substrate is much smaller than the peak corresponding to the liquid crystal aligned approximately at 70° with respect to the substrate for the 7x5x5 nm^3 sample whereas this same peak is comparable or more intense for the 20x5x5 nm^3 sample. 1. L. J. Martínez-Miranda, Kaitlin M. Traister, Iriselies Meléndez-Rodríguez, and Lourdes Salamanca-Riba, Appl. Phys. Letts, 97, 223301 (2010).

[1]This work was supported by NSF-DMR- MRSEC-0520471, and its REU program, and in part by NSF-DMR-0906433.
[2]REU student from Florida Institute of Technology

1:27PM J51.00012 ZnO Nanowire Arrays with Liquid Crystals for Photovoltaic Applications[1] , LOURDES SALAMANCA-RIBA, JOSHWA TAILLON, LUZ MARTINEZ-MIRANDA, Materials Science and Engineering Department, University of Maryland, College Park, MD — Liquid crystals are small monodisperse molecules with high mobilities and are easy and cheap to process. In addition, some of their phases exhibit molecular orientation that can provide a path for the electrons, or holes, to move from one electrode to the other. We have added a smectic A liquid crystal (8CB) to ZnO nanowire arrays of different diameters and have observed a photovoltaic effect as a function of the concentration of ZnO in the liquid crystal. The nanowire arrays are covered with 8CB liquid crystal for hole conduction. We have observed an increase in the light absorption of the PV cells as a function of wavelength of the light for the ZnO nanowire cells. We present a detailed study of the structure of the system.

[1]Supported by NSF under MRSEC DMR 0520471.

1:39PM J51.00013 Ligation of Complementary Oligomers in Liquid Crystals of nanoDNA[1] , GREGORY SMITH, DAVID WALBA, NOEL CLARK, LCMRC, CU Boulder, WEIXIAN XI, TAO GONG, CHRISTOPHER BOWMAN, Chemical Engineering, CU Boulder, TOMMASO FRACCIA, GIULIANO ZANCHETTA, TOMMASO BELLINI, University of Milan, LIQUID CRYSTAL MATERIALS RESEARCH CENTER, UNIVERSITY OF COLORADO, BOULDER COLLABORATION, DEPARTMENT OF CHEMICAL AND BIOLOGICAL ENGINEERING, UNIVERSITY OF COLORADO, BOULDER COLLABORATION, DIPARTMENTO DI CHIMICA, BIOCHIMICA E BIOTECNOLOGIE, UNIVERSITY OF MILAN, MILAN COLLABORATION — The chromonic stacking mode of short oligomeric DNA upon forming liquid crystalline phases presents an intriguing possibility for liquid crystal autocatalysis, the promotion, by LC ordering, of chemical synthesis that stabilizes LC ordering. In such a scenario the concentration and physical organization of ligation reactants and the fluidity of the liquid crystal phase promotes the appropriate chemical ligation of oligomers. Because it is a mode of elongation free of other catalysts, this offers a tantalizing means of oligonucleotide self-elongation that might have implications in prebiotic life. We present here work toward elucidating possible catalytic enhancement by liquid crystalline phase formation. Ligation approaches based on water soluble carbodiimide base activation and photopolymerization will be presented.

[1]This work was supported by NSF MRSEC Grant DMR-0820579.

1:51PM J51.00014 Liquid Crystal Ordering of Random DNA Oligomers , TOMMASO BELLINI, GIULIANO ZANCHETTA, TOMMASO FRACCIA, ROBERTO CERBINO, University of Milan, Milan, ETHAN TSAI, MARK MORAN, GREGORY SMITH, DAVID WALBA, NOEL CLARK, LCMRC, University of Colorado, Boulder, DIPARTIMENTO DI CHIMICA, BIOCHIMICA E BIOTECNOLOGIE, UNIVERSITY OF MILAN, MILAN COLLABORATION, LIQUID CRYSTAL MATERIALS RESEARCH CENTER, UNIVERSITY OF COLORADO, BOULDER COLLABORATION — Concentrated solutions of DNA oligomers (6 to 20 base pairs) organize into chiral nematic (NEM) and columnar (COL) liquid crystal (LC) phases. When the oligomer duplexes are mixed with single strands, LC phase formation proceeds through macroscopic phase separation, as a consequence of the combination of various self-assembly processes including strand pairing, reversible linear aggregation, demixing and LC ordering. We extended our investigation to the case of LC ordering in oligonucleotides whose sequences are partially or entirely randomly chosen, and we observed LC phases even in entirely random 20mers, corresponding to a family of $4^{20} \approx 10^{12}$ different sequences. We have tracked the origin of this behaviour: random sequences pair into generally defected duplexes, a large fraction of them terminating with stretches of unpaired bases (overhangs); overhangs promote linear aggregation of duplexes, with a mean strength depending on the overhang length; LC formation is accompanied by a phase separation where the duplexes with longer overhangs aggregate to form COL LC domains that coexist with an isotropic fluid rich in duplexes whose structure cannot aggregate.

Tuesday, February 28, 2012 11:15AM - 2:15PM –

Session J52 GSNP DFD: Focus Session: Extreme Mechanics - Plates 153C

11:15AM J52.00001 Radial stretching of thin sheets: A prototypical model for morphological complexity , BENNY DAVIDOVITCH, UMass Amherst — The complex morphologies of thin sheets consist of wrinkles, crumples, folds, creases, and blisters. These descriptive words may sound lucid – but do they carry any quantitatively distinguishable content? Following the classical approach of pattern formation theory, we seek to impart a universal meaning to these modes of deformation as distinct types of symmetry-breaking instabilities of a flat, featureless sheet. This idea motivates us to consider the general problem of *axisymmetric stretching* of a sheet. A familiar realization of this problem is the "map maker's conflict": projecting a flat sheet onto a foundation of spherical shape. Another representative realization is the Lame' set-up: exerting a radial tension gradient on a sheet, which may be free-standing or resting on a solid or liquid foundation. I will introduce a set of *generic parameters: bendability, confinement, stiffness, adhesiveness,* that span a phase space for the morphology of radially stretched sheets. In this phase space, wrinkling, crumpling, folding, creasing and blistering could be identified as primary and secondary symmetry-breaking instabilities.

11:27AM J52.00002 Bending of a surface with spontaneous curvature , CATHERINE QUILLIET, PHILIPPE MARMOTTANT, ALEXANDRE FARUTIN, CHAOUQI MISBAH, LIPhy, Univ. Grenoble, France — We interest to curvature deformations that can be described by Helfrich's energy: a quadratic mean curvature term, and a gaussian curvature term. When the surface is not strictly incompressible and presents a nonzero spontaneous mean curvature, we focus on simple cases to show that a priori determination of key features (spontaneous curvature, equilibrium area) may be biased according the expression taken for the energy.

11:39AM J52.00003 Deformations of 2D Random Elastic Networks , HENDRIK FLORIJN, M. VAN DEEN, HENK IMTHORN, MARTIN VAN HECKE, Leiden University, GRANULAR & DISORDERED MEDIA TEAM — We study the linear and nonlinear behavior of random 2D elastic networks at the desktop scale. We demonstrate how to fabricate random networks and characterize them with the lattice coordination number Z. We investigate experimentally if there is a relation between the mechanical response and the lattice coordination number Z of the network.

11:51AM J52.00004 Packing with a twist: from Wrinkles to Scrolls , ARSHAD KUDROLLI, JULIEN CHOPIN, Department of Physics, Clark University — We discuss an experimental investigation of a thin elastic sheet in the form of a ribbon with clamped boundary conditions at both ends which is then subjected to a twist by rotating the ends through a prescribed angle. We find that a wrinkling instability appears even at a small twist angle which depends on the aspect ratio of the ribbon, its bending modulus and initial tension. Using x-ray tomography, we show that the pattern of this first instability has an impact on the folding at larger twist angles which can result in ordered configurations including Fermat scrolls. Still further twisting results in a highly compressive packing as in wringing a towel without application of direct radial compression. Implications for developing yarns with novel mechanical and transport properties [Lima, et al., Science 331, 51 (2011)] will be discussed.

12:03PM J52.00005 Geometry and Mechanics of Chiral Pod Opening[1] , ERAN SHARON, SHAHAF ARMON, The Hebrew University of Jerusalem, EFI EFRATI, University of Chicago, RAZ KUPFERMAN, The Hebrew University of Jerusalem — We study the geometry and mechanics that drive the opening of Bauhinia seeds pods. The pod valve wall consists of two fibrous layers oriented at ± 45° with respect to the pod axis. Upon drying, each of the layers shrinks uniaxially, perpendicularly to the fibers orientation. This active deformation turn the valve into an incompatible sheet with reference saddle-like curvature tensor and a flat (Euclidean) reference metric. These two intrinsic properties are incompatible. The shape is, therefore, selected by a stretching-bending competition. Strips cut from the valve tissue and from synthetic model material adopt various helical configurations. We provide analytical expressions for these configurations in the bending and stretching dominated regimes. Surface measurements show the transition from minimal surfaces (narrow limit) to cylindrical ones (wide limit). Finally, we show how plants use these mechanical principles using different tissue architectures.

[1]Supported by ERC "soft Growth" project and by BSF grant #2008432

12:15PM J52.00006 Flat-twisted-helical transition in composed gel sheets and self assembled chiral molecules[1] , SHAHAF ARMON, ERAN SHARON, Hebrew University, Jerusalem, EFI EFRATI, University of Chicago, RAZ KUPFERMAN, Hebrew University, Jerusalem — We recently presented a new chirality creating mechanism in elastic strips. in such frustrated bodies, the chiral configuration is determined in a competition between bending and stretching energies, controlled by a dimensionless parameter $\tilde{w} = w\sqrt{k/t}$, in which w is the strip's width, t – its thickness and k - the spontaneous curvature. I will show the geometrical and mechanical equivalence between such elastic strips and self assembled molecules made of twisted elements. I will also show experiments in responsive gels, showing how a continuous variation in $\tilde{w}$ yields an ordered shape transition from flat to twisted and helical shapes and to tubes. Similar transitions have been observed in self assembled macromolecules.

[1]This work was supported by Eshkol scholarship of the Israeli ministery of Science and ERC "SoftGrowth" project.

12:27PM J52.00007 Curvature and defects in soft membranes with orientational order[1] , THANH SON NGUYEN, JUN GENG, JONATHAN V. SELINGER, Liquid Crystal Institute, Kent State University — Previous research has demonstrated that soft membranes have a coupling between curvature and in-plane orientational order. Defects in the orientational order can induce curvature, and conversely, curvature leads to an effective geometrical potential acting on defects [1]. Recently, our group has done simulations which show that the interaction between curvature and defects depends on several important issues, including the baseline curvature of the membrane (flat, cylinder, sphere, torus), the phase of the defects (radial or tangential), and the relative contribution of in-plane (intrinsic) vs. out-of-plane (extrinsic) variations of the director [2]. To understand the simulations, we develop a theoretical approach that can address those issues. Using this approach, we calculate the energy of defect structures in curved geometries, and determine how the energy varies as a function of the defect position and separation and the membrane distortions. The interaction energy depends on the relative magnitude of intrinsic vs. extrinsic couplings, and on the mechanical properties of the membrane. This approach provides opportunities to design membranes that will relax into selected shapes. [1] AM Turner et al, Rev Mod Phys 82, 1301 (2010). [2] RLB Selinger et al, J Phys Chem B, in press.

[1]This work was supported by NSF DMR-1106014.

12:39PM J52.00008 Capillary induced buckling of floating sheets , MIGUEL PINEIRUA, JOSE BICO, BENOIT ROMAN, PMMH-ESPCI, NARAYANAN MENON, Umass — When a water droplet is deposited over a thin floating sheet, radial wrinkles appear in the vicinity of the droplet as a result of capillary forces exerted at the contact line [1]. However, determining the stress state at the contact line is still challenging and limits the full description of the wrinkling pattern. In order to avoid this contact line ambiguities, we propose the experimental study of the buckling of a macroscopic annulus floating on the surface of water and submitted to a difference in surface tension between its inner and outer edges. This particular configuration allows to generate radial wrinkles on the membrane with well defined border conditions. The topography of the wrinkled patterns are precisely measured using a synthetic Schlieren technique. Based on the standard buckling theory, we develop scaling laws for the buckling threshold of the annulus as well as for the wave length and radial extension of the wrinkles, which are compared to our experimental results and numerical simulations.

[1] J. Huang, M. Juszkiewicz, W.H. de Jeu, E. Cerda, T. Emrick, N. Menon, and T.P. Russell. Capillary wrinkling of floating thin polymer films. Science, 317(5838):650-653, 2007.

12:51PM J52.00009 The wrinkle transition of a sheet on a drop , ROBERT SCHROLL, BENNY DAVIDOVITCH, HUNTER KING, NARAYANAN MENON, Physics Department, University of Massachusetts — A thin sheet subject to confinement will wrinkle in order to relieve compressive stress. We discuss the case of a circular sheet living on the surface of a liquid drop. The pressure of the drop forces the sheet to be non-planar, which may induce confinement along the outer edge of the sheet. We show that, in the limit of very thin, highly bendable sheets, the system is governed by a single confinement parameter. This parameter determines if and where wrinkles appear on the sheet. Comparison to experimental results provides the first detailed confirmation of a new far-from-threshold theory to describe such ultra-thin sheets. According to this model, the transition to the wrinkled state represents the loss of axisymmetry in the height field, while the stress field maintains its symmetry.

1:03PM J52.00010 Transition from Wrinkling to Crumpling in a Sheet Floating on a Drop[1] , HUNTER KING, NARAYANAN MENON, ROBERT SCHROLL, BENNY DAVIDOVITCH, University of Massachusetts, Amherst — An ultrathin* circular polystyrene sheet floating on the surface of a water drop stretches radially and compresses along its circumference as the curvature of the drop increases. The compression is at first fully relaxed by a wrinkle pattern extending inward from the edge. When the wrinkles occupy too large a fraction of the area of the sheet, sharp, localized, crumpled features continuously emerge. We show that the onset of crumpling is a primary symmetry breaking transition of the stress field. We experimentally characterize this transition from wrinkling to crumpling by studying the distribution of gaussian curvature in the film, measured by optical profilometry. *Typical dimensions are tens of nanometers in thickness and millimeters in lateral size.

[1]NSF DMR 0907245

1:15PM J52.00011 Supported conical defects , EFI EFRATI, University of Chicago — In this work we study the elastic equilibrium configurations of a hyperbolic conical defect (a flat disc with a single negative Gaussian curvature condensation), supported on a rigid plane. Originating from the study of strictureplasty, this problem which seems to be a natural extension to the D-cone problem displays a distinct behavior.

1:27PM J52.00012 Stamping and wrinkling of elastic plates , JEREMY HURE, JOSE BICO, BENOIT ROMAN, PMMH - ESPCI ParisTech — In classical Euler buckling a beam is found to buckle with the lowest mode as a compressive strain is applied. Higher modes are however observed if the amplitude of the out-of-plane displacement is bounded by geometrical constraints. What is the limit when the maximum amplitude prescribed is decreased to zero? We show that the wavelength tends towards a finite value dictated by the thickness of the beam. This one-dimensional model is used to describe the compression of a circular elastic plate into an hemispherical mold.

1:39PM J52.00013 Deterministic Wrinkling Patterns of Thin Polymeric Coatings on Soft Substrates , JIE YIN, Department of Mechanical Engineering, Massachusetts Institute of Technology, JOSE L. YAGUE, Department of Chemical Engineering,Massachusetts Institute of Technology, KAREN K. GLEASON, Department of Chemical Engineering, Massachusetts Institute of Technology, MARY C. BOYCE, Department of Mechanical Engineering, Massachusetts Institute of Technology — Wrinkling surface patterns in soft materials have become increasingly important for a broad range of applications including stretchable electronics, microfluidics, thin-film property measurement, wetting and adhesion, and other surface area and topology controlled phenomena. Thermal and swelling mismatch between the thin surface layer and the soft substrate lead to spontaneous formation of buckling-induced disordered labyrinth patterns, which exhibit a mechanistically-determined short wavelength, but an undetermined and highly varied long wavelength. In this paper, analytical and computational models are presented to create deterministic wrinkling patterns through directed buckling methods, which capture the physics of the instabilities governing the formation of multiple wavelength wrinkling patterns, providing a predictive tool for design of deterministic wrinkling patterns. The fabrication of the deterministic patterns is accomplished using novel chemical vapor deposition processes. The role of these patterns in providing multifunctional performance is illustrated and discussed.

1:51PM J52.00014 Wrinkles in reinforced membranes , ATSUSHI TAKEI, ESPCI, FABIAN BRAU, Université de Mons, BENOÎT ROMAN, JOSÉ BICO, ESPCI — We study, through model experiments, the buckling under tension of an elastic membrane reinforced with a more rigid strip or a fiber. In these systems, the compression of the rigid layer is induced through Poisson contraction as the membrane is stretched perpendicularly to the strip. Although strips always lead to out-of-plane wrinkles, we observe a transition from out-of-plane to in plane wrinkles beyond a critical strain in the case of fibers embedded into the elastic membranes. The same transition is also found when the membrane is reinforced with a wall of the same material depending on the aspect ratio of the wall. We describe through scaling laws the evolution of the morphology of the wrinkles and the different transitions as a function of material properties and stretching strain.

2:03PM J52.00015 Mechanics of Graphene Electronics[1] , XUANHE ZHAO, Soft Active Materials Laboratory, Duke University — Graphene, a monolayer of tightly-packed carbon atoms, has demonstrated great academic and industrial promises for integrating superior properties of nanomaterials and nanostructures into novel macroscale devices. Here, we demonstrate a simple method to enable over 200% reversible deformation of continuous large-area graphene sheet (over 1cm x 1cm) on polymer substrates. By patternning large-area graphene on a pre-stretched polymer layer by 200%, the graphene film develops hierachical patterns including wrinkles with wavelengthes on the order 10$\sim$100 nm and delaminated buckles with wavelengths on the the order of 1μm. If the polymer is stretched again (<100%), the wrinkled region relaxes and the graphene on this region becomes flat. As the stretch further increases (over 100%), the graphene on delaminated buckles slides toward the flat regions, decreasing the amplitude of the buckles. The relaxation of the wrinkles and buckles enables the large deformation of graphene electrode without fracture. We further demonstrate potential applications of the graphene electrodes capable of large deformation. For example, a polymer film can be sandwiched between two graphene electrodes. As a voltage is applied between the two graphene electrodes, the polymer can achieve an actuation strain over 200%.

[1]Funding for this research was provided by the NSF's Research Triangle MRSEC (DMR-1121107) and Pratt School of Engineering at Duke University.

Tuesday, February 28, 2012 2:30PM - 5:30PM –
Session L33 GSNP DFD: Invited Session: Frontiers of Granular Physics 106

2:30PM L33.00001 Packing Nonspherical Particles: All Shapes Are Not Created Equal[1] , SALVATORE TORQUATO, Depatrments of Chemistry and Physics, and Princeton Center for Theoretical Science, Princeton University, Princeton, NJ 08544 — Over the past decade there has been increasing interest in the effects of particle shape on the characteristics of dense particle packings, since deviations from sphericity can lead to more realistic models of granular media, nanostructured materials, and tissue architecture. It is clear the that the broken rotational symmetry of a nonspherical particle is a crucial aspect in determining its resulting packing characteristics, but given the infinite variety of possible shapes (ellipsoids, superballs, regular and irregular polyhedra, etc.) it is desirable to formulate packing organizing principles based the particle shape. Such principles are beginning to be elucidated; see Refs. 1 and 2 and references therein. Depending upon whether the particle has central symmetry, inequivalent principle axes, and smooth or flat surfaces, we can describe the nature of its densest packing (which is typically periodic) as well as its disordered jammed states (which may or may not be isostatic). Changing the shape of a particle can dramatically alter its packing attributes. This tunability capability via particle shape could be used to tailor many-particle systems (e.g., colloids and granular media) to have designed crystal, liquid and glassy states.

[1] S. Torquato and F. H. Stillinger, "Jammed Hard-Particle Packings: From Kepler to Bernal and Beyond," *Rev. Modern Phys.* **82**, 2633 (2010).
[2] Y. Jiao and S. Torquato, Communication: "A Packing of Truncated Tetrahedra That Nearly Fills All of Space and its Melting Properties," *J. Chem. Phys.* **135**, 151101 (2011).

[1]This work was supported by the Materials Research Science and Engineering Center (MRSEC) Program of the National Science Foundation under Grant No. DMR-0820341.

3:06PM L33.00002 Network Analysis of Granular Flows , MICHELLE GIRVAN, University of Maryland — The flow of granular materials is important to many natural and industrial processes, yet connecting microscale materials properties of grains to bulk flow behavior has remained a challenging task. Our work leverages tools from complex network theory to study granular flow at multiple scales. By characterizing the statistical properties of time-evolving contact networks using metrics like average path length, giant component size, and modularity, we are able to identify how macroscale system features like the loss of reversibility are connected to micro- and meso- scale rearrangements in the contact network. In addition, we employ a network-based approach to explore the role of rotations in facilitating cooperative rearrangements. For both the reversibility and rotation studies, we apply network analysis to time-dependent contact network data obtained from both experiments and simulations and show that this approach can provide new insights on how bulk system properties are connected to particle-scale motion.

3:42PM L33.00003 Swimming in a granular frictional fluid[1] , DANIEL GOLDMAN, School of Physics, Georgia Institute of Technology — X-ray imaging reveals that the sandfish lizard swims within granular media (sand) using axial body undulations to propel itself without the use of limbs. To model the locomotion of the sandfish, we previously developed an empirical resistive force theory (RFT), a numerical sandfish model coupled to an experimentally validated Discrete Element Method (DEM) model of the granular medium, and a physical robot model. The models reveal that only grains close to the swimmer are fluidized, and that the thrust and drag forces are dominated by frictional interactions among grains and the intruder. In this talk I will use these models to discuss principles of swimming within these granular "frictional fluids". The empirical drag force laws are measured as the steady-state forces on a small cylinder oriented at different angles relative to the displacement direction. Unlike in Newtonian fluids, resistive forces are independent of speed. Drag forces resemble those in viscous fluids while the ratio of thrust to drag forces is always larger in the granular media than in viscous fluids. Using the force laws as inputs, the RFT overestimates swimming speed by approximately 20%. The simulation reveals that this is related to the non-instantaneous increase in force during reversals of body segments. Despite the inaccuracy of the steady-state assumption, we use the force laws and a recently developed geometric mechanics theory to predict optimal gaits for a model system that has been well-studied in Newtonian fluids, the three-link swimmer. The combination of the geometric theory and the force laws allows us to generate a kinematic relationship between the swimmer's shape and position velocities and to construct connection vector field and constraint curvature function visualizations of the system dynamics. From these we predict optimal gaits for forward, lateral and rotational motion. Experiment and simulation are in accord with the theoretical prediction, and demonstrate that swimming in sand can be viewed as movement in a localized frictional fluid.

[1]Work supported by NSF Physics of Living Systems

4:18PM L33.00004 Geometrically Cohesive Granular Materials[1] , SCOTT FRANKLIN, Rochester Institute of Technology — Geometrically cohesive granular materials (GCGM) are collections of particles whose individual shape leads to entanglements that resist extension forces, resulting in a non-zero Young's modulus. Examples include long, thin (anisometric) rods, arcs of varying length, and U-shaped staples. I will report on experimental and computational work that investigates the peculiar rigidity of GCGM. These include canonical stress-strain and vibration-induced melting experiments on U-shaped staples that have revealed a non-monotonic dependence of collective rigidity on particle shape. For concave particles, rigidity appears proportional to an "entanglement number" — the number of neighbors that pass through the area partially bounded by the particle. Computational and analytic work on arcs and staples confirm the non-monotonic behavior of the entanglement number, and simulations that match the experimental conditions are underway to confirm entanglement as the basic mechanism of GCGM's rigidity.

[1]This work funded in part by the National Science Foundation and Donors from the Petroleum Research Fund.

4:54PM L33.00005 Strain-stiffening in random packings of entangled granular chains[1] , ERIC BROWN, University of California, Merced — Random packings of granular chains are presented as a model polymer system to investigate the consequences of entanglements in the absence of Brownian motion. The packings are compressed uniaxially and the structure is characterized by x-ray tomography. For short chain lengths, these packings yield when the shear stress exceeds the scale of the confining pressure, similar to packings of spherical particles. In contrast, packings of chains which are long enough to bend into closed loops exhibit strain-stiffening, in which the effective stiffness of the material increases with strain, similar to many polymer materials. The latter packings can sustain stresses orders-of-magnitude greater than the confining pressure, and do not yield until the chain links break. These strain-stiffening packings are found to contain system-spanning clusters of entangled chains.

[1]This work was done with Alice Nasto, Athanasios G. Athanassiadis, and Heinrich M. Jaeger at The University of Chicago

Tuesday, February 28, 2012 2:30PM - 5:30PM –

Session L41 DFD: Pattern Formation, Nonlinear Dynamics, Computational Fluid Dynamics

156B

2:30PM L41.00001 A Thermodynamic Model for Behavioral Intelligence , ALEXANDER WISSNER-GROSS, CAMERON FREER, Massachusetts Institute of Technology — Recent advances in cosmology and computer science have hinted at a potentially deep connection between intelligence and thermodynamics. Here we attempt to elucidate that connection by showing that a generalization of entropic forces can induce archetypically intelligent behaviors in a variety of classical mechanical systems. These results suggest a simple, but general, thermodynamic model for behavioral intelligence.

2:42PM L41.00002 Data collapse and critical dynamics in neuronal avalanche data , THOMAS BUTLER, Massachusetts Institute of Technology, NIR FRIEDMAN, KARIN DAHMEN, University of Illinois at Urbana-Champaign, JOHN BEGGS, Indiana University, LEE DEVILLE, University of Illinois at Urbana-Champaign, SHINYA ITO, Indiana University — The tasks of information processing, computation, and response to stimuli require neural computation to be remarkably flexible and diverse. To optimally satisfy the demands of neural computation, neuronal networks have been hypothesized to operate near a non-equilibrium critical point. In spite of their importance for neural dynamics, experimental evidence for critical dynamics has been primarily limited to power law statistics that can also emerge from non-critical mechanisms. By tracking the firing of large numbers of synaptically connected cortical neurons and comparing the resulting data to the predictions of critical phenomena, we show that cortical tissues in vitro can function near criticality. Among the most striking predictions of critical dynamics is that the mean temporal profiles of avalanches of widely varying durations are quantitatively described by a single universal scaling function (data collapse). We show for the first time that this prediction is confirmed in neuronal networks. We also show that the data have three additional features predicted by critical phenomena: approximate power law distributions of avalanche sizes and durations, samples in subcritical and supercritical phases, and scaling laws between anomalous exponents.

2:54PM L41.00003 Self Organized Criticality as a new paradigm of sleep regulation[1] , PLAMEN CH. IVANOV, RONNY P. BARTSCH, Harvard Medical School and Division of Sleep Medicine, Brigham and Womens Hospital, Boston, MA 02115, USA — Humans and animals often exhibit brief awakenings from sleep (arousals), which are traditionally viewed as random disruptions of sleep caused by external stimuli or pathologic perturbations. However, our recent findings show that arousals exhibit complex temporal organization and scale-invariant behavior, characterized by a power-law probability distribution for their durations, while sleep stage durations exhibit exponential behavior. The co-existence of both scale-invariant and exponential processes generated by a single regulatory mechanism has not been observed in physiological systems until now. Such co-existence resembles the dynamical features of non-equilibrium systems exhibiting self-organized criticality (SOC). Our empirical analysis and modeling approaches based on modern concepts from statistical physics indicate that arousals are an integral part of sleep regulation and may be necessary to maintain and regulate healthy sleep by releasing accumulated excitations in the regulatory neuronal networks, following a SOC-type temporal organization.

[1]Supported by: NIH Grant 1R01HL098437-01A1, Office of Naval Research Grant 000141010078, Brigham and Womens Hospital BRI Fund and the German Academic Exchange Service (DAAD).

3:06PM L41.00004 Frost nucleation, growth and propagation on a hydrophobic surface[1] , JOSÉ GUADARRAMA-CETINA, University of Navarra, ANNE MONGRUEL, PMMH, UMR 7636 CNRS-ESPCI-University Paris 6-University Paris 7, WENCESLAO GONZÁLEZ-VIÑAS, University of Navarra, DANIEL BEYSENS, PMMH, UMR 7636 CNRS-ESPCI-University Paris 6-University Paris 7 and CEA-Grenoble — We report experimental results on the condensation of water vapor on a substrate (-9 °C) at supercooled conditions. The resulting breath figure grows until the liquid to solid phase transition takes place. The frost seeds start to grow by deposition at the expense of neighboring supercooled water drops that evaporate. Sometimes the propagation (due to the growth of the ice) is faster than the evaporation of the drops, hence they transit to the solid state via a percolation mechanism. In this work [1], we analyze the growth of supercooled condensed drops (first stage), the growth of the ice crystals and the evolution of the supercooled water drops (intermediate and late stages). We also consider the liquid - solid front propagation (growth of the frost figure).

[1] J. Guadarrama-Cetina, A. Mongruel, W. González-Viñas, D. Beysens. In preparation

[1]This work is partly supported by the Spanish Government (contract No. FIS2008-01126). J.G. acknowledges the financial support from the "Asociación de Amigos de la Universidad de Navarra".

3:18PM L41.00005 Pattern formation in oscillatory fluid flows , DAPHNE KLOTSA, University of Michigan, MICHAEL SWIFT, University of Nottingham — Rigid spherical particles in oscillating fluid flows form interesting structures as a result of fluid mediated interactions. Here we show that two spheres under horizontal vibration align themselves at right angles to the oscillation and sit with a gap between them, which scales in a non-classical way with the boundary layer thickness. The details of this behavior have been investigated through experiments and simulations. We then look at a collection of spherical particles, which form chains perpendicular to the direction of oscillation. Comparing experiments and simulations we study the stages of evolution from a dispersed initial configuration to an ordered chain structure. We investigate the details of the interactions and find that the nonlinear hydrodynamic effect of steady streaming is the driving force.

3:30PM L41.00006 Dynamic effects induced by renormalization in anisotropic pattern forming systems , MATTEO NICOLI, Physique de la Matière Condensée, École Polytechnique, CNRS, Palaiseau, France, ADRIAN KELLER, STEFAN FACSKO, Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany, RODOLFO CUERNO, Departamento de Matemáticas and Grupo Interdisciplinar de Sistemas Complejos, Universidad Carlos III de Madrid, Leganés, Spain — The dynamics of patterns in large two-dimensional domains remains a challenge in nonequilibrium phenomena. Often it is addressed through mild extensions of one-dimensional equations. We show that full two-dimensional generalizations of the latter can lead to unexpected dynamic behavior. As an example we consider the anisotropic Kuramoto-Sivashinsky equation, which is a generic model of anisotropic pattern forming systems and has been derived in different instances of thin film dynamics. A rotation of a ripple pattern by 90° occurs in the system evolution when nonlinearities are strongly suppressed along one direction. This effect originates in nonlinear parameter renormalization at different rates in the two system dimensions, showing a dynamic interplay between scale invariance and wavelength selection. Potential experimental realizations of this phenomenon are identified. A. Keller, M. Nicoli, S. Facsko, and R. Cuerno, Phys. Rev. E 84, 015202(R) (2011).

3:42PM L41.00007 Self-Sustained Front Propagation in Disordered Flow , SEVERINE ATIS, HAROLD AURADOU, CNRS, DOMINIQUE SALIN, UPMC, LAURENT TALON, CNRS — We generate propagative fronts resulting from a balance between molecular diffusion and non-linear chemical reaction. These fronts behave as solitary waves with a constant velocity and a stationary concentration profile. The interaction between this self-sustained system and a disordered flow leads to complex structures formation. We have performed experiments of the front propagation over a wide range of stochastic flow rates, in porous media. We have determined the structure and the velocity distribution measured along the front. The concentration profile displays salient spatial features such as scaling laws and pattern formation.

3:54PM L41.00008 Sidebranching in the Dendritic Crystal Growth of Ammonium Chloride , ANDREW DOUGHERTY, Lafayette College — We report measurements of the dendritic crystal growth of NH_4Cl from supersaturated aqueous solution at small supersaturations. Sidebranch growth in this regime is challenging to model well, and the origin of the sidebranches is not fully understood. The early detection of sidebranches requires measurements of small deviations from the smooth steady state shape, but that shape is not well known at the intermediate distances relevant for sidebranch measurements. One model is that sidebranches result from the selective amplification of microscopic noise. We compare measurements of the sidebranch envelope with predictions of the noise-induced sidebranching model of González-Cinca, Ramírez-Piscina, Casademunt, and Hernández-Machado [Phys Rev. E, 63, 051602 (2001)]. We find that the measured amplitude is somewhat larger than predicted, and the shape of the sidebranch envelope is also different. A second model is that sidebranches result from small oscillations of the tip. We have observed no such oscillations, but very small ones can not be ruled out. No measurement of the tip region can be completely free of contamination from early sidebranches, so it can be challenging to distinguish between an oscillating tip and a smooth tip with sidebranches starting nearby.

4:06PM L41.00009 Burning invariant manifolds in spatially disordered advection-reaction-diffusion[1] , DYLAN BARGTEIL, Bucknell University/University of Maryland, TOM SOLOMON, Bucknell University, JOHN MAHONEY, KEVIN MITCHELL, University of California, Merced — We introduce burning invariant manifolds (BIMs) which act as barriers to front propagation, similar to the role played by invariant manifolds as barriers to passive transport in two-dimensional flows. We present experimental studies of BIMs in a spatially disordered, time-independent flow. We generate the flow with a magnetohydrodynamic technique that uses a DC current and a disordered pattern of permanent magnets. The velocity field is determined from this flow using particle tracking velocimetry, and reaction fronts are produced using the Ferroin-catalyzed Belousov-Zhabotinsky (BZ) chemical reaction. We use the experimental velocity field and a three-dimensional set of ODEs to predict from theory the location and orientation of BIMs. These predicted BIMs are found to match up well with the propagation barriers observed experimentally in the same flow using the BZ reaction. We explore the nature of BIMs as one-sided barriers, in contrast to invariant manifolds that act as barriers for passive transport in all directions. We also explore the role of projection singularities in the theory and how these singularities affect front behavior.

[1]NSF Grants DMR-0071771, PHY-0552790

4:18PM L41.00010 Chaotic advection of immiscible fluids[1] , BENJAMIN VOLLMAYR-LEE, Bucknell University, DANIEL BELLER, University of Pennsylvania, SOHEI YASUDA, Purdue University — We consider a system of two immiscible fluids advected by a chaotic flow field. A nonequilibrium steady state arises from the competition between the coarsening of the immiscible fluids and the domain bursting caused by the chaotic flow. It has been established that the average domain size in this steady state scales as a inverse power of the Lyapunov exponent. We examine the issue of local structure and look for correlations between the local domain size and the finite-time Lyapunov exponent (FTLE) field. For a variety of chaotic flows, we consistently find the domains to be smallest in regions where the FTLE field is maximal. This raises the possibility of making universal predictions of steady-state characteristics based on Lyapunov analysis of the flow field.

[1]Supported by NSF grant REU-0552790

4:30PM L41.00011 Hamiltonian traffic dynamics in microfluidic-loop networks , RAPHAEL JEANNERET, DENIS BARTOLO, PMMH-ESPCI, Université Paris Diderot, BARTOLO TEAM — Recent microfluidic experiments revealed that large particles advected in a fluidic loop display long-range hydrodynamic interactions. However, the consequences of such couplings on the traffic dynamics in more complex networks remain poorly understood. In this letter, we focus on the transport of a finite number of particles in one-dimensional loop networks. By combining numerical, theoretical, and experimental efforts, we evidence that this collective process offers a unique example of Hamiltonian dynamics for hydrodynamically interacting particles. In addition, we show that the asymptotic trajectories are necessarily reciprocal despite the microscopic traffic rules explicitly break the time reversal symmetry. We exploit these two remarkable properties to account for the salient features of the effective three-particle interaction induced by the exploration of fluidic loops.

4:42PM L41.00012 Intensity statistics of branched flow , JAKOB METZGER, RAGNAR FLEISCHMANN, THEO GEISEL, Max-Planck-Institute for Dynamics and Self-Organization, Goettingen, Germany — Branched flow is a universal phenomenon of particle and wave flows which are subjected to weak, correlated disorder. It has been observed on length scales ranging from a few micrometres, affecting the transport properties of semiconductor devices [1], up to several thousand kilometres, influencing sound propagation through the ocean [2]. It is also responsible for the appearance of large and hazardous freak waves and tsunamis [3]. While the statistics of the number of such branches has recently been calculated [4], the influence on the statistics of the intensity of the waves remains an open question [5]. Here, we show how the classical ray intensity impacts on the wave intensity statistics, and illuminate the role played by the decoherence of the wavefunction.

[1] Topinka et al., Nature 410, 183 (2001), Jura et al., Nat. Phys. 3, 841 (2007)
[2] Wolfson & Tomsovich, J. Acous. Soc. Am. 109, 2693 (2001)
[3] Berry, Proc. R. Soc. A 463, 3055 (2007); Heller et al., J. Geophys. Res. 113, C09023 (2008)
[4] Metzger, Fleischmann and Geisel, Phys. Rev. Lett. 105, 020601 (2010)
[5] Höhmann et al., Phys. Rev. Lett. 104, 093901 (2010), Arecchi et al., Phys. Rev. Lett. 106, 153901 (2011), Ying et al., Nonlinearity 24, R67 (2011)

4:54PM L41.00013 Flow past a circular cylinder with momentum injection: Optimal control cylinder design , SUBHASH REDDY, PRASAD PATNAIK, Indian Institute of Technology, Madras — The primary aim of this work is to suppress vortex shedding behind a circular cylinder by placing two small rotating control cylinders very close to it and hence injecting momentum into the boundary layer. The position and circulation strengths of the control cylinders are the important aspects of our study. Solving the complete Navier-Stokes (NS) equations can be time consuming while identifying the position and circulation strength of the control cylinders. Instead, reduced order models (ROM) can be used to save the computational expenditure associated with solving the complete NS model. Physics-based approaches to reduced order modeling include many of the techniques for modeling and simplification commonly used in fluid dynamics analysis such as potential flow analysis, vortex methods etc. Each of these are approximations to the full NS equations and each can serve as effective ROMs under appropriate conditions. In the present study, we try to achieve potential flow behavior by optimum positioning of the control cylinders and hence potential flow analysis is carried out with different analytical methods like Föppl vortex model and conformal mapping techniques. For these optimum values, the analytical solution obtained is compared with the numerical viscous flow simulations.

5:06PM L41.00014 ABSTRACT WITHDRAWN —

5:18PM L41.00015 Simulating Tablet Dissolution in Complex Hydrodynamic Environment with Lattice-Boltzmann Method , ARPON RAKSIT, Harvard University, NING SUN, VADIM POZIN, DILIP GERSAPPE, Department of Materials Science and Engineering, Stony Brook University — Using the Lattice-Boltzmann method, we developed a 3D mesoscopic model to study the drug-dissolution process in a complex hydrodynamic environment involving spatially varying velocity and shear forces. The results showed turbulent flow in region above tablet, which was also obtained by visualization experiments. The dissolution profiles obtained by incorporating detailed kinetics showed good agreement with case studies from literature. The influence of the paddle speed and the size of the system were studied, and a multicomponent approach was also incorporated. Our results show how that the hydrodynamic environment would affect the dissolution process by changing the local concentration of components near the tablet and by the particle erosion under high fluid velocity. The code was also successfully parallelized so that the simulation of comparatively large system is now possible.

Tuesday, February 28, 2012 2:30PM - 5:42PM —

Session L51 DCMP DFD: Self Assembly: Mostly Colloids, Lipids and Surfactants Boston Convention Center 154

2:30PM L51.00001 Basic parameters affecting nanoparticle self-assembly: An experimental approach , CHAKRA JOSHI, The University of Toledo, Department of Chemistry, YEVGEN KRYUKOV, JACQUES AMAR, University of Toledo, Department of Physics and the Wright Center for Photovoltaics Innovation and Commercialization, TERRY BIGIONI, The University of Toledo, Department of Chemistry and the Wright Center for Photovoltaics Innovation and Commercialization — Understanding the basic parameters that govern the nanoparticle self-assembly process is important for high-quality monolayer formation and technological advances. A complete theory that explains nanoparticle self assembly, in the bulk and at the liquid-air interface, is lacking. In this paper, dodecanethiolated gold nanoparticles were used as a model system for studying the forces that govern self assembly. These nanoparticles are known to make compact and highly-ordered monolayers at the liquid-air interface via a mechanism that is analogous to epitaxial growth of atomic layers. Epitaxial theory was used as a starting point to study the nanoparticle self-assembly at the liquid-air interface. Experimental measurements were successfully interpreted using an epitaxy-based analysis, including flux of nanoparticles onto the liquid air-interface, decay rate of the island density, and the dependence of critical nucleus size on nanoparticle diameter. Furthermore, anomalous diffusion was observed as was a remarkable ordering of islands at the liquid-air interface. This ordering was determined to be due to a long-range repulsive force between islands.

2:42PM L51.00002 Self-assembly of gold nanoparticles at water/vapor interface , GARY S. GREST, J. MATTHEW D. LANE, Sandia National Laboratories — The self-assembly of coated gold nanoparticles at the water/vapor interfaces are studied using explicit-atom molecular dynamic simulations. While it is often assumed that uniformly coating spherical nanoparticles with short organic ligands lead to symmetric nanoparticles, we find that the high curvature of small nanoparticle and the relatively short dimensions of the coatings can produce highly asymmetric coatings. At an interface this asymmetry of the ligands tends to orient the nanoparticles with the surface to minimize free energy. First esults for individual gold nanoparticles of diameter 2-8 nm coated with alkanethiol ligands of various lengths and different end group will be presented. Results for the self-assembly of the multiple nanoparticles at the water/vapor interfaces will then be presented for the diameter 2 and 4 nm nanoparticles which show how these asymmetric and oriented coatings affect the interactions between nanoparticles and the structure of the resulting aggregate. Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

2:54PM L51.00003 Electric Field Driven Self-Assembly of Colloidal Rods , JAIME JUAREZ, KUNDAN CHAUDHARY, QIAN CHEN, STEVE GRANICK, JENNIFER LEWIS, Department of Materials Science and Engineering, University of Illinois at Urbana-Champaign — The ability to assemble anisotropic colloidal building blocks into ordered configurations is of both scientific and technological importance. We are studying how electric field-induced interactions guide the self-assembly of these blocks into well aligned microstructures. Specifically, we present observations of the assembly of colloidal silica rods (L/D ~ 4) within planar electrode cells as a function of different electric field parameters. Results from video microscopy and image analysis demonstrate that aligned microstructures form due to the competition between equilibrium interactions of induced dipoles and non-equilibrium processes (i.e., electro-osmosis). Under the appropriate electric field conditions ($\sim$ kHZ AC fields), aligned colloidal rod fluids form over large areas on the electrode surface. The superposition of a DC electric field to this aligned colloidal rod fluid initiates their condensation into a vertically oriented crystalline phase. Ongoing work is now focused on exploring how temporal changes to electric fields influence colloidal rod dynamics and, hence, the assembly kinetics of aligned colloidal monolayers.

3:06PM L51.00004 Electron-induced Three Dimensional Self-assembly and Disassembly of Molecules on a Gold Surface , QING LI, Oak Ridge National Laboratory, CHENGBO HAN, North Carolina State University, MIGUEL FUENTES-CABRERA, HUMBERTO TERRONES, BOBBY SUMPTER, Oak Ridge National Laboratory, JERRY BERNHOLC, North Carolina State University, JIEYU YI, ZHENG GAI, ART BADDORF, PETRO MAKSYMOVYCH, MINGHU PAN, Oak Ridge National Laboratory — The immensely successful methodology of molecular self-assembly on surfaces has produced thousands of new applications and paved ways to new research areas, such as molecular electronics and the dip-pen nanolithography. Here we demonstrate a seminal example of non-thermal control over molecular self-assembly, where hot-electrons transform a largely disordered layer of hydrocarbon molecules, into a highly ordered, densely packed and three-dimensional monolayer on a gold surface. Subsequently, hot-electron/hot-hole injection can heal the defects within the self-assembled layer, and even entirely and reversibly disassemble it. From a theoretical analysis we have identified that electron-induced processes allow the formation of a very strongly-bonded molecule, and yet it is inaccessible by thermally-activated reactions due to a large number of competing processes. This work thus demonstrates the feasibility of accessing and controlling non-thermal reaction pathways that may lead to unique and controllable order-disorder transitions in supported molecular layers.

3:18PM L51.00005 Self assembly of anisotropic colloidal particles , DANIEL FLOREA, HANS WYSS, Eindhoven Technical University — Colloidal particles have been successfully used as "model atoms", as their behavior can be more directly studied than that of atoms or molecules by direct imaging in a confocal microscope. Most studies have focussed on spherical particles with isotropic interactions. However, a range of interesting materials such as many supramolecular polymers or biopolymers exhibit highly directional interactions. To capture their behavior in colloidal model systems, particles with anisotropic interactions are clearly required. Here we use a colloidal system of nonspherical colloids, where highly directional interactions can be induced via depletion. By biaxially stretching spherical PMMA particles we create oblate spheroidal particles. We induce attractive interactions between these particles by adding a non-adsorbing polymer to the background liquid. The resulting depletion interaction is stronger along the minor axis of the oblate spheroids. We study the phase behavior of these materials as a function of the ellipsoid aspect ratio, the strength of the depletion interactions, and the particle concentration. The resulting morphologies are qualitatively different from those observed with spherical particles. This can be exploited for creating new materials with tailored structures.

3:30PM L51.00006 Adsorption of Core-Shell Nanoparticles at Liquid-Liquid Interfaces , EMANUELA DEL GADO, LUCIO ISA, ETH Zurich, ESTHER AMSTAD, Harvard, KONRAD SCHWENKE, PATRICK ILG, MARTIN KROEGER, ETH Zurich, ERIK REIMHULT, BOKU Wien, SURFACE TECHNOLOGY, ETH ZURICH TEAM, MICROSTRUCTURE AND RHEOLOGY, ETH ZURICH TEAM, POLYMER PHYSICS, ETH ZURICH TEAM, NANOBIOTECHNOLOGY, BOKU TEAM — The use of nanoparticles as building blocks for the self-assembly of functional materials has been rapidly increasing in recent years. In particular, two-dimensional materials can be effectively self-assembled at liquid interfaces thanks to particle localization and mobility at the interface in combination with tailoring of specific interactions. Many recent advances have been made in the understanding of the adsorption and assembly at liquid interfaces of small hydrophobic nanoparticles, stabilized by short-chain rigid dispersants, but the corresponding studies on core-shell nanoparticles sterically stabilized by extended hydrophilic polymer brushes are presently missing. Such particles offer significant advantages in terms of fabrication of functional, responsive and bio-compatible materials. We present here a combination of experimental and numerical data together with an intuitive and simple model aimed at elucidating the mechanisms governing the adsorption of iron oxide nanparticles (5-10nm) stabilized by low molecular weight poly(ethylene glycol) (1.5-10 kDa). We show that the adsorption dynamics and the structure of the final assembly depend on the free energy of the particles at the interface and discuss the thermodynamics of the adsorpt

3:42PM L51.00007 ABSTRACT WITHDRAWN —

3:54PM L51.00008 Encapsulation by Janus Oblate Spheroids[1] , WEI LI, YA LIU, Lehigh University, GENEVIEVE BRETT, Skidmore College, JAMES GUNTON, Lehigh University — The micro/nano encapsulation technology has acquired considerable attention in the fields of drug delivery, biomaterial engineering, and material science. Based on recent advances in chemical particle synthesis, we propose a preliminary model of encapsulation system inducted by self-assembly of Janus oblate ellipsoids, the particles with oblate ellipsoidal cores and two semi-surfaces coded with dissimilar chemical properties. Using Monte Carlo simulation, we investigate the encapsulation system with spherical particles as encapsulated guests in different densities. We study the anisotropic effect brought by encapsulating agent's geometric shape and chemical composition on encapsulation morphology and efficiency. In the relative high encapsulation efficiency we observe from the simulation, we believe this method of encapsulation is of potential value in practical use.

[1]This work was supported by grants from the Mathers Foundation and the National Science Foundation (Grant DMR-0702890). One of us (GB) was supported by the NSF REU Site Grant in Physics at Lehigh University.

4:06PM L51.00009 Particle Deposition in Drying Drops of Colloidal Suspensions Containing Different Surfactants[1] , TIM STILL, PETER J. YUNKER, A.G. YODH, University of Pennsylvania — When a drop of water containing small solid particles dries, most of the solid material is deposited in a ring-shape stain after evaporation (the so-called coffee ring), driven by initial contact line pinning and a subsequent outward-flow. The fluid dynamics and, hence, the deposition mechanism in such suspensions can be dramatically changed when surfactants are introduced into the system. In a colloidal model-system, the ionic sodium dodecyl sulfate (SDS) produces a concentration-driven Marangoni flow counteracting the outward-flow of the coffee ring effect. SDS locally concentrates at the air/water interface next to the contact line, leading to a reduced local surface tension. Thus, a circulating flow ('Marangoni eddy') is introduced that prevents particles from deposition. This flow is visualized by the movements of the dragged particles using video microscopy. Other surfactants can influence this highly non-equilibrium systems in completely other ways. E.g., the non-ionic Polaxamer block-copolymer surfactants lead to a uniform particle deposition, which we explain by hydrophilization of the colloidal particles. Controlling the solid deposition in drying drops is of major importance for many technical applications.

[1]We acknowledge financial support from MRSEC DMR11-20901 and DAAD.

4:18PM L51.00010 Formation of Lipid-Based Nanodiscs and Their Dependence of Temperature and Chemical Composition[1] , YING LIU, YONGKUN YANG, MU-PING NIEH, UNIVESITY OF CONNECTICUT — Phospholipid mixtures composed of *1,2-dipalmitoyl-sn-glycero-3-phosphocholine* (DPPC), *1,2-dihexanoyl-sn-glycero-3-phosphocholine* (DHPC) and *1,2-dipalmitoyl-sn-glycero-3-phospho-(1'-rac-glycerol) (sodium salt)*(DPPG) and *1,2-distearoyl-sn-glycero-3-phosphoethanolamine-N-[methoxy(polyethylene glycol)-2000] (ammonium salt)* (PEGylated DSPE) and cholestrol were found to form nanodiscs (bicelles) in both non-ionic and phosphate buffer solutions . The structure of the aggregates is resolved using dynamic light scattering, transmission electron microscopy and small angle neutron scattering. The effects of temperature and chemical composition (e.g., PEGylated DSPE and cholesterol) on the structural variation and polydispersity will be discussed in this presentation. These nanodiscs have the potential of serving as a model delivery carrier for hydrophobic molecules for their biological compatibility and capability of incorporating with targeting molecules.

[1]Thanks NSF - CMMI 1131589

4:30PM L51.00011 How to control GUV shape transformations , KEJIA CHEN, ADAM SZMELTER, SUNG CHUL BAE, STEVE GRANICK, University of Illinois at Urbana-Champaign — Using a microfluidic platform, we expose giant unilamellar vesicles (GUVs) to programmed time-varying profiles of osmotic pressure. In response to these conditions that intentionally do not approach equilibrium, water flows in and out, and the excess area changes in response. Shape transformations are observed that were not previously reported, nor predicted theoretically.

4:42PM L51.00012 Aqueous Gemini Surfactant Self-Assembly into Complex Lyotropic Phases , MAHESH MAHANTHAPPA, GREGORY SORENSON, Department of Chemistry, University of Wisconsin-Madison, 1101 University Ave., Madison, WI 53703 — In spite of the potentially wide-ranging applications of aqueous bicontinuous lyotropic liquid crystals (LLCs), the discovery of amphiphiles that reliably form these non-constant mean curvature morphologies over large phase windows remains largely serendipitous. Recent work has established that cationic gemini surfactants exhibit a pronounced tendency to form bicontinuous cubic (e.g. gyroid) phases as compared to their parent single-tail amphiphiles. The universality of this phenomenon in other surfactant systems remains untested. In this paper, we will report the aqueous LLC phase behavior of a new class of anionic gemini surfactants derived from long chain carboxylic acids. Our studies show that these new surfactants favor the formation of non-constant mean curvature gyroid and primitive ("Plumber's Nightmare") structures over amphiphile concentration windows up to 20 wt% wide. Based on these observations, we will discuss insights gained into the delicate force balance governing the self-assembly of these surfactants into aqueous bicontinuous LLCs.

4:54PM L51.00013 Shear-Driven Circulation Patterns in Lipid Membrane Vesicles , FRANCIS WOODHOUSE, AURELIA HONERKAMP-SMITH, RAYMOND GOLDSTEIN, DAMTP, University of Cambridge — Recent experiments [C. Vézy, G. Massiera, and A. Viallat, Soft Matter 3, 844 (2007)] have shown that when a near-hemispherical lipid vesicle attached to a solid surface is subjected to a simple shear flow it exhibits a pattern of membrane circulation much like a dipole vortex. This is in marked contrast to the toroidal circulation that would occur in the related problem of a drop of immiscible fluid attached to a surface and subjected to shear. This profound difference in flow patterns arises from the lateral incompressibility of the membrane, which restricts the observable flows to those in which the velocity field in the membrane is two-dimensionally divergence free. We theoretically study these circulation patterns within the simplest model of membrane fluid dynamics. A systematic expansion of the flow field is developed for differing bulk fluid viscosities incorporating a non-zero membrane shear viscosity and curvature effects. It is shown how such studies can allow measurements of the membrane viscosity from flow field data. New experimental results utilising this method are discussed.

5:06PM L51.00014 Self standing nanoparticulate networks by self assembly surfactant H_1 mesophase , GURUSWAMY KUMARASWAMY, NCL, Pune, India, KAMENDRA SHARMA, SAYAM SEN GUPTA, NCL — We show that nanoparticles (size $>$ 10 nm) that are dispersed in nonionic surfactant/water system, assemble into networks on cooling into the H_1 phase, independent of particle surface chemistry. Coating the particles with a crosslinkable polymer, and covalent coupling of the coated particle assemblies in the H1 phase allows us to form free standing particulate networks that are stable after surfactant removal. Thus, dynamic templating of surfactant H_1 domains is a facile technique that involves near ambient temperatures, and a benign water wash for template removal. The network mesh size can be varied from the sub-micron to tens of microns by controlling the cooling rate. Particle networks can be flow-oriented prior to crosslinking, and interpenetrating networks can also be formed. We will show examples of macroporous nanoparticulate networks formed using nanoparticles of inorganic oxides, polymer latices, as well as bionanoparticles such as proteins.

5:18PM L51.00015 SAXS on ice crystals reveals fractal structure on nanometer length scales , JESSE HOPKINS, RYAN BADEAU, MATTHEW WARKENTIN, ROBERT THORNE, Cornell University — We have used small angle x-ray scattering (SAXS) to probe ice formation in supercooled aqueous solutions and water. The SAXS shows that the ice formed in supercooled aqueous solutions and water has power law behavior that is invariant across a wide range of solute type, concentration, and temperature. We interpret this power law as scatter from fractal structures in the ice. The consistency of this power law across four different solutes and in pure water, and at temperatures between 150 K and 220 K suggests an underlying similarity between macroscopically/visually different forms of ice on length scales of 10-100 nm. Time dependent SAXS curves reveal two scattering regimes, one occurring at early times and one dominating at later times, which we interpret within the context of fractal scatterers. Finally, we use scaling collapses on the data to extract information about the time and temperature dependence of the ice growth. We interpret this within the established framework of the ice nucleation and growth community.

5:30PM L51.00016 Molecular Dynamics simulations of flow-structure interactions in fluids containing cylindrical micelles and micelle-nanoparticle complexes[1] , RADHAKRISHNA SURESHKUMAR, Syracuse University, Syracuse, NY, ASHISH SANGWAI, Intel Corporation, Hillboro, OR, ABHINANDEN SAMBASIVAM, Syracuse University, Syracuse, NY, SYRACUSE UNIVERSITY TEAM — Coarse-grained (CG) force fields, benchmarked against fully atomistic ones, are used in Molecular Dynamics simulations to predict shape transitions and binary interactions in cationic surfactant micelles as well as to understand the molecular mechanisms of self-assembly of micelles with noble metal nanoparticles germane to plasmonics. Non-equilibrium MD simulations are conducted to probe the effect of flow shear on cylindrical micelle dynamics and estimate properties such as tumbling frequency, relaxation time and scission energy. Simulations are also performed to understand flow-mediated alignment and merger of two cylindrical micelles which is hypothesized to be the mechanism underlying the formation of shear-induced structures in micellar fluids.

[1]NSF CBET 1049454

Tuesday, February 28, 2012 2:30PM - 5:30PM –
Session L52 GSNP DFD: Focus Session: Extreme Mechanics - Origami, Creasing, and Folding
153C

2:30PM L52.00001 Extreme Folding , ERIK DEMAINE, Massachusetts Institute of Technology — Our understanding of the mathematics and algorithms behind paper folding, and geometric folding in general, has increased dramatically over the past several years. These developments have found a surprisingly broad range of applications. In the art of origami, it has helped spur the technical origami revolution. In engineering and science, it has helped solve problems in areas such as manufacturing, robotics, graphics, and protein folding. On the recreational side, it has led to new kinds of folding puzzles and magic. I will give an overview of the mathematics and algorithms of folding, with a focus on new mathematics and sculpture.

3:06PM L52.00002 Geometry in the mechanics of origami , MARCELO A. DIAS, CHRISTIAN D. SANTANGELO, University of Massachusetts Amherst — We present a mechanical model for curved fold origami in which the bending energies of developable regions are balanced with a phenomenological energy for the crease. The latter energy comes into play as a source of geometric frustration, allowing us to study shape formation by prescribing crease patterns. For a single fold annular configuration, we show how geometry forces a symmetry breaking of the ground state by increasing the width of the ribbon. We extend our model to study multiple fold structures, where we derive geometrical constraints that can be written as recursive relations to build the surface from valley to mountain, and so on. We also suggest a mechanical model for single vertex folds, mapping this problem to an elastica on the sphere.

3:18PM L52.00003 Photo-Origami – Using Light to Bend, Fold, and Buckle[1] , JENNIE RYU, University of Colorado, MATTEO D'AMATO, University of Trento, KEVIN LONG, Sandia National Laboratories, XIAODONG CUI, H. JERRY QI, MARTIN DUNN, University of Colorado — We describe photo-origami, a method to program spatially- and temporally-variable mechanical, chemical, and optical fields into a polymer that enable controllable, sequenced, macroscopic bending and folding to create three-dimensional structures. We combine mechanical and optical stimuli to locally rearrange the polymer's network topology which allows us to program a residual stress state into the film; upon release of mechanical constraints, we realize a wide variety of desired shapes. We demonstrate, through a combination of theory, simulation-based design, synthesis, and experiment, the operative phenomena and capabilities of photo-origami. We demonstrate architectures that rely on bending, folding, instabilities, and post-buckling behavior to achieve their three-dimensional form, starting from a flat sheet. We also describe a theory that couples the hereditary nature of photophysics, chemistry, and large-deformation mechanics and enables simulations of the fabricated structures that are in good agreement with the experiments.

[1]AFOSR, National Science Foundation, Sandia National Laboratories

3:30PM L52.00004 Pleated and Creased Structures[1] , LEVI DUDTE, ZHIYAN WEI, L. MAHADEVAN, Harvard University — The strategic placement of curved folds on a paper annulus produces saddle-shaped origami. These exotic geometries resulting from simple design processes motivate our development of a computational tool to simulate the stretching, bending and folding of thin sheets of material. We seek to understand the shape of the curved origami figure by applying the computational tool to simulate a thin annulus with single or multiple folds. We aim to quantify the static geometry of this simplified model in order to delineate methods for actuation and control of similar developable structures with curved folds. Miura-ori pattern is a periodic pleated structure defined in terms of 2 angles and 2 lengths. The unit cell embodies the basic element in all non-trivial pleated structures - the mountain or valley folds, wherein four folds come together at a single vertex. The ability of this structure to pack and unpack with a few degrees of freedom leads to their use in deployable structures such as solar sails and maps, just as this feature is useful in insect wings, plant leaves and flowers. We probe the qualitative and quantitative aspects of the mechanical behavior of these structures with a view to optimizing material performance.

[1]Grant Acknowledgement: Harvard NSF MRSEC, DARPA, Kavli Institute, Wyss Institute

3:42PM L52.00005 Hierarchical Stress Focusing in Elastic Ridge , LEE WALSH, BENNY DAVIDOVITCH, University of Massachusetts — A crumpled or confined elastic sheet contains many stress-focusing structures and singularities, primarily ridges and vertices, which may contain much of the strain. We seek to determine the degree and quality of stress focusing within the geometry of a single ridge. Previous work on the ridge assumes the asymptotic limit of infinitely sharp vertices. However, in a physically realistic sheet any vertex or intersection of ridges will naturally have a finite radius of curvature greater than the sheet's thickness. We simulate these more physically realistic boundary conditions in a ridge using Surface Evolver.

3:54PM L52.00006 Stress focusing and collapse of a thin film under constant pressure[1] , EUGENIO HAMM, NICOLAS CABEZAS, Universidad de Santiago de Chile — Thin elastic sheets and shells are prone to focus stress when forced, due to their near inextensibility. Singular structures such as ridges, vertices, and folds arising from wrinkles, are characteristic of the deformation of such systems. Usually the forcing is exerted at the boundaries or at specific points of the surface, in displacement controlled experiments. On the other hand, much of the phenomenology of stress focusing can be found at micro and nanoscales, in physics and biology, making it universal. We will consider the post-buckling regime of a thin elastic sheet that is subjected to a constant normal distributed force. Specifically, we will present experiments made on thin elastoplastic sheets that collapse under atmospheric pressure. For instance, in vacuum-sealing technology, when a flat plastic bag is forced to wrap a solid volume, a series of self-contacts and folds develop. The unfolded bag shows a pattern of scars whose structure is determined by the geometry of the volume and by the exact way it stuck to its surface, by friction. Inspired by this everyday example we study the geometry of folds that result from collapsing a hermetic bag on regular rigid bodies.

[1]Fondecyt 1110584 and Anillo ACT95

4:06PM L52.00007 Creasy modeling of a compressed elastic surface , TUOMAS TALLINEN, L. MAHADEVAN, Harvard University — Compression of an elastic layer attached to a rigid substrate leads to nucleation and growth of creases. We explore crease formation by a numerical model allowing control of compressive strain, anisotropy and bulk modulus. We address questions on arrangement and geometry of creases and model also the stabilizing effect of surface tension at small scales.

4:18PM L52.00008 Creasing instability of elastomers under uniaxial compression , DAYONG CHEN, RYAN HAYWARD, Polymer Science and Engineering Department at UMass-Amherst — Soft polymers placed under compressive stress can undergo an elastic creasing instability in which sharp folds spontaneously form on the free surfaces. This process may play an important role in contexts as diverse as brain morphogenesis, failure of tires, and electrical breakdown of soft polymer actuators, but our understanding of this instability is still quite limited. We describe a simple experimental system to study creasing of thin elastomer films under uniaxial compression. The equilibrium depths, spacings and shapes of creases are characterized and found to show excellent agreements with numerical results. Further, we use this system to explore the important roles played by surface energy and adhesion in the onset and hysteretic behavior of creases.

4:30PM L52.00009 Sulcus formation in a compressed elastic half space , JOHN BIGGINS, L. MAHADEVAN, Harvard University — When a block of rubber, biological tissue or other soft material is subject to substantial compression, its surfaces undergo a folding instability. Rather than having a smooth profile, these folds contain cusps and hence have been called creases or sulcii rather than wrinkles. The stability of a compressed surface was first investigated by Biot (1965), assuming the strains associated with the instability were small. However, the compression threshold predicted with this approach is substantially too high. I will introduce a family of analytic area preserving maps that contain cusps (and hence points of infinite strain) that save energy before the linear stability threshold even at vanishing amplitude. This establishes that there is a region before the linear stability threshold is reached where the system is unstable to infinitesimal perturbations, but that this instability is quintessentially non-linear and cannot be found with linear strain elasticity.

4:42PM L52.00010 Compression induced folding of a sheet: An integrable system , HAIM DIAMANT, Tel Aviv University, THOMAS A. WITTEN, University of Chicago — The apparently intractable shape of a fold in a compressed elastic film lying on a fluid substrate is found to have an exact solution. Such systems buckle at a nonzero wave vector set by the bending stiffness of the film and the weight of the substrate fluid. Our solution describes the entire progression from a weakly displaced sinusoidal buckling to a single large fold that contacts itself. The pressure decrease is exactly quadratic in the lateral displacement. We demonstrate a subtle connection to the sine-Gordon problem, which reveals a new symmetry in the folding phenomenon.

4:54PM L52.00011 Wrinkles or creases in a bi-layer structure , LIHUA JIN, School of Engineering and Applied Sciences, Kavli Institute, Harvard University, ANESIA BURNS, RYAN HAYWARD, Department of Polymer Science & Engineering, University of Massachusetts, ZHIGANG SUO, School of Engineering and Applied Sciences, Kavli Institute, Harvard University — Wrinkles and creases are different modes of instability. In this work, we try to answer for a bi-layer structure with different modulus ratios and thickness ratios of the film and substrate whether wrinkles or creases form first when the bi-layer is under uniform compression. The onset of wrinkles corresponds to a bifurcation point, and we use the linear perturbation method to analyze the critical strain for the onset of wrinkles. Since the initiation of creases is autonomous, we directly apply the critical condition for crease initiation in a half space calculated by the finite element method in the literature to the situation of a bi-layer structure with finite thickness. By comparing the critical strains for the formation of wrinkles and creases under different modulus and thickness ratios, a phase diagram of the formation of wrinkles or creases is obtain. Although the critical strains for both wrinkle and crease initiation depend on the state of strain, remarkably the phase diagram is independent of the state of strain. As a result, creases tend to set in for more compliant and thicker films, while wrinkles tend to set in for stiffer and thinner films. Especially, when the modulus ratio of the film and substrate is smaller than 1.67, creases always form earlier than wrinkles, no matter what the thickness ratio is. We further verify the result experimentally by compressing a bi-layer of polymers with different modulus and thickness ratios.

5:06PM L52.00012 Wrinkles and Folds in Ultra-Thin Polymer Films[1] , YURI EBATA, University of Massachusetts, Amherst, ANDREW B. CROLL, North Dakota State University, ALFRED J. CROSBY, University of Massachusetts, Amherst — Wrinkles and folds are observed in many biological systems during morphogenesis processes. However, the mechanics of how these wrinkles and folds form are not completely understood. Studying the mechanics of wrinkles and folds will not only provide us with fundamental insights of nonlinear deformation processes but also allow for the fabrication of unique patterned surfaces that can be controlled reversibly. In this study, we examine wrinkles and folds of polystyrene films of thickness ranging from 5 nm to 180 nm attached to uniaxially-strained polydimethylsiloxane substrates. The strain is released incrementally to apply increasing compressive strain to the attached film. The wavelength and the amplitude of local out-of-plane deformation are measured as global compression is increased to distinguish between different buckling modes. The transition from wrinkling to folding is observed by tracking the statistics of amplitude distribution sampled across a large lateral area, and a critical strain map is constructed to observe how film thickness affect the resulting buckling modes.

[1]NSF-DMR 0907219

5:18PM L52.00013 Relaxation mechanisms in the unfolding of thin sheets , BENJAMN THIRIA, PMMH-ESPCI, MOKHTAR ADDA-BEDIA, LPS-ENS — When a thin sheet is crumpled, creases form in which plastic deformations are localized. Here we study experimentally the relaxation process of a single fold in a thin sheet subjected to an external strain. The unfolding process is described by a quick opening at first, and then a progressive slow relaxation of the crease. In the latter regime, the necessary force needed to open the folded sheet at a given displacement is found to decrease logarithmically in time, allowing its description through an Arrhenius activation process. We accurately determine the parameters of this law and show its general character by performing experiments on both Mylar and paper sheets.

Wednesday, February 29, 2012 8:00AM - 10:48AM –
Session P41 DFD: Drops, Bubbles and Interfacial Fluid Mechanics 156B

8:00AM P41.00001 The Life and Death of the Air Film Beneath an Impacting Drop , JOHN KOLINSKI, Harvard School of Engineering and Applied Sciences, Cambridge, MA, USA, SHMUEL RUBINSTEIN, Weizmann Institute of Science, Physics of Complex Systems, Rehovot, Israel, L. MAHADEVAN, Harvard School of Engineering and Applied Sciences, Cambridge, MA, USA — Droplet impact is ubiquitous in our everyday experience; yet many mysteries associated with the phenomenon remain, including the role played by air during the impact process. When a liquid meets a solid surface in an atmosphere, it must drain the air beneath it before initiating contact. In spite of the relatively low viscosity of the air, recent experiments and simulations suggest that this drainage dominates the dynamics of drop impact. Here I present recent experimental work, wherein Total Internal Reflection (TIR) microscopy is used to directly observe the thin air films that develop above the impact surface. We find that the formation of the thin air film is insensitive to liquid viscosity over a range of impact velocities, confirming prior theoretical predictions of thin air film formation. Going beyond this, the viscous response of the drop is also found to be important - high viscosity liquids maintain a steep front that progresses outward as the breadth of the air film increases, whereas lower viscosity liquids broaden without a steep front, suggesting a transition in the kinematics of the air liquid interface.

8:12AM P41.00002 Manipulating Leidenfrost temperature with surface modification , HYUK-MIN KWON, Massachusetts Institute of Technology, JACY BIRD, Boston University, KRIPA VARANASI, Massachusetts Institute of Technology — When a drop contacts a surface that is at a sufficiently high temperature, the drop can float on it's own vapor in a process known as the Leidenfrost effect. Although it is known that the critical temperature needed to achieve this effect depends on the properties of the drop and its vapor, often these parameters are fixed for a particular process. Here, we demonstrate a new way to control the critical temperature through the surface structure.

8:24AM P41.00003 Reducing contact time of drops on superhydrophobic surfaces , R. DHIMAN, J.C. BIRD, H. KWON, K.K. VARANASI, Massachusetts Institute of Technology — When water drops impact on to a superhydrophobic surface, the drops can recoil to such an extent that they completely bounce off the solid material. The time it takes for the drop to spread and recoil the contact time scales with the hydrodynamic inertial-capillary timescale. However, there is evidence that the coefficient of this scaling depends on surface-structure interactions, such as pinning. Here we investigate how surface interactions can influence droplet contact time, and we compare our results to existing models. We highlight an assumption in the current theory that imposes a lower-bound on the contact time. By designing around this constraint, we demonstrate novel superhydrophobic surfaces on which water droplets impact with shorter contact times than previously thought possible.

8:36AM P41.00004 Hydrodynamic self-rectification: A novel mechanism for generating uniform static droplet arrays , SIVA VANAPALLI, SWASTIKA BITHI, MENG SUN, Texas Tech University — Microfluidic static droplet arrays are a powerful means to simultaneously monitor many biochemical reactions in individual drops. We report a new mechanism for generating exceptionally monodisperse microfluidic droplet arrays. When a train of surfactant-free confined droplets are introduced into a fluidic network with hydrodynamic traps, the droplets are immobilized in the traps due to collective hydrodynamic resistive interactions. In the event, that an immobilized drop either under-fills or overfills the trap, we find that subsequent drops rectify its volume through coalescence, followed by break-up. This self-rectification mechanism thus yields highly monodisperse static droplet arrays. We map the phase space in terms of drop size, spacing and capillary number and find a broad window where this mechanism operates. Because this mechanism alleviates the need to control drop size and spacing in the train to create arrays, we demonstrate its capability to create static arrays with tuneable drop volumes and variable composition.

8:48AM P41.00005 In Situ Observation of Liquid Capillary Bridges on Superhydrophobic Surfaces , ADAM PAXSON, SUSHANT ANAND, KRIPA VARANASI, MIT — We describe a new technique for observing the dynamic behavior of the contact line of a liquid droplet on a superhydrophobic surface using environmental scanning electron microscopy. We find that on a surface patterned with an array of superhydrophobic micropillars, the receding contact line exhibits discrete hierarchical de-pinning events. As the macroscopic contact line recedes across the pillars, capillary bridges are formed along with microscale contact lines, thus perpetuating a self-similar wetting condition. We are able to measure the local receding angle and find that it follows the Gibbs criterion of depinning. By considering the line density of the microscale features and the pinning strength of each of those features, we relate the macroscopic adhesion force to that derived from a model based on pinning of the capillary bridges.

9:00AM P41.00006 Two particle microrheology of quasi-2D viscous systems in the limit of shallow bulk layer , THIBAUT DIVOUX, Ecole Normale Supérieure de Lyon, 46 allée d'Italie, 69007 Lyon, France, KENNETH DESMOND, JAMES SEBEL, ERIC WEEKS, Department of Physics, Emory University, Atlanta, Georgia 30322, USA — Human serum albumin (HSA) protein molecules at an air-water interface is a model system for which it is difficult to decouple the properties of the 2D interfacial film from those of the 3D fluid. Here we focus on the influence of the bulk confinement (i.e. the thickness of the layer of water) on the dynamics of HSA at an air-water interface. To do so, we have developed a setup which allows us to control the depth of the water layer over which HSA protein molecules are dispersed. In particular, we investigate the limit of shallow layers, for which we report measurements of the spatially correlated motion of colloidal particles embedded at the interface, for different surface viscosities. We describe the influence of the bulk finite size on the behaviour of the spatial correlation functions of the particle motion, and extend the description of the correlation functions in terms of a master curve first obtained for large bulk volumes, to the limit of shallow layers.

9:12AM P41.00007 Measuring interfacial viscosity using macro- and micro-rheology , JAMES SEBEL, KENNETH DESMOND, ERIC R. WEEKS, THIBAUT DIVOUX, Emory University — We measure the viscous moduli of thin films using two different methods. First, we use a magnetic needle viscometer. Our apparatus employs Helmholtz coils to control the position and orientation of the needle in the film. By driving the needle we can produce a response in the film which allows us to probe the bulk viscous properties of the film. Second, we use single particle microrheology to probe the local properties of the film. Tracking the mean-squared displacement of particles as they undergo Brownian motion probes the local viscous properties of any heterogeneous domains. Coupling this technique with the magnetic needle viscometer provides information on the effect local viscous properties have on the bulk properties.

9:24AM P41.00008 Molecular Modeling of Three Phase Contact for Static and Dynamic Contact Angle Phenomena , ATEEQUE MALANI, Department of Chemical Engineering, Massachusetts Institute of Technology, Cambridge, MA, MIGUEL AMAT, Department of Chemical and Biological Engineering, Princeton University, Princeton, NJ, ANILKUMAR RAGHAVANPILLAI, E.I. du Pont de Nemours,, Wilmington, DE, ERNEST WYSONG, Experimental Section, E.I. du Pont de Nemours,, Wilmington, DE, GREGORY RUTLEDGE, Department of Chemical Engineering, Massachusetts Institute of Technology, Cambridge, MA — Interfacial phenomena arise in a number of industrially important situations, such as repellency of liquids on surfaces, condensation, etc. In designing materials for such applications, the key component is their wetting behavior, which is characterized by three-phase static and dynamic contact angle phenomena. Molecular modeling has the potential to provide basic insight into the detailed picture of the three-phase contact line resolved on the sub-nanometer scale which is essential for the success of these materials. We have proposed a computational strategy to study three-phase contact phenomena, where buoyancy of a solid rod or particle is studied in a planar liquid film. The contact angle is readily evaluated by measuring the position of solid and liquid interfaces. As proof of concept, the methodology has been validated extensively using a simple Lennard-Jones (LJ) fluid in contact with an LJ surface. In the dynamic contact angle analysis, the evolution of contact angle as a function of force applied to the rod or particle is characterized by the pinning and slipping of the three phase contact line. Ultimately, complete wetting or de-wetting is observed, allowing molecular level characterization of the contact angle hysteresis.

9:36AM P41.00009 Nonlinear electrohydrodynamics of a viscous droplet , PAUL SALIPANTE, PETIA VLAHOVSKA, Brown University — A classic result due to G.I.Taylor is that a drop placed in a uniform electric field adopts a prolate or oblate spheroidal shape, the flow and shape being axisymmetrically aligned with the applied field. We report an instability and transition to a nonaxisymmetric rotational flow in strong fields, similar to the rotation of solid dielectric spheres observed by Quincke in the 19th century. Our experiments reveal novel droplet behaviors such as tumbling, oscillations and chaotic dynamics even under creeping flow conditions. A phase diagram demonstrates the dependence of these behaviors on drop size, viscosity ratio and electric field strength. The theoretical model, which includes anisotropy in the polarization relaxation, elucidates the interplay of interface deformation and charging as the source of the rich nonlinear dynamics.

9:48AM P41.00010 Breakup of Bubbles or Drops by Capillary Waves Induced by Coalescence or Other Excitations , FENG HUA ZHANG, Singapore-MIT Alliance, National University of Singapore, Singapore, PETER TABOREK, Department of Physics and Astronomy, University of California, Irvine, USA, JUSTIN BURTON, James Franck Institute, University of Chicago, Chicago, USA, BOO CHEONG KHOO, Singapore-MIT Alliance, National University of Singapore, Singapore, SIGGI THORODDSEN, King Abdullah University of Science and Technology, Saudi Arabia — Capillary breakup of a bubble or drop by various excitations is ubiquitous in both nature and technology. Examples include coalescence with another bubble or drop, wetting on a solid surface, impact on a solid surface, detachment from a nozzle, or vibrations driven by acoustic, electrical, or magnetic fields. When the excitation ceases, capillary forces on the surface naturally drive the deformed bubble or drop to recover its spherical shape. However, when the viscosity is small, this recovery can lead to nonlinear oscillations of the interface and a singularity in the flow. Here we use high-speed imaging to investigate the coalescence of bubbles and drops of various sizes. In many cases, coalescence leads to pinch-off events and the formation of the satellite and sub-satellite. Our experiments use pressured xenon gas in glycerol/water mixtures so that the density ratio and viscosity ratio can be varied over many orders of magnitude. We characterize the generation, propagation, and convergence of capillary waves, the formation time and sizes of satellites, and the dynamics of two-fluid pinch-off as a function of the density ratio and viscosity ratio. The work shall benefit the wide-spread applications and fulfill the scientific and public curiosities.

10:00AM P41.00011 Thermo-actuated migration in a micro-system , MARIE-CAROLINE JULLIEN, UMR 7083 CNRS ESPCI, BERTRAND SELVA, Unité Mixte Rhodia CNRS 5258, ISABELLE CANTAT, Université de Rennes 1, MMN, LABORATOIRE GULLIVER TEAM, LOF TEAM, INSTITUT DE PHYSIQUE DE RENNES TEAM — Digital microfluidics require element displacement by simple means featuring high integration rates. Within this context, the transport and handling of elements constitutes a problem [Squires and Quake, 2005]. This context has rekindled interest in the Marangoni surface effect, which refers to tangential stresses along an interface. Producing a surface tension gradient by imposing a temperature gradient is especially efficient and easy to control. In a recent paper, we have shown [Selva et al., Phys. Fluids (2011)] that a bubble undergoing a constant temperature gradient is indeed set into motion. However, the direction of motion (toward the cooler side) is in contradiction with experiments performed at the millimetre scale in which bubble migration is driven towards hoter regions. We believe this observation is due to the PDMS deformability. Indeed, PDMS expands when the temperature increases. A temperature gradient inside a microsystem results in a cavity thickness gradient, and thus leads to the bubble travelling towards the thicker part of the cavity. The physical phenomena involved in such a system are multifaceted (PDMS dilation, thermocapillarity, solutocapillarity) and may have either complementary or opposite effects depending on the experimental conditions.

10:12AM P41.00012 Towards an effective surface tension at a foam/water interface[1] , HERVE CAPS, ARIANE BRONFORT, CHARLES DUBOIS, GILES DELON, GRASP - University of Liege — Foams are defined as assemblies of gas bubbles immersed into a continuous liquid phase. Depending on the ration between the total volume occupied by the foam and the amount of liquid inside the foam, different rheological behaviors are observed. Beside the numerous studies on the foam's bulk behavior, poor is known concerning the interface between a foam and the liquid bath it has been generated from. This interface is however separating two identical liquids where, one of these, also contained a dispersed phase. Our studies aim in describing this interface in terms of an effective surface tension, while considering the foam as a continuous medium. Monodisperse foams are produced in Hele-Shaw cells and the features of the boundary between the foam and the baliquid pool is studied by means of hydrodynamical instabilities. Namely, Faraday waves, Rayleigh-Taylor instability and Saffmann-Taylor fingering are considered. Among these instabilities, the shearing of the interface is studied within a rotating drum experiment, similarly to the granular case.

[1]ESA MAP - FNRS-FRS - Belspo Prodex

10:24AM P41.00013 Continuous dielectrophoretic centering of compound droplets , GREG RANDALL, BRENT BLUE, General Atomics — Compound droplets, or droplets-within-droplets, are traditionally key components in applications ranging from drug delivery to the food industry. Presently, millimeter-sized compound droplets are precursors for foam shell targets in inertial fusion energy work. A key constraint is a uniform foam shell thickness, which in turn requires a centered core in the compound droplet precursor. Previously, Bei et al. (2009, 2010) have shown that compound droplets could be centered in a static fluid using an electric field of 0.7 kV/cm at 20 MHz. To apply centering to existing or future applications, it is imperative to develop a continuous droplet centering process by overcoming the additional complications from motion. Here, we present analysis and experimental data of a continuous droplet centering device that uses an electric field to force a core droplet to the center of a moving compound drop. Our analysis focuses on how interfacial rheology and electrohydrodynamic flows affect the centering dynamics and droplet deformation. Proof-of-principle experiments are performed in a vertical channel using buoyancy to drive a solution of compound droplets stabilized with phospholipid and protein emulsifiers through a kV/cm electric field.

10:36AM P41.00014 The Dynamics of Coupled Droplets Under Gravity Condition , HAIDER HEKIRI, TAKUMI HAWA, School of Aerospace and Mechanical Engineering, The University of Oklahoma — The dynamics of a two-dimensional, incompressible, and two coupled spherical-cap water droplets pinned in a straight channel is investigated under gravity condition through the use of CFD. Since the capillary length is three times as large as the channel width, the effect of gravity is small but not negligible. In this simulations FLUENT with a 2-D pressure based solver is utilized. The suspended droplet states are measured by the location of the center of mass of the droplet. Under no gravity condition we find that there is a critical volume, Vc, where a bifurcation of asymmetric states occurs. However, gravity changes the pitchfork bifurcation diagram of coupled droplets systems into two separate branches of equilibrium states. The primary branch describes a gradual and stable change of the droplet states from symmetric to non-symmetric as V is increased across Vc. The secondary branch appears at a certain modified critical volume, Vmc, and describes two additional non-symmetric states for V>Vmc. CFD demonstrated that the large-amplitude state along the secondary branch is stable whereas the small-amplitude states are unstable.

Wednesday, February 29, 2012 8:00AM - 11:00AM – Session P51 DCMP DFD: Colloids III: Shear and Hydrodynamics Boston Convention Center 154

8:00AM P51.00001 Confined colloidal suspensions under simple shear , XINLIANG XU, STUART RICE, AARON DINNER, James Franck Institute, University of Chicago — Here we report a study of a simple model system, a colloidal suspension of near hard spheres in an otherwise Newtonian fluid using Stokesian Dynamics (SD) simulations in combination with Non-Equilibrium Umbrella Sampling (NEUS) techniques. The suspension is confined by an external potential in the y direction and is driven far out of equilibrium with a simple shear flow. At moderate shear rate, the suspension forms layers normal to the flow gradient direction, in contrast to equilibrium. In addition to that, novel anisotropic structures (strings in vorticity direction at low density for example) are observed within each layer. We use Non-Equilibrium Umbrella Sampling to explore the relationship between this string structure and the strength of the layer formation. Furthermore we have also studied the relationship between the non-Newtonian behavior of the suspension and the strength of the layer structure.

8:12AM P51.00002 The nonlinear structural response of colloidal suspensions under large amplitude oscillatory shear , NEIL Y.C. LIN, XIANG CHENG, ITAI COHEN, Physics Department, Cornell University — When a colloidal suspension is under oscillatory shear, the particle configuration has a flow-induced anisotropy. While these structural rearrangements have been intensively studied in the linear regime where the amplitude of the applied shear is small, the nonlinear structural response of suspensions under large amplitude oscillatory shear is poorly understood. Using a shear cell coupled to a fast confocal microscope, we directly measured the microscopic structure of colloidal suspensions under large amplitude oscillatory shear. To quantify the structural response, we integrated the pair correlation function over all contact positions; this quantity is proportional to the entropic stress of the suspension. We investigated the structural/stress response of colloidal suspensions systematically with increasing shear amplitudes. We observed strong nonlinear responses in both dense and dilute suspensions under large amplitude oscillatory shear. At even higher amplitudes, we found an overshoot of the stress response in dense suspensions. Our results provide insight on the microscopic structural origin of the nonlinear response of sheared colloidal suspensions.

8:24AM P51.00003 Imaging the microscopic structure of shear thinning and thickening colloidal suspensions , XIANG CHENG, Cornell University, JONATHAN MCCOY, Colby College, JACOB ISRAELACHVILI, University of California Santa Barbara , ITAI COHEN, Cornell University — The viscosity of colloidal suspensions can vary by orders of magnitude depending on how quickly they are sheared. Although this non-Newtonian behavior is believed to arise from the arrangement of suspended particles and their mutual interactions, microscopic particle dynamics in such suspensions are difficult to measure directly. Here, by combining fast confocal microscopy with simultaneous force measurements, we systematically investigate a suspension's structure as it transitions through regimes of different flow signatures. Our measurements of the microscopic single-particle dynamics unambiguously show that shear thinning results from the decreased relative contribution of entropic forces and that shear thickening arises from particle clustering induced by inter-particle hydrodynamic lubrication forces. Furthermore, we explore out-of-equilibrium structures of sheared colloidal suspensions and report a novel string phase, where particles link into log-rolling strings normal to the plane of shear. Our techniques illustrate an approach that complements current methods for determining the microscopic origins of non-Newtonian flow behavior in complex fluids.

8:36AM P51.00004 Shear induced diffusion in hard sphere glasses , NICK KOUMAKIS, GEORGE PETEKIDIS, FORTH & Univ. of Crete, Creece, JOHN BRADY, Chemical Engineering, Caltech, USA, FORTH TEAM, CALTECH TEAM — The response of dense hard sphere suspensions is examined during the application of steady and non-linear oscillatory shear using Brownian Dynamics (BD) simulations and experimental Light Scattering echo coupled with rheology. At rest, volume fractions around the glass transition exhibit long or infinite relaxation times. However, non-linear shear induces out of cage motions of comparable time scale to the applied rates. We found two distinct regimes in terms of stresses and dynamic response under shear. One regime for lower rates or frequencies of oscillation, governed by Brownian activated diffusion, and a second for higher rates related to shear activated diffusion. A linear dependence with rate was found for the diffusivity in the high rate regime, mirroring the viscous loss due to shear activated particle rearrangements, while diffusivities in the Brownian activated regime showed a power law exponent of less than unity. The exponent was found to increase with volume fraction. For applied rates inducing diffusivities above the in-cage diffusivity at rest, we find a time window of super-diffusive behavior, between the short time (in-cage) and long time (out-of cage) diffusivities under shear, a signature of a dynamic breaking and reforming of the cage.

8:48AM P51.00005 Diffusion in sheared athermal soft-particle suspensions: the role of inertia and dissipation mechanism , CRAIG MALONEY, KAMRAN KARIMI, Carnegie Mellon — We perform numerical simulations to study diffusion in a model bi-disperse frictionless athermal soft-particle suspension of disks in two dimensions (2D). To model athermal shear, we damp the motion of a particle *either* with respect to the globally imposed flow *or* with respect to its near neighbors. We study shear flows at various rate $\dot{\gamma}$, system size L, and damping strength b at packing fractions well above the random close packing point. At low $\dot{\gamma}$, we find a quasi-static effective transverse diffusion co-efficient, D_{eff}, which has very weak dependence on ϕ, b, or the damping mechanism yet has a pronounced linear dependence on L in agreement with what is observed in conventional models of bulk metallic glasses. Away from the quasi-static regime, D_{eff} no longer depends on L, and b has a profound impact on the scaling behavior of D_{eff} with $\dot{\gamma}$.

9:00AM P51.00006 Shear thinning in soft particle suspensions , PANAYIOTIS VOUDOURIS, Eindhoven University of Technology (a) Department of Mechanical Engineering, Materials Technology (b) Institute for Complex Molecular Systems, BERCO VAN DER ZANDEN, Eindhoven University of Technology - Department of Mechanical Engineering, DANIEL FLOREA, ZAHRA FAHIMI, HANS WYSS, Eindhoven University of Technology (a) Department of Mechanical Engineering, Materials Technology (b) Institute for Complex Molecular Systems — Suspensions of soft deformable particles are encountered in a wide range of food and biological materials. Examples are biological cells, micelles, vesicles or microgel particles. While the behavior of suspenions of hard spheres - the classical model system of colloid science - is reasonably well understood, a full understanding of these soft particle suspensions remains elusive. The relation between single particle properties and macroscopic mechanical behavior still remains poorly understood in these materials. Here we examine the surprising shear thinning behavior that is observed in soft particle suspensions as a function of particle softness. We use poly-N-isopropylacrylamide (p-NIPAM) microgel particles as a model system to study this effect in detail. These soft spheres show significant shear thinning even at very large Peclet numbers, where this would not be observed for hard particles. The degree of shear thinning is directly related to the single particle elastic properties, which we characterize by the recently developed Capillary Micromechanics technique. We present a simple model that qualitatively accounts for the observed behavior.

9:12AM P51.00007 Anisotropic Diffusion of Colloidal Particles in a Shear Flow , BRIAN LEAHY, DESMOND ONG, XIANG CHENG, ITAI COHEN, Cornell University — Asymmetrically-shaped particles show anisotropic diffusive behavior along different particle axes. This anisotropic diffusion, however, is averaged out on long time scales due to the rotational diffusion of the particles. Here we report on an experimental study of anisotropic colloidal dimers suspended in an oscillatory shear flow. A preferred orientation of the dimers arises due to the applied oscillatory shear. This results in anisotropic particle diffusion that is persistent at long time scales. We compare our results to a simple model of diffusing particles in a shear flow, and comment briefly on the possibility of using this result for assembling out-of-equilibrium colloidal structures.

9:24AM P51.00008 Pattern formation in colloidal explosions: Theory and experiment , ARTHUR STRAUBE[1], Humboldt University of Berlin, Germany, ARD LOUIS COLLABORATION[2], JÖRG BAUMGARTL, CLEMENS BECHINGER COLLABORATION[3], ROEL DULLENS COLLABORATION[4] — We study the nonequilibrium pattern formation that emerges when magnetically repelling colloids, trapped by optical tweezers, are abruptly released, forming colloidal explosions [EPL 94, 48008 (2011)]. For multiple colloids in a single trap, we observe a pattern of expanding concentric rings. For colloids individually trapped in a line, we observe explosions with a zigzag pattern that persists even when magnetic interactions are much weaker than those that break the linear symmetry in equilibrium. Theory and computer simulations quantitatively describe these phenomena both in and out of equilibrium. An analysis of the mode spectrum allows us to accurately quantify the nonharmonic nature of the optical traps. Colloidal explosions provide a new way to generate well-characterized nonequilibrium behavior in colloidal systems.

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9:36AM P51.00009 Universal Scaling Law of Diffusion and Hydrodynamic Corrections in Colloidal Monolayers[1] , XIAO-GUANG MA, Hong Kong University of Science and Technology, WEI CHEN, Fudan University, Shanghai, China, ZIREN WANG, YUAN PENG, YILONG HAN, PENGER TONG, Hong Kong University of Science and Technology — Using dense monolayers of colloidal particles and the techniques of optical microscopy and particle tracking, we tested the universal scaling law of the diffusion constant of colloidal particles as a function of excess entropy. By varying the area fraction of the colloidal monolayer, we measured the diffusion constant and the corresponding pair correlation function of the colloidal particles, from which the excess entropy can be calculated. It is found that the universal scaling law applies to a monolayer of latex suspensions at an air-water interface when the inter-particle repulsions are dominant over the hydrodynamic interactions. For colloidal monolayers of hard spheres at the air-water interface and near a solid wall, the universal scaling law starts to deviate from its original form as the short-ranged hydrodynamic interactions increase.

[1]Work supported in part by the Research Grants Council of Hong Kong SAR.

9:48AM P51.00010 Long Range Hydrodynamic Correlations in Quasi-One-Dimensional Circular and Linear Geometries , EKATERINA KOSHELEVA, Harvard Univ., BRIAN LEAHY, Cornell Univ., HAIM DIAMANT, Tel Aviv Univ., STUART A. RICE, BINHUA LIN, Univ. of Chicago — We report the results of studies of the collective and pair diffusion coefficients of particles in two quasi-one-dimensional geometries: straight 2 mm long channels and rings with radii between 3 and 35 μm. We investigate, for both geometries, the observed density dependence in the collective diffusion coefficient as predicted by Frydel and Diamant (Phys. Rev. Letts. 104, 248302 (2010). The origin of this density dependence is the nonvanishing q = 0 component of the Green's function of the linearized one-dimensional hydrodynamic equation, which is indicative of the hydrodynamic coupling resulting from collective motion of particles in periodic or infinite quasi-one-dimensional geometries.

10:00AM P51.00011 Using artificial microswimmers for particle separation

, VYACHESLAV R. MISKO, University of Antwerp, Belgium, WEN YANG, Taiyuan University of Science and Technology, P.R. China, KWINTEN NELISSEN, University of Antwerp, Belgium, MINGHUI KONG, Institute of Plasma Physics, Hefei, P.R. China, FRANCOIS M. PEETERS, University of Antwerp, Belgium — Microscopic self-propelled swimmers capable of autonomous navigation through complex environments provide appealing opportunities for localization, pick-up and delivery of micro-and nanoscopic objects. Inspired by motile cells and bacteria, man-made microswimmers have been created, and their motion was studied experimentally in patterned surroundings [1]. We propose to use artificial microswimmers – Janus spheres [2] illuminated by light – as "driving agents" that move through a binary mixture of colloidal particles. We demonstrated [3] that binary mixtures can be effectively separated in this way. We analyzed the main features of the particle separation and explained mechanisms of different regimes including the one with a velocity inversion. Our finding can be readily verified in experiments with colloidal binary mixtures and could be of use for various biological and medical applications.

[1] G. Volpe et al., Soft Matter **7**, 8810 (2011).
[2] Q. Chen et al., Science **331**, 199 (2011).
[3] W. Yang, V.R. Misko, K. Nelissen, M. Kong, and F.M. Peeters, arXiv:1109.5099 (2011).

10:12AM P51.00012 Diffusion in Dense Inhomogeneous Colloid Suspensions in Narrow Channels

, BINHUA LIN, EMILY WONDER, STUART A. RICE, Univ. of Chicago — We report the results of a study of single particle diffusion in dense colloid fluids confined in a ribbon channel geometry that is intermediate between quasi-one-dimensional (q1D) and quasi-two-dimensional (q2D). In all of the systems studied the colloid density distribution transverse to the ribbon channel is stratified with peak amplitudes that depend on the colloid density. Although the virtual walls that confine a stratum are structured with a scale length of the colloid diameter, that structure does not have an apparent influence on the single particle diffusion, which shows the characteristic features of diffusion in a q1D channel with smooth walls. We find that for all channel widths and packing fractions studied the single particle transverse diffusion coefficient in a stratum is smaller than the single particle longitudinal diffusion coefficient in the same stratum, and that the single particle longitudinal diffusion coefficient varies very little from stratum to stratum, being only slightly smaller in the dense strata next to the walls than in central strata. The lack of variation of the longitudinal diffusion coefficient with apparent stratum density is explained by application of the Fischer-Methfessel approximation to the local density in an inhomogeneous liquid. The ratio of the transverse to longitudinal diffusion coefficients varies very slowly with ribbon width, implying a very slow transition from q1D to q2D behavior.

10:24AM P51.00013 Flow of concentrated emulsion in a microchannel: walls effects and roughness impact

, VINCENT MANSARD, ANNIE COLIN, LOF, Universite de Bordeaux, LYDÉRIC BOCQUET, LPMCN, UniversiteLyon 1 — Soft glassy materials have ubiquitous rheological properties. At small stress they deform elastically. For stress above a threshold they flow like liquids. At microscale, they are composed of highly disordered particles caged by the neighborhood. Flow happens by successive cage-jumps -or rearrangement. We study concentrated emulsion as a model fluid. When it flows in confined geometry, the viscosity does not correspond to the rheometer measurements but obeys to a non-local relation (Goyon-2008) due to rearrangement's correlation. As they impose viscosity's boundary conditions, walls modify the flow. We study carefully the conditions imposed by the walls and the impact of the roughness. In a microchannel, we create a Poiseuille flow. Using a fast confocal microscope we visualize the droplets and measure the velocity with high spatial resolution. At high stress, we observe one or two discontinuities of the velocity at respectively one and two droplets' diameters. They are due to stratification of the first droplets' layers. Far from them the non-local model remains valid. We create roughness by adding controlled size patterns. The roughness modifies the apparition of the stratifications and the limit conditions on the viscosity. We will compare these results with theory.

10:36AM P51.00014 Non-equilibrium dynamics in particle-interface systems

, ANNA WANG, School of Engineering and Applied Sciences, Harvard University, RYAN MCGORTY[1], University of California, San Francisco, DAVID M. KAZ[2], University of California, Berkeley, VINOTHAN N. MANOHARAN[3], School of Engineering and Applied Sciences, Harvard University — When a particle is at equilibrium at a fluid-fluid interface, its position can be calculated with Young's law (which has been used since 1805). The non-equilibrium behavior of particles at fluid-fluid interfaces, however, is only just beginning to be studied. In this talk, we will discuss the behavior of colloidal particles as they approach and meet an oil-water interface. A variety of different systems, such as approach from both the aqueous and oil phases and using aqueous phases of various salt concentrations will be compared. The motion of the polymer microspheres is captured using digital holographic microscopy in real time. As the holograms are simply two-dimensional images, the frame rate is limited only by the CMOS sensor and frame rates of up to 2000fps are used in this study. We then analyze the high frame rate data to recover the three-dimensional trajectory and fluctuations of the particles.

[1] Formerly at the Department of Physics, Harvard University
[2] Formerly at the Department of Physics, Harvard University
[3] Also affiliated with the Department of Physics, Harvard University

10:48AM P51.00015 Granular Fluid Kinetics Approach to Modeling Soft Colloid and Polymer Materials[1]

, DIMITER PETSEV[2], JHOAN TORO-MENDOZA[3], University of New Mexico, FRANK VAN SWOL[4], University of New Mexico and Sandia National Laboratories — The objective of this study is to understand the fundamental laws governing the Brownian motion of viscoelastic particles suspended in solvent at macroscopic equilibrium. Our hypothesis is that the internal degrees of freedom of the particles couple to their translational Brownian motion and affect their mean square displacement. Our system is similar to granular fluids with the important distinction that the energy absorbed by the particles during a collision is returned back thus maintaining a global thermodynamic equilibrium. We propose a new Molecular Dynamics model system that consists of tracer Brownian particles, solvent, and a virtual third component that serves as a thermal bath. The energy that is lost in an inelastic collision between Brownian and solvent particles is returned to the bath. The bath particles are undergoing elastic collisions among themselves and also with the solvent and Brownian particles. This provides a mechanism to restore and maintain an overall thermal equilibrium in the whole system. We report data on the effect of particle inelasticity on the translational diffusion.

[1] This work was supported by NSF Grants 0844645 and 0611616.
[2] Department of Chemical and Nuclear Engineering, and Center for Biomedical Engineering
[3] Department of Chemical and Nuclear Engineering
[4] Department of Chemical and Nuclear Engineering, and Center for Biomedical Engineering

Wednesday, February 29, 2012 8:00AM - 11:00AM –

Session P52 GSNP DFD: Focus Session: Extreme Mechanics - Structures for Form and Function 153C

8:00AM P52.00001 Soft Robots: Manipulation, Mobility, and Fast Actuation , ROBERT SHEPHERD, FILIP ILIEVSKI, WONJAE CHOI, ADAM STOKES, STEPHEN MORIN, AARON MAZZEO, REBECCA KRAMER, Harvard, CARMEL MAJIDI, Carnegie Mellon, ROB WOOD, GEORGE WHITESIDES, Harvard — Material innovation will be a key feature in the next generation of robots. A simple, pneumatically powered actuator composed of only soft-elastomers can perform the function of a complex arrangement of mechanical components and electric motors. This talk will focus on soft-lithography as a simple method to fabricate robots–composed of exclusively soft materials (elastomeric polymers). These robots have sophisticated capabilities: a gripper (with no electrical sensors) can manipulate delicate and irregularly shaped objects and a quadrupedal robot can walk to an obstacle (a gap smaller than its walking height) then shrink its body and squeeze through the gap using an undulatory gait. This talk will also introduce a new method of rapidly actuating soft robots. Using this new method, a robot can be caused to jump more than 30 times its height in under 200 milliseconds.

8:12AM P52.00002 Low-Dimensional Generalized Coordinate Models of Large-Deformation Elastic Joints[1] , LAEL ODHNER, AARON DOLLAR, Department of Mechanical Engineering, Yale University — In the field of robotics, it is increasingly common to use elastic elements such as rods, beams or sheets to allow motion between the rigid links of a robot, rather than conventional sliding mechanisms such as pin joints. Although these elastic joints are simpler to manufacture, especially at meso- and micro-scales, representational simplicity is sacrificed. It is far easier to compute the Lagrangian of a robot using joint angles as generalized coordinates, rather than by considering the large-deformation continuum behavior of elastic joints. In this talk, we will discuss our work toward finding accurate, low-dimensional discretizations of elastic joint mechanics, suitable for use in generalized coordinate models of robot kinematics and dynamics. We use modally parameterized backbone curves to describe the kinematic configuration of the elastic joints, and compute the energy associated with deformation using rod and shell theory. In the plane, only three smooth deformation modes are sufficient to describe Euler-Bernoulli bending of 90 degrees to within 1 percent. Parametric models for the three-dimensional motion of sheet hinges are more complex, but can be simplified significantly using boundary conditions and constraints imposed by ruled surface assumptions.

[1]This work is supported by National Science Foundation grant IIS-0952856.

8:24AM P52.00003 Liquid-Embedded Elastomer Electronics , REBECCA KRAMER, Harvard University, CARMEL MAJIDI, Carnegie Mellon University, YONG-LAE PARK, JAMIE PAIK, ROBERT WOOD, Harvard University — Hyperelastic sensors are fabricated by embedding a silicone rubber film with microchannels of conductive liquid. In the case of soft tactile sensors, pressing the surface of the elastomer will deform the cross-section of underlying channels and change their electrical resistance. Soft pressure sensors may be employed in a variety of applications. For example, a network of pressure sensors can serve as artificial skin by yielding detailed information about contact pressures. This concept was demonstrated in a hyperelastic keypad, where perpendicular conductive channels form a quasi-planar network within an elastomeric matrix that registers the location, intensity and duration of applied pressure. In a second demonstration, soft curvature sensors were used for joint angle proprioception. Because the sensors are soft and stretchable, they conform to the host without interfering with the natural mechanics of motion. This marked the first use of liquid-embedded elastomer electronics to monitor human or robotic motion. Finally, liquid-embedded elastomers may be implemented as conductors in applications that call for flexible or stretchable circuitry, such as robotic origami.

8:36AM P52.00004 Extreme Mechanics in Soft Pneumatic Robots and Soft Microfluidic Electronics and Sensors , CARMEL MAJIDI, Carnegie Mellon University — In the near future, machines and robots will be completely soft, stretchable, impact resistance, and capable of adapting their shape and functionality to changes in mission and environment. Similar to biological tissue and soft-body organisms, these next-generation technologies will contain no rigid parts and instead be composed entirely of soft elastomers, gels, fluids, and other non-rigid matter. Using a combination of rapid prototyping tools, microfabrication methods, and emerging techniques in so-called "soft lithography," scientists and engineers are currently introducing exciting new families of soft pneumatic robots, soft microfluidic sensors, and hyperelastic electronics that can be stretched to as much as 10x their natural length. Progress has been guided by an interdisciplinary collection of insights from chemistry, life sciences, robotics, microelectronics, and solid mechanics. In virtually every technology and application domain, mechanics and elasticity have a central role in governing functionality and design. Moreover, in contrast to conventional machines and electronics, soft pneumatic systems and microfluidics typically operate in the finite deformation regime, with materials stretching to several times their natural length. In this talk, I will review emerging paradigms in soft pneumatic robotics and soft microfluidic electronics and highlight modeling and design challenges that arise from the extreme mechanics of inflation, locomotion, sensor operation, and human interaction. I will also discuss perceived challenges and opportunities in a broad range of potential application, from medicine to wearable computing.

9:12AM P52.00005 Macrocomposite mechanical design, modeling, and behavior of physical models of bioinspired fish armor , ASHLEY BROWNING, Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, CHRISTINE ORTIZ, Department of Materials Science and Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, MARY C. BOYCE, Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139 — The macrocomposite design of flexible biological exoskeletons, consisting of overlapping mineralized armor units embedded in a compliant tissue, is a key determinant of their mechanical function (e.g penetration resistance and biomechanical flexibility). Here, we investigate the role of macrocomposite structure, composition, geometric orientation, and spatial distribution in a flexible model natural armor system present in the majority of teleost fish species. Physical multi-material composite models are fabricated using a combination of 3-D printing and molding methods. Mechanical experiments using digital image correlation enable measurement of both the macroscopic response and underlying deformation mechanisms during various loading scenarios. Finite element-based mechanical models yield detailed insights into the roles and the tradeoffs of the composite structure providing constraint, shear, and bending mechanisms to impart protection and flexibility.

9:24AM P52.00006 Periodic Structural Solids: Mechanics and Multifunctional Applications , LIFENG WANG, Clarkson University — Triply periodic minimal surfaces have been of great interest to mathematicians, physical scientists, material scientists, and biologists. Close physical approximations to triply periodic minimal surfaces arise in a few material systems, such as block copolymers, nanocomposites, and biological exoskeletons. Here, we demonstrate the potential to design and fabricate two-component periodically ordered structures which correspond to the level set structures associated with triply periodic minimal surfaces. These structures are shown to have a unique combination of stiffness, strength, and energy absorption, as well as damage tolerance. The results provide guidelines for engineering and tailoring the nonlinear mechanical behavior and energy absorption of cocontinuous composites for a wide range of applications and further creating multifunctional materials. For example, polymeric materials which can change shape and material properties in response to external stimuli (temperature or electric field) can provide additional functionality when used as one of the phases, such as 3D shape memory. The periodic and multiphase nature of the structures also enables mechanically tunable band gap (phononic or photonic) materials, and tunable sensors in tissue engineering.

9:36AM P52.00007 Honeycombs with hierarchical organization[1] , AMIN AJDARI, BABAK HAGHPANAH JAHROMI, JIM PAPADOPOULOS, ASHKAN VAZIRI, Northeastern University — We investigated the mechanical behavior of two-dimensional hierarchical honeycomb structures using analytical, numerical and experimental methods. Hierarchical honeycombs were constructed by replacing every three-edge vertex of a regular hexagonal lattice with a smaller hexagon. Repeating this process builds a fractal-appearing structure. The resulting isotropic in-plane elastic properties (effective elastic modulus and Poisson's ratio) of this structure are controlled by the dimension ratios for different hierarchical orders. Hierarchical honeycombs of first and second order can be up to 2.0 and 3.5 times stiffer than regular honeycomb at the same mass (i.e., same overall average density). The Poisson's ratio varies from nearly 1.0 (when planar "bulk" modulus is considerably greater than Young's modulus, so the structure acts "incompressible" for most loadings) to 0.28, depending on the dimension ratios. The work provides insight into the role of structural organization in regulating the mechanical behavior of materials, and new opportunities for developing low-weight cellular structures with tailorable properties.

[1]This work was supported in part by the U.S. Air Force Office of Scientific Research under AFOSR YIP grant award, #FA 9550-10-1-0145 and in part by the U.S. Department of Homeland Security under Award Number 2008-ST-061-ED0001.

9:48AM P52.00008 Buckling-induced Tunable Chirality in Rationally-Designed Surface-Attached Cellular Structures[1] , SICONG SHAN, SUNG HOON KANG, WIM NOORDUIN, School of Engineering and Applied Sciences, Harvard University, MUGHEES KHAN, Wyss Institute for Biologically Inspired Engineering, KATIA BERTOLDI, JOANNA AIZENBERG, School of Engineering and Applied Sciences, Harvard University — Chirality is crucial in understanding and controlling the behavior of living and non-living systems since the presence or absence of chirality in the structures plays important roles in their interactions with molecules, enzymes, light, and mechanical stress. Processes that induce chirality have been extensively studied at the molecular and macroscopic scales, but are relatively unexplored at the mesoscale. By rational design based on modeling, we experimentally demonstrate the controlled reversible switching between achiral and chiral configurations using swelling/de-swelling of surface-attached cellular structures. Importantly, the buckling patterns and the associated symmetry reduction of the initially achiral centrosymmetric structures could be tuned, simply by changing their dimensions. This approach opens the way to deterministically select to select the appearance of either mixed (racemic) or chiral phases. In the case of chiral transformations, spontaneous symmetry breaking resulted in the formation of large uniform areas of structures of single handedness. The fundamental understanding of this process provides a general route to designing deterministically deformable structures with dynamically switchable mechanical and/or optical properties.

[1]Materials Research Science and Engineering Center under NSF Award No. DMR-0820484

10:00AM P52.00009 Buckling-induced Planar Chirality of Porous Elastic Structure , JONGMIN SHIM, SICONG SHAN, SUNG H. KANG, PAI WANG, Harvard University, BETH R. CHEN, University of Michigan, Ann Arbor, JOANNA AIZENBERG, KATIA BERTOLDI, Harvard University — We present two periodic elastomeric structures which develop planar chirality induced by buckling under uniaxial/biaxial loading. The geometry of the structure comprises a 2-D plate patterned with a regular array of circular voids. Two specific circular void arrangements are obtained by investigating buckling-induced pattern transformations for void closure. Beyond the critical load, the thin ligaments between two adjacent voids buckle leading to a cooperative buckling cascade within the 2-D plate. Both micro-scale swelling experiments and finite element simulations are used to explore the underlying mechanics in detail and to show a proof of concept of the proposed structures. During swelling, the initial non-chiral pattern of the circular voids is transformed to a deformed pattern which exhibits planar chirality through buckling-induced symmetry breaking. In order to explore the effect of planar chirality, we perform an acoustic band structure calculation at different level of deformation. The planar chirality is found to strongly affect the in-plane phononic band gaps, providing opportunities for tunable phononic band structures.

10:12AM P52.00010 Anisotropy-induced wave steering in periodic linear and nonlinear lattices , FILIPPO CASADEI, JULIAN RIMOLI, MASSIMO RUZZENE, Georgia Institute of Technology — Structural lattice configurations can be designed with tailored topologies which provide them with unusual behaviors, such as negative bulk modulus, negative Poisson's ratios, or extreme anisotropy[1]. The latter is of particular relevance to explore the inherent anisotropic behavior of periodic lattices as a design paradigm for wave guiding and steering applications. The equivalent material anisotropy of square and skew periodic lattices is investigated through the application of Bloch's theorem[2] to the finite element discretization of the representative unit cell. The in-plane directions of wave propagation are determined through detailed analysis of the longitudinal and shear wave velocities, and verified through full-field wave propagation simulations. Similar wave behaviors are investigated analytically and experimentally for multilayer composite panels with anisotropic lay-ups in order to demonstrate the feasibility of micro structural design as an effective approach for wave management.

[1]M. Ruzzene et al. Phisica Status Solidi B, **242**, 665 (2005)
[2]Bloch F., Z. Physik **52**, 555 (1928)

10:24AM P52.00011 2-D Phononic Crystals – Unraveling the Effect of Void Distribution in Porous Structures , PAI WANG, JONGMIN SHIM, KATIA BERTOLDI[1], Harvard University, KATIA'S GROUP TEAM[2] — Phononic crystals are periodic materials consisting of different constituents with the capability to control the propagation of elastic waves. In this study, the dispersion relations of two-dimensional phononic crystals with *circular voids* are investigated using Bloch-wave analysis. Porous patterns are derived from the *Laves tilings*, which are duals of the eleven *convex uniform tilings* of the *Euclidean plane*. Numerical simulations are performed on the microstructures using finite element method. Frequency band-gaps are calculated and compared among different geometric configurations, void-volume fractions, and material properties, providing valuable insight into the behavior of phononic crystals. The predictive technical procedure developed here offers opportunities for the design of mechanical wave filters that have many potential applications such as noise-cancelling devices, acoustic wave guides and vibration isolators.

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10:36AM P52.00012 Guiding of High Amplitude Stress Waves Through Stress-Induced Domain Switching in Multiphase Materials , JULIAN RIMOLI, LUCA GUIDONI, BRETT REICHARD, MASSIMO RUZZENE, Georgia Institute of Technology — Periodic and graded Multiphase Materials (MMs) are of great interest to scientists and engineers because of their unique static and dynamic mechanical properties, and the design flexibility they provide. In the linear range operation, MMs can be designed to attenuate vibrations over wide frequency bands and in specified directions, as defined by topology, geometry and material of the unit cell. Similarly, unit cell design and topology can be selected to obtain a desired anisotropy in the material, which can be exploited to alter the path of propagation of elastic and high amplitude stress waves. Specifically, steering of waves in preferential directions can be achieved through the proper arrangement of periodic hard inclusions within a matrix. Such a capability is extremely important for the design of materials capable of guiding stress waves to propagate along specified paths. In the present work, we explore the use of periodic metamaterials for wave management in force protection applications. We define topologies which adapt to high amplitude mechanical inputs, and study through numerical simulations and experiments local and global instabilities which lead to adaptive mechanical behavior through topological and structural modifications.

10:48AM P52.00013 Soft Modes and Deformations of Three-Dimensional Isostatic Periodic Lattices , ANTON SOUSLOV, Georgia Institute of Technology, T.C. LUBENSKY, University of Pennsylvania — Each particle in a three-dimensional isostatic lattice is connected by springs on average to six nearest neighbors, a condition obtained by J.C. Maxwell for marginal stability. The cubic and pyrochlore lattices satisfy this condition. By calculating the dispersion relations and the density of states for phonons in these lattices, we expand on previous studies of isostatic periodic structures [1], which have largely been focused on the simpler two-dimensional cases. The low energy phonon spectrum of these lattices exhibits features common to isostatic systems in any dimension, such as the presence of floppy modes and the scaling of a divergent length and a vanishing critical frequency. However, the allowed symmetries of an elasticity theory and the number of floppy modes depend on dimension and play a crucial role in the structure of the low-frequency response. We relate these findings to the isostatic transition in systems of close-packed athermal spheres and look at an analogy with three-dimensional crystals with zeolite structure.

[1] A. Souslov, A. J. Liu, and T. C. Lubensky, Phys. Rev. Lett. 103, 205503 (2009)

Wednesday, February 29, 2012 11:15AM - 2:03PM –
Session Q41 DFD: Biofluids 156B

11:15AM Q41.00001 Fool's Gold Footprinting: microfluidic probing of nucleic acids[1] , CHRISTOPHER D. JONES, Cornell University, School of Applied & Engineering Physics, JOERG C. SCHLATTERER, Albert Einstein College of Medicine, Department of Biochemistry, MICHAEL BRENOWITZ, Albert Einstein College of Medicine, LOIS POLLACK, Cornell University — We describe a microfluidic device containing a mineral matrix capable of rapidly generating hydroxyl radicals that enables high-resolution structural studies of nucleic acids. Hydroxyl radicals cleave the solvent accessible backbone of DNA and RNA; the cleavage products can be detected with as fine as single nucleotide resolution. Protection from hydroxyl radical cleavage (footprinting) can identify sites of protein binding or the presence of tertiary structure. Here we report preparation of micron sized particles of iron sulfide (pyrite) and fabrication of a microfluidic prototype that together generate enough hydroxyl radicals within 20 ms to cleave DNA sufficiently for a footprinting analysis to be conducted. This prototype enables the development of high-throughput and/or rapid reaction devices with which to probe nucleic acid folding dynamics and ligand binding.

[1]This work was supported by the NSF through the IDBR program and the Cornell NanoScale Facility, a member of the National Nanotechnology Infrastructure Network.

11:27AM Q41.00002 Dislocation dynamics and bacterial growth , ARIEL AMIR, DAVID NELSON, Harvard University — Recent experiments have revealed remarkable phenomena in the growth mechanisms of rod-shaped bacteria: proteins associated with the cell wall growth move at constant velocity in circles oriented approximately along the cell circumference (Garner et al., Science 2011, Domínguez-Escobar et al., Science 2011, Deng et al., PNAS 2011). We view these dislocations in the partially ordered peptidoglycan structure, and study theoretically the dynamics of these interacting dislocations on the surface of a cylinder. The physics of the nucleation of these dislocations and the resulting dynamics within the model show surprising effects arising from the cylindrical geometry, which are predicted to have important implications on the growth mechanism. We also discuss how long range elastic interactions affect the dynamics of the fraction of active dislocations in the environment.

11:39AM Q41.00003 Signal Relay During Cell Migration , CAN GUVEN, Department of Physics, University of Maryland, ERIN RERICHA, School of Medicine, Vanderbilt University, EDWARD OTT, WOLFGANG LOSERT, Department of Physics, University of Maryland — We developed a signal relay model to quantify the effect of intercellular communication in presence of an external signal, during the motion of groups of Dictyostelium discoideum cells. A key parameter is the ratio of amplitude of the cAMP (cyclic adenosine monophosphate) a signaling chemical secreted from individual cells versus the external cAMP field, which defines a time scale. Another time scale is set by the degradation rate of the cAMP. In our simulations, the competition between these two time scales results rich dynamics including uniform motion, as well as streaming and clustering instabilities. The simulations are compared to experiments for a wide range of different external signal strengths for both cells that secrete cAMP and a mutant which cannot relay cAMP. Under different strength of external linear cAMP gradient, the wild type cells form streams and exhibit clustering due to the intercellular signaling through individual cAMP secretion. In contrast, cells lacking signal relay move relatively straight. We find that the model captures both independent motion and the formation of aggregates when cells relay the signal.

11:51AM Q41.00004 Intracellular Transport in Beta Cells - from Anti-Corellated to Active , STANISLAV BUROV, ALI TABEI, AARON DINNER, NORBERT SCHERER, University of Chicago — The intracellular transport along micro-tubules is the main focus of this research. We study the transport of insulin granules inside Beta cells. By developing new technique for the analysis of single 2D trajectories we observe a transition in the transport behavior from anti-correlated to active as a function of time. We further use the observed effect in order to discriminate between possible scenarios of active transport through disordered media as models of efficient intracellular transport.

12:03PM Q41.00005 Acoustic streaming in the cochlea under compressive bone conduction excitation , KATHERINE AHO, MEGHA SUNNY, TAOUFIK NABAT, JENNY AU, CHARLES THOMPSON, University of Masachusetts Lowell — This work examines the acoustic streaming in the cochlea. A model will be developed to examine the steady flow over a flexible boundary that is induced by compressive excitation of the cochlear capsule. A stokeslet based analysis of oscillatory flows was used to model fluid motion. The influence of evanescent modes on the pressure field is considered as the limit of the aspect ratio epsilon approaches zero. We will show a uniformly valid solution in space.

12:15PM Q41.00006 Subtle exchange model of flow depended on the blood cell shape to enhance the micro-circulation in capillary[1] , IATNENG CHAN, Physics Group, Faculty of Science and Technology, University of Macau — In general the exchange of gases or other material in capillary system is conceptualized by the diffusion effect. But in this model, we investigate a micro-flow pattern by simulation and computation on a micro-exchange model in which the blood cell is a considered factor, especially on its shape. It shows that the cell benefits the circulation while it is moving in the capillary. In the study, the flow detail near the cell surface is mathematically analyzed, such that the Navier-Stokes equations are applied and the viscous factor is also briefly considered. For having a driven force to the motion of micro-circulation, a breathing mode is suggested to approximately compute on the flow rate in the blood capillary during the transfer of cell. The rate is also used to estimate the enhancement to the circulation in additional to the outcome of diffusion. Moreover in the research, the shape change of capillary wall under pressure influence is another element in the beginning calculation for the effect in the assistance to cell motion.

[1]Funded by the research grant of the University of Macau

12:27PM Q41.00007 Modeling fluid diffusion in cerebral white matter with random walks in complex environments , AMICHAI LEVY, GABRIEL CWILICH, SERGEY V. BULDYREV, Department of Physics, Yeshiva University, VAN J. WEEDEN, Athinoula A. Martinos Center for Biomedical Imaging, Harvard Medical School — Recent studies with diffusion MRI have shown new aspects of geometric order in the brain, including complex path coherence within the cerebral cortex, and organization of cerebral white matter and connectivity across multiple scales. The main assumption of these studies is that water molecules diffuse along myelin sheaths of neuron axons in the white matter and thus the anisotropy of their diffusion tensor observed by MRI can provide information about the direction of the axons connecting different parts of the brain. We model the diffusion of particles confined in the space of between the bundles of cylindrical obstacles representing fibrous structures of various orientations. We have investigated the directional properties of the diffusion, by studying the angular distribution of the end point of the random walks as a function of their length, to understand the scale over which the distribution randomizes. We will show evidence of qualitative change in the behavior of the diffusion for different volume fractions of obstacles. Comparisons with three-dimensional MRI images will be illustrated.

12:39PM Q41.00008 Adhesion of a Cylindrical Bacterium in the Presence of DLVO Potential , JIAYI SHI, SINAN MUFTU, APRIL GU, KAI-TAK WAN, Northeastern university — A single cigar shape bacterium attaches to a rigid substrate (e.g. sand surface). In the presence of electrostatic double layers and van der Waals attraction according to the Derjaguin-Landau-Verwey-Overbeek (DLVO) theory, the bacterium glycoprotein shell deforms and may settle in either the primary or secondary energy minimum depending on whether it has sufficient energy to overcome the repulsive energy barrier. The adhesion-detachment mechanics is derived using a computational approach, and the followings are obtained: (i) relation between the applied load and contact area with the substrate, (ii) deformed profile at equilibrium, (iii) mechanical stress distribution in the shell, (iv) critical compressive load to force the shell going from secondary energy minimum to primary, and (v) "pull-off" forces to detach the shell from substrate. The model leads to better understanding of bacteria adhesion-aggregation-transportation, and has significant relevance to environmental and medical sciences.

12:51PM Q41.00009 Hydrodynamic behavior of tumor cells in a confined model microvessel , ZEINA S. KHAN, SIVA A. VANAPALLI, Department of Chemical Engineering, Texas Tech University — An important step in cancer metastasis is the hydrodynamic transport of circulating tumor cells (CTCs) through microvasculature. In vivo imaging studies in mice models show episodes of confined motion and trapping of tumor cells at microvessel bifurcations, suggesting that hydrodynamic phenomena are important processes regulating CTC dissemination. Our goal is to use microfluidics to understand the interplay between tumor cell rheology, confinement and fluid forces that may help to identify physical factors determining CTC transport. We use leukemia cells as model CTCs and mimic the in vivo setting by investigating their motion in a confined microchannel with an integrated microfluidic manometer to measure time variations in the excess pressure drop during cell motion. Using image analysis, variations in excess pressure drop, cell shape and cell velocity are simultaneously quantified. We find that the throughput of the technique is high enough (100 cells/min) to assess tumor cell heterogeneity. Therefore, in addition to measuring the hydrodynamic response of tumor cells in confined channels, our results indicate that the microfluidic manometer device could be used for rapid mechanical phenotyping of tumor cells.

1:03PM Q41.00010 Flow and rupture of vesicles in narrow channels , ALISON HARMAN, MARTIN BERTRAND, BELA JOOS, University of Ottawa, Ontario, Canada — Small lipid bilayer vesicles, also known as liposomes, are used for drug delivery systems in vasculature. Consequently how they deform and when they become unstable and rupture (lose their inner contents) under capillary flow is of great interest. In addition vesicles with a filling fraction of 0.6 can be considered as a simple mechanical model of red blood cells. We use coarse-grained molecular dynamics (CGMD) simulations with explicit solvent to study lipid bilayer vesicles in 3D capillary flow with filling fractions of 1.0 and 0.6. The shapes of the vesicles obtained in these simulations compare well to other experimental and theoretical studies. Using CGMD allows the study of rupture. This is in contrast to the majority of other approaches which model the bilayer as a purely elastic surface and only allow the investigation of deformation. We look at the stress profiles of these vesicles as measured by the area expansion per lipid along the membrane, and determine the location and pressure of rupture for a given confinement ratio (diameter of the vesicle divided by diameter of the channel). We also discuss the subsequent loss of inner fluid content.

1:15PM Q41.00011 Simulations of cardiovascular blood flow accounting for time dependent deformational forces[1] , AMANDA PETERS RANDLES, Harvard University, SIMONE MELCHIONNA, JONAS LATT, SAURO SUCCI, Consiglio Nazionale delle Ricerche, EFTHIMIOS KAXIRAS, Harvard University — Cardiovascular disease is currently the leading cause of death in the United States, and early detection is critical. Despite advances in imaging technology, 50% of these deaths occur suddenly and with no prior symptoms. The development and progression of coronary diseases such as atherosclerosis has been linked to prolonged areas of low endothelial shear stress (ESS); however, there is currently no way to measure ESS in vivo. We will present a patient specific fluid simulation that applies the Lattice Boltzmann equation to model the blood flow in the coronary arteries whose geometries are derived from computed tomography angiography data. Using large-scale supercomputers up to 294,912 processors, we can model a full heartbeat at the resolution of the red blood cells. We are investigating the time dependent deformational forces exerted on the arterial flows from the movement of the heart. The change in arterial curvature that occurs over a heartbeat has been shown to have significant impact on flow velocity and macroscopic quantities like shear stress. We will discuss a method for accounting for these resulting forces by casting them into a kinetic formalism via a Gauss-Hermite projection and their impact on ESS while maintaining the static geomtry obtained from CTA data.

[1]Fellowship support provided by DOE CSGF program under grant DE-FG02-97ER2530.

1:27PM Q41.00012 Using vortex corelines to analyze the hemodynamics of patient specific cerebral aneurysm models , GREG BYRNE, FERNANDO MUT, JUAN CEBRAL, George Mason University — We construct one-dimensional sets known as vortex corelines for computational fluid dynamic (CFD) simulations of blood flow in patient specific cerebral aneurysm models. These sets identify centers of swirling blood flow that may play an important role in the biological mechanisms causing aneurysm growth, rupture, and thrombosis. We highlight three specific applications in which vortex corelines are used to assess flow complexity and stability in cerebral aneurysms, validate numerical models against PIV-based experimental data, and analyze the effects of flow diverting devices used to treat intracranial aneurysms.

1:39PM Q41.00013 Picoliter droplet-based digital peptide nucleic acid clamp PCR and dielectric sorting for low abundant K-ras mutations , HUIDAN ZHANG, RALPH SPERLING, ASSAF ROTEM, LIANFENG SHAN, JOHN HEYMAN, YIZHE ZHANG, DAVID WEITZ, School of Engineering and Applied Sciences, Department of Physics, Harvard University — Colorectal cancer (CRC) remains the second leading cause of cancer-related mortality in the US, and the 5-year survival of metastatic CRC (mCRC) is less than 10%. Although monoclonal antibodies against epidermal growth factor receptor (EGFR) provide incremental improvements in survival, approximately 40% of mCRC patients with activating KRAS mutations won't benefit from this therapy. Peptide nucleic acid (PNA), a synthetic non-extendable oligonucleotides, can bind strongly to completely complementary wild-type KRAS by Watson-Crick base pairing and suppress its amplification during PCR, while any mutant allele will show unhindered amplification. The method is particularly suitable for the simultaneously detection of several adjoining mutant sites, just as mutations of codons 12 and 13 of KRAS gene where there are totally 12 possible mutation types. In this work, we describe the development and validation of this method, based on the droplet-based digital PCR. Using a microfluidic system, single target DNA molecule is compartmentalized in microdroplets together with PNA specific for wild-type KRAS, thermocycled and the fluorescence of each droplet was detected, followed by sorting and sequencing. It enables the precise determination of all possible mutant KRAS simultaneously, and the precise quantification of a single mutated KRAS in excess background unmutated KRAS.

1:51PM Q41.00014 Liquid solution delivery through the pulled nanopipette combined with QTF-AFM system[1]

, SANGMIN AN, Seoul Nation University, COREY STAMBAUGH, National Institute of Standards and Technology, GUNN KIM, Sejong University, MANHEE LEE, Harvard University, YONGHEE KIM, KUNYOUNG LEE, WONHO JHE, Seoul Nation University — Nanopipette is a versatile fluidic tool for biochemical analysis, controlled liquid delivery in bio-nanotechnology. However, most of the researches have been performed in solution based system, thus it is challenge to study nanofluidic properties of the liquid solution delivery through the nanopipette in ambient conditions. In this work, we demonstrated the liquid ejection, dispersion, and subsequent deposition of the nanoparticles via a 30 nm aperture pipette based on the quartz tuning fork – atomic force microscope (QTF-AFM) combined nanopipette system.

[1]This work is supported by NRF of Korea (OISE 0853104).

Wednesday, February 29, 2012 11:15AM - 2:15PM – Session Q51 DCMP DFD: Gels, Complex Fluids and Vesicles Boston Convention Center 154

11:15AM Q51.00001 Linear Viscoelasticity and Swelling of Polyelectrolyte Complex Coacervates

, FAWZI HAMAD, RALPH COLBY, Pennsylvania State University — The addition of near equimolar amounts of poly(diallyldimethylammonium chloride) to poly(isobutylene-alt-maleate sodium), results in formation of a polyelectrolyte complex coacervate. Zeta-potential titrations conclude that these PE-complexes are nearly charge-neutral. Swelling and rheological properties are studied at different salt concentrations in the surrounding solution. The enhanced swelling observed at high salt concentration suggests the system behaves like a polyampholyte gel, and weaker swelling at very low salt concentrations implies polyelectrolyte gel behavior. Linear viscoelastic oscillatory shear measurements indicate that the coacervates are viscoelastic liquids and that increasing ionic strength of the medium weakens the electrostatic interactions between charged units, lowering the relaxation time and viscosity. We use the time-salt superposition idea recently proposed by Spruijt, et al., allowing us to construct master curves for these soft materials. Similar swelling properties observed when varying molecular weights. Rheological measurements reveal that PE-complexes with increasing molecular weight polyelectrolytes form a network with higher crosslink density, suggesting time-molecular weight superposition idea.

11:27AM Q51.00002 Multicomponent effects in diffusion within microemulsions

, WYATT MUSNICKI, STEPHANIE DUNGAN, RONALD PHILLIPS, University of California Davis, CHEMICAL ENGINEERING AND MATERIAL SCIENCE DEPARTMENT TEAM — Holographic interferometry was used to monitor transport of hydrophobic solutes in systems containing nanometer-scale microemulsion droplets. In this technique, variations in the refractive index between a reference time and a later time are monitored via interference fringes that are formed with the help of a holographic plate. The refractive index change is driven by imposed concentration differences of either the solute (at constant surfactant concentration), or of the surfactant (at constant solute concentration). We find that, especially for hydrophobic solutes, the transport kinetics cannot be interpreted by using a pseudobinary approximation. Multicomponent interaction effects must be taken into account even at micelle concentrations as low as 6%. By performing multiple experiments with different initial concentration gradients, and extending earlier analyses of the experimental interference fringes, the multicomponent effects can be resolved, yielding results for all the relevant diffusion coefficients.

11:39AM Q51.00003 Determining the structure and properties of complex coacervate crosslinked triblock copolymer hydrogels

, DANIEL KROGSTAD, SOO-HYUNG CHOI, JASON SPRUELL, NATHANIEL LYND, EDWARD KRAMER, Materials Research Laboratory, University of California at Santa Barbara, MATTHEW TIRRELL, Institute for Molecular Engineering, University of Chicago — The mechanical properties and structures of functionalized P(AGE-b-EO-b-AGE) hydrogels utilizing complex coacervation as a physical crosslink have been studied. The effects of variables such as polymer concentration, salt concentration, pH, stoichiometric ratios and temperature have been investigated by rheology and SAXS. It was found that the organization of the cores has a very strong effect on the mechanical properties. This can be observed as the storage modulus increases significantly between 15 and 16 wt% corresponding to a transition from a disordered gel to a BCC structure. Another dramatic change is observed when the storage modulus drops between 25 and 30 wt% as the hexagonal structure becomes predominant. Just as polymer concentration causes changes in structure and thus the properties, salt concentration has a similar effect due to the electrostatic nature of the hydrogels. As salt is added, the electrostatic interactions in the cores are screened until they are weak enough that the polymers are dissolved into the matrix. The mechanical properties and the physical nature of the crosslinks lead to the possibility of these gels being used as an injectable drug delivery system.

11:51AM Q51.00004 Density mode microrheology in polyacrylamide gels

, BEATRIZ BURROLA GABILONDO, DANIEL SISAN, Georgetown University, JONATHAN LANDY, ALEX LEVINE, University of California, Los Angeles, JEFFREY URBACH, Georgetown University — In passive microrheology the viscoelastic properties of soft materials are deduced by observing thermal fluctuations of tracer particles embedded within the material, and the response function obtained from the spectrum of thermally excited modes is then related to the viscoelastic shear modulus. This approach is valid for single-component, isotropic, incompressible materials. However, for heterogeneous materials, such as hydrogels, a more comprehensive approach is needed. We measure the equilibrium density fluctuations of a cross-linked polymer gel swollen in a solvent and compare them to the predictions of the 'two–fluid' model of the dynamics of polymer gels. We will describe a direct method of extracting the longitudinal response function of a soft material based on the temporal and spatial correlations of density fluctuations of fluorescent markers, called density mode microrheology (DMM). We will also present results of applying DMM to fluorescent polyacrylamide gels in an aqueous solvent of varying viscosity and comparing them with parameters obtained from conventional macrorheology.

12:03PM Q51.00005 Effect of Polymer Molecular Weight and Synthesis Temperature on Structure and Dynamics of Microgels[1]

, KRISTA G. FREEMAN, KIRIL A. STRELETZKY, Cleveland State University — Environmentally-sensitive microgels have been synthesized under varying conditions to study the dependences on polymer molecular weight (M_W) and synthesis temperature (T_{syn}). The dynamics and structure of the synthesized microgels below and above the LCST of the polymer ($T_c \sim 41^oC$) were studied using dynamic and static light scattering spectroscopy. All microgels exhibit a volume phase transition above the LCST of the polymer and undergo a reversible 15-50-fold volume shrinkage. The size distribution, structure, deswelling ability, and temperature response of microgels strongly depend on synthesis conditions. T_{syn} dependence was studied with 1000kDa polymer. Increasing $\Delta T = T_{syn} - T_C$ yields smaller microgels with a smaller swelling ratio up to $\Delta T = 8.5^oC$, after which the trend is reversed. The amphiphilic nature of the polymer may explain this trend. T_{syn} also affects the structure of microgels; low T_{syn} yields elongated particles, while high T_{syn} microgels are more spherical. Polymer M_W directly effects microgel polydispersity and temperature response. While microgels synthesized with 1000kDa polymer are relatively monodisperse, synthesis with low M_W polymers (80-370kDa) yields systems with a large population ($R_h \sim$1000nm) precipitating out of solution and a smaller population ($R_h \sim$300nm) staying in suspension. M_W also influences the temperature response of microgels; high M_W microgels show a gradual shrinkage with increasing temperature while low M_W microgels display a delayed and sudden shrinkage at high temperatures.

[1]COTTRELL Science Award (CC6861) and CSU's FRD

12:15PM Q51.00006 Gelation and state diagram for a model nanoparticle system with adhesive hard sphere interactions , NORMAN WAGNER, University of Delaware, EBERLE AARON, NIST — We provide the first comprehensive state diagram of thermoreversible gelation in a model nanoparticle system from dilute concentrations to the attractive driven glass. We show the temperature dependence of the interparticle potential is related to a surface molecular phase transition of the brush layer using neutron reflectivity (NR) and small-angle neutron scattering (SANS) [1]. We establish the temperature dependence of the interparticle potential using SANS, dynamic light scattering (DLS), and rheology. The potential parameters extracted from SANS suggest that, for this system, gelation is an extension of the Mode Coupling Theory (MCT) attractive driven glass line (ADG) to lower volume fractions and follows the percolation transition. Below the critical concentration, gelation proceeds without competition for phase separation [2]. These results are used to develop a complete state diagram for the sticky hard sphere reference system.

[1] A.P.R. Eberle, N.J. Wagner, B. Akgun, S.K. Satija, Langmuir **26** 3003 (2010).
[2] A.P.R. Eberle, N.J. Wagner, R. Castaneda-Priego, Phys. Rev. Let. **105704** (2011).

12:27PM Q51.00007 Hydrodynamics and Rheology of Active Liquid Crystals , ZHENLU CUI, Fayetteville State University — Active liquid crystals such as swimming bacteria, active gels and assemblies of motors and filaments are active complex fluids. Such systems differ from their passive counterparts in that particles absorb energy and generate motion. They are interesting from a more fundamental perspective as their dynamic phenomenons are both physically fascinating and potentially of great biological significance. In this talk, I will present a continuum model for active liquid crystals and analyze the behavior of a suspension subjected to a weak Poiseuille flow. Hydrodynamics, stability and rheology will also be discussed.

12:39PM Q51.00008 Electrostatics-driven assembly of uni-lamellar catanionic facetted vesicles , CHEUK-YUI LEUNG, LIAM PALMER, SUMIT KEWALRAMANI, RASTKO SKNEPNEK, GRAZIANO VERNIZZI, MEGAN GREENFIELD, SAMUEL STUPP, MICHAEL BEDZYK, MONICA OLVERA DE LA CRUZ, Northwestern University — Nature utilizes shape to generate function. Organelle and halophilic bacteria wall envelopes, for example, adopt various polyhedral shapes to compartmentalize matter. The origin of these shapes is unknown. A large variety of shell geometries, either fully faceted polyhedra or mixed Janus-like vesicles with faceted and curved domains that resemble cellular shells can be generated by coassembling water-insoluble anionic (−1) amphiphiles with high valence cationic (+2 and +3) amphiphiles. Electron microscopy, X-ray scattering, theory and simulations demonstrate that the resulting faceted ionic shells are crystalline, and stable at high salt concentrations. The crystallization of the co-assembled single tail amphiphiles is induced by ionic correlations, and modified by the solution pH. This work promotes the design of faceted shapes for various applications and improves our understanding of the origin of polyhedral shells in nature.

12:51PM Q51.00009 Modeling controlled release from responsive microgel capsules[1] , ALEXANDER ALEXEEV, HASSAN MASOUD, Georgia Institute of Technology, George W. Woodruff School of Mechanical Engineering — We introduce a coarse-grained computational method that explicitly captures the release of nanoparticles and macromolecules from responsive microgel capsules. The model is based on the dissipative particle dynamics. Our simulations reveal that not only swelling, but also deswelling of hollow microcapsules can be harnessed for controlled release. We show that the release from swollen capsules is diffusion driven, whereas the release from deswelling gel capsules occurs due to the flow of encapsulated solvent that is expelled from the shrinking capsule interior. The latter hydrodynamic release is burst-like and continues only during capsule deswelling. We find that deformable polymer chains that can easily penetrate thorough membrane pores are released in larger amounts from deswelling capsules, than nanoparticles that are filtered out by shrinking membrane pores. Our simulations further demonstrate that the inclusion of rigid microrods inside deswelling capsules mitigates the membrane pore closing, and, in this fashion, provides an effective method for regulating the rate of hydrodynamic release of nanoparticles.

[1] Financial supports from the Donors of the Petroleum Research Fund administered by the ACS and from the National Science Foundation (DMR-0844115) through ICAM-I2CAM (1 Shields Avenue, Davis, CA 95616) are gratefully acknowledged.

1:03PM Q51.00010 Thermoresponsive microcapsules for controlled release of hydrophilic cargo , ESTHER AMSTAD, DAVID WEITZ, Harvard University — Thermoresponsive microcapsules that collapse upon increasing the temperature above their lower critical solution temperature (LCST) such as poly(N-isopropyl acrylamide) (PNIPAM) capsules are well known. However, capsules consisting of thermoresponsive polymers that possess an upper critical solution temperature (UCST) and therefore swell upon increasing the temperature above their UCST are scarce. We will present a microfluidic method to assemble thermoresponsive poly([2-(methacryloyloxy)-ethyl]-dimethyl-[3-sulfopropyl-ammoniumhzdroxide) (PMEDSH) microcapsules that have UCST. These capsules are in a collapsed state at room temperature and become highly water permeable upon increasing the temperature above the UCST. To simultaneously allow for encapsulation of hydrophilic cargo and enable the water based polymerization reaction of the PMEDSH shell, these microcapsules are assembled as water/water/oil emulsions using capillary microfluidic devices. The resulting PMEDSH microcapsules are envisaged as delivery vehicles and microreactors that allow for temperature induced controlled release of hydrophilic cargo. .

1:15PM Q51.00011 A Nano Engineered Membrane for Oil-Water Separation , BRIAN SOLOMON, NASIM HYDER, KRIPA VARANASI, Massachusetts Institute of Technology, VARANASI RESEARCH GROUP TEAM — Oil and water separation is an extremely costly problem in the petroleum industry. Pumping the complete emulsion to the surface requires substantially more power than pumping the oil alone. A membrane that can efficiently separate oil from water at the source would revolutionize this process. To this end a novel, layered, hierarchical thermoplastic membrane was fabricated with both nanoscale and microscale features. Modifying the length scales involved in fabrication of the membrane yields interesting and non-obvious implications. Under certain regimes, the microscale features independently control the membrane's permeability, while the microscale features control only the membrane's breakthrough pressure. By operating in this regime, separation efficiencies can be realized that are otherwise unattainable by conventional membranes. Taking it a step further, chemical treatments have been used to achieve higher hydrophobicity for the membrane by lowering the surface energy of the membrane surface. Although this research focused on oil-water separation, the results have implications for other multiphase systems and hold for many other filtration and separation technologies including in lab-on-chip devices and micro/nanofluidic devices.

1:27PM Q51.00012 Tether formation on a settling vesicle , GWENN BOEDEC, M2P2 UMR 6181 CNRS Aix Marseille University, MARC JAEGER, M2P2 UMR 6181 CNRS Aix Marseille University - Centrale Marseille, MARC LEONETTI, IRPHE UMR 6594 CNRS Aix Marseille University — When submitted to a point-like force, a phospholipid vesicle (a lipid membrane enclosing a drop) is known to develop a narrow tether. This tether formation is reminiscent of drop pinch-off, but the peculiar properties of the vesicle interface prevents the apparition of a finite-time singularity. It is shown that a settling vesicle may develop such tethered shapes, with hydrodynamic stresses acting as the pulling force. These shapes are studied numerically and theoretically, and continuous families of stationary tethered shapes are found, depending on two control parameters. Dynamics of formation is studied and it is shown that changing the initial condition can lead to complex transients, with formation of pearls onto the tether.

1:39PM Q51.00013 Electrohydrodynamic instabilities of biomimetic bilayer membranes , JACOPO SEIWERT, PETIA VLAHOVSKA, Brown university — Living cells actively maintain electrochemical potentials across their membranes, which regulates cell migration, motility, and development. In this presentation, we focus on the effect of an external electric field on membrane dynamics. We present a physical model for the dynamic coupling between transmembrane potential and deformation of biomimetic membranes. We perform linear stability analysis to clarify and quantify the effects of the lipid bilayer properties (conductivity and capacitance), and asymmetry in the embedding electrolyte solutions, on membrane deformation.

1:51PM Q51.00014 Polyoxometalate (POM) Nanocluster-Induced Phase Transition and Structural Disruption in Lipid Bilayers. , BENXIN JING, Y. ELAINE ZHU, Department of Chemical and Biomolecular Engineering, University of Notre Dame, Notre Dame, Indiana 46556, United States, MARIE HUTIN, LEROY CRONIN, School of Chemistry, University of Glasgow, Glasgow G12 8QQ, United Kingdom, CRONIN GROUP OF COMPLEX CHEMICAL SYSTEM COLLABORATION — Polyoxometalate (POM) nanoclusters that are transition metal oxygen clusters with well defined atomic coordination structures have recently emerged as new and functional nanocolloidal materials used as catalysts, anti-cancer medicines, and building blocks for novel functional materials. However, their implications to human health and environment remain poorly investigated. In this work, we examine the interaction of highly charged anionic POM nanocluters with lipid bilayers as a model cell membrane system. It is observed that upon the adsorption of anionic POMs, lipid dynamics is significantly suppressed and lipid bilayers are disrupted with resultant pore and budding-like structural formation. Direct calorimetric experiment of POM interaction with lipid bilayers of varied lipid compositions confirms the POM-induced fluid-to-gel phase transition in lipid bilayers, due to strong electrostatic interaction between POM nanocluster and lipid head groups.

2:03PM Q51.00015 Liquid-to-solid transition in suspensions of swollen microgels , JUAN JOSE LIETOR-SANTOS, ALBERTO FERNANDEZ-NIEVES, BENJAMIN SIERRA-MARTIN, Georgia Tech — We investigate the phase and non-equilibrium behavior of suspensions comprised of swollen, ionic microgels as a function of particle stiffness. We find that stiff particles exhibit all three phases observed in hard sphere suspensions, liquid, crystal and glass. For particles with intermediate stiffness, the crystal phase disappears and the microgel suspension transitions from a liquid to a glassy state at certain particle concentration. For even softer particles, no glassy state is observed. Instead the system remains liquid within the experimentally accessed concentration range. Interestingly, for microgels with intermediate stiffness, we find that the bulk modulus of individual particles seems to control the mechanical properties of the microgel suspension in the overpacked regime, emphasizing the relevance of being compressible.

Wednesday, February 29, 2012 11:15AM - 2:15PM – Session Q52 GSNP DFD: Focus Session: Extreme Mechanics - Shells & Snapping 153C

11:15AM Q52.00001 Mechanics and Dynamics of a Snapping Arch , DOUGLAS HOLMES, Virginia Tech, MATTHIEU ROCHÉ, TARUN SINHA, HOWARD STONE, Princeton University — Snap-buckling of geometric arches and thin spherical shells occur in a variety of different geometric situations, exhibiting a highly nonlinear response dictated by the geometry and material properties of the system. As this elastic instability often precedes the catastrophic failure of a mechanical system, significant work has focused on the stability criteria for such structures. In order to properly understand the biomechanics of plants that rely on this instability, and in addition use snap-buckling in the design of advanced materials, it is necessary to also develop a fundamental understanding of the timescale and post-buckling response of a snapping structure. Currently, a fundamental understanding of the osmotically-induced snap-buckling phenomena is lacking. In this presentation, we examine the osmotic swelling of a bistable arch to identify the stability criteria, relevant snap-through timescale, and the impact of geometric confinement on snap-through symmetry and damping.

11:27AM Q52.00002 Elastocapillary-driven snap-through instability , AURELIE FARGETTE, ARNAUD ANTKOWIAK, SEBASTIEN NEUKIRCH, Institut Jean le Rond d'Alembert, UPMC — The snap-through instability, which is present in a wide range of systems ranging from carnivorous plants to MEMS, is a well-known phenomenon in solid mechanics : when a buckled elastic beam is subjected to a transverse force, above a critical load value the buckling mode is switched. Here, we revisit this phenomenon by studying snap-through under capillary forces. In our experiment, a droplet (which replaces the usual dry load) is deposited on a buckled thin strip, clamped horizontally at both ends. In this setup both the weight of the drop and capillary forces jointly act toward the instability. The possibility of reverse elastocapillary snap-through, where the droplet is put under the beam, is then tested and successfully observed, showing the predominance of capillary forces at small enough scales.

11:39AM Q52.00003 Fast Motion of Plants through mechanical instability: Mechanics without Muscles[1] , QIAOHANG GUO[2], College of Materials Science and Engineering, Fuzhou University; FuJian University of Technology, Fuzhou, China, ZI CHEN, Biomedical Engineering, Washington University in St. Louis, HUANG ZHENG, Fujian Radio and Television University, Fuzhou, China, WENZHE CHEN, Fuzhou University, FuJian University of Technology, Fuzhou, China — Plants are not well known for fast motions, yet some plants such as the Venus flytrap can move in a fraction of a second to capture insects, even though they do not have nerves or muscles. This type of rapid motion has intrigued scientists for centuries. Darwin did a first systematic study on the trap closure mechanism, and considered the plant as "one of the most wonderful in the world". Thereafter, several physical mechanisms have been proposed, such as the rapid loss of turgor pressure, an irreversible acid-induced wall loosening mechanism, and the snap-through model by mechanical instability, but with no unanimous agreement among researchers. Here we propose a coupled mechanical bistable mechanism that explains the rapid closure of the Venus flytrap in a comprehensive manner, consistent with a series of experimental observations. Such bistabile behaviors are theoretically modeled and validated with table-top experiments. Based on the principles learnt from the Venus flytrap, we are also able to manufacture a preliminary "flytrap robot". Hence, it is promising to design smart bio-mimetic materials and devices with snapping mechanisms as sensors, actuators, artificial muscles and biomedical devices.

[1]The authors acknowledge National Science Foundation of China (Grant No. 11102040) and Sigma Xi GIAR program.
[2]Qiaohang Guo and Zi Chen contributed equally to this work.

11:51AM Q52.00004 Strange instabilities of simple elastic structures , DAVIDE BIGONI, DIEGO MISSERONI, University of Trento, Trento, Italy, GIOVANNI NOSELLI, Cambridge University, UK, DANIELE ZACCARIA, University of Trieste, Trieste, Italy — A class of simple elastic structures is shown exhibiting bifurcation and instability under tensile dead loading, multiple bifurcations, and softening/hardening behaviour in the postcritical regime. These structures evidences new and unexpected behaviours which are theoretically predicted and experimentally verified. These nonlinear behaviours can be exploited in the design of flexible mechanics devices and open new perspective in the control of vibrations.

12:03PM Q52.00005 Materials with Tunable Behavior due to Constrained Instabilities: Performance and Stability Analysis , DENNIS KOCHMANN, California Institute of Technology, WALTER J. DRUGAN, University of Wisconsin-Madison — Combining several materials into a composite permits the creation of new materials with overall properties tunable via a careful choice of the constituent materials with favorable specifics. The probably simplest example is a particle-matrix system, in which particles of one material enhance the mechanical behavior of the matrix material. Recent advances have confirmed that the overall performance of such a composite (e.g., its viscoelastic properties) can be dramatically altered, and stiffness and damping can be tuned to an extreme if one allows for temporarily negative elastic moduli in the inclusion. Such incremental negative moduli imply instability; e.g. a free-standing body of negative stiffness is thermodynamically unstable. However, through its geometric constraint a matrix phase can stabilize the otherwise unstable state of the inclusion phase, thus rendering the overall composite stable. In this contribution, we show, based on dynamic stability analyses, that the matrix constraint does indeed allow for the existence and use of negative moduli, and that this effect can be utilized to design novel composites of superior performance. Approaches to stabilize the negative-stiffness effect will be discussed as well as the performance of such composites.

12:15PM Q52.00006 Snap-Through of Graphene: An Elasto-Capillary Perspective , TILL WAGNER, DAMTP, University of Cambridge, DOMINIC VELLA, OCCAM, University of Oxford — Understanding the interaction between graphene flakes and various substrates is of crucial importance for nanoelectromechanical systems (NEMS) applications, among others. The 'snap-through' instability of graphene flakes placed onto corrugated substrates has recently received much attention as a potential assay for the study of this interaction. A sharp transition has been found in the morphology of the graphene between a) closely adhering to the corrugations of the substrate and b) lying almost completely flat on top. Which of these morphologies is observed depends on the geometry of the substrate and the mechanical properties of the flake. In this talk we shall focus on understanding the nature of this transition and, in particular, the 'sharpness' of the transition. We investigate how the location of snap through and its sharpness might be used to yield estimates of adhesion strength and friction with the substrate.

12:27PM Q52.00007 Electromechanical phase transition in dielectric elastomers under uniaxial tension and electrical voltage , RUI HUANG, University of Texas at Austin, ZHIGANG SUO, Harvard University — Subject to forces and voltage, a dielectric elastomer may undergo electromechanical phase transition. A phase diagram is constructed for an ideal dielectric elastomer membrane under uniaxial force and voltage, reminiscent of the phase diagram for liquid-vapor transition of a pure substance. We identify a critical point for the electromechanical phase transition. Two states of deformation (thick and thin) may coexist during the phase transition, with the mismatch in lateral stretch accommodated by wrinkling of the membrane in the thin state. The processes of electromechanical phase transition under various conditions are discussed. A reversible cycle is suggested for electromechanical energy conversion using the dielectric elastomer membrane, analogous to the classical Carnot cycle for a heat engine. The amount of energy conversion, however, is limited by failure of the dielectric elastomer due to electrical breakdown. With a particular combination of material properties, the electromechanical energy conversion can be significantly extended by taking advantage of the phase transition without electrical breakdown.

12:39PM Q52.00008 Soft Dielectrics: Heterogeneity and Instabilities , STEPHAN RUDYKH, GAL DEBOTTON, Ben-Gurion University of the Negev, KAUSHIK BHATTACHARYA, California Institute of Technology — Dielectric Elastomers are capable of large deformations in response to electrical stimuli. Heterogeneous soft dielectrics with proper microstructures demonstrate much stronger electromechanical coupling than their homogeneous constituents. In turn, the heterogeneity is an origin for instability developments leading to drastic change in the composite microstructure. In this talk, the electromechanical instabilities are considered. Stability of anisotropic soft dielectrics is analyzed. Ways to achieve giant deformations and manipulating extreme material properties are discussed. 1. S. Rudykh and G. deBotton, "Instabilities of Hyperelastic Fiber Composites: Micromechanical Versus Numerical Analyses." Journal of Elasticity, 2011. http://dx.doi.org/2010.1007/s10659-011-9313-x 2. S. Rudykh, K. Bhattacharya and G. deBotton, "Snap-through actuation of thick-wall electroactive balloons." International Journal of Non-Linear Mechanics, 2011. http://dx.doi.org/10.1016/j.ijnonlinmec.2011.05.006 3. S. Rudykh and G. deBotton, "Stability of Anisotropic Electroactive Polymers with Application to Layered Media." Zeitschrift für angewandte Mathematik und Physik, 2011. http://dx.doi.org/10.1007/s00033-011-0136-1 4. S. Rudykh, A. Lewinstein, G. Uner and G. deBotton, "Giant Enhancement of the Electromechanical Coupling in Soft Heterogeneous Dielectrics." 2011 http://arxiv.org/abs/1105.4217v1

12:51PM Q52.00009 Modeling of dielectric elastomeric materials: theory, finite element simulation, and applications , DAVID HENANN, KATIA BERTOLDI, School of Engineering and Applied Science, Harvard University — Elastomeric materials that undergo large deformations in response to an electric field have garnered attention in recent years. Applications of these dielectric elastomeric materials include actuators capable of converting electrical energy to mechanical work and energy harvesting devices that convert mechanical energy into electrical energy. Furthermore, dielectric elastomers exhibit interesting instabilities, especially under constrained geometries, opening the door for possible applications in active surfaces. Interest has increased in the mechanics community concerning the formulation of a finite-deformation constitutive theory for an electro-mechanically-coupled material. While the details of the formulation of such a theory are beginning to come into focus in the literature, numerical techniques for solving these equations are in their infancy. In this work, we have developed a finite-element-based numerical simulation capability for dielectric elastomers. This talk will highlight the application of our numerical simulation capability to dielectric elastomeric actuators, energy harvesting devices, as well instabilities of small dielectric elastomeric structures on a constraining substrate.

1:03PM Q52.00010 Giant linear voltage-induced deformation of a dielectric elastomer actuator , JIAN ZHU, School of Engineering and Applied Sciences, Harvard University, MATTHIAS KOLLOSCHE, GUGGI KOFOD, University of Potsdam, Germany, ZHIGANG SUO, School of Engineering and Applied Sciences, Harvard University — For dielectric elastomers, one of the most conspicuous attributes is large deformation of actuation induced by voltage. However, electromechanical instability may limit their deformation. In this seminar, I will illustrate how dielectric elastomers survive or eliminate electromechanical instability, through mechanical designs. For example, I will analyze a dielectric elastomer with a "pure shear" boundary condition. The membrane is first prestretched along the transverse direction, and then fixed by a rigid bar. As a result, the stretch in transverse direction is fixed, and the membrane can only be actuated along the vertical direction. The theory shows that the actuator can avert electromechanical instability, and achieve a giant linear deformation of actuation. The experiments confirm the theoretical predictions. For SEBS material, the linear strain of actuation can be 80%. For VHB material, the linear strain of actuation can be 300%. The actuator shows advantages compared to the classic designs (say, tube and circular actuators), and can be used as artificial muscles in soft robots.

1:15PM Q52.00011 Geometry-induced rigidity in pressurized elastic shells , PEDRO REIS, Massachusetts Institute of Technology, BASTIAAN FLORIJN, MIT and Leiden University, ARNAUD LAZARUS, MIT — We study the indentation of pressurized thin elastic shells, with positive Gauss curvature. In our precision desktop-scale experiments, the geometry of the shells and their material properties are custom-controlled using rapid prototyping and digital fabrication techniques. The mechanical response is quantified through load-displacement compression tests and the differential pressure is set by a syringe-pump system under feedback control. Focus is given to the linear regime of the response towards quantifying the geometry-induced rigidity of pressurized shells with different shapes. We find that this effective stiffness is proportional to the local mean curvature in the neighborhood of the locus of indentation. Combining classic theory of shells with recent developments by D. Vella et al. (2011), we rationalize the dependence of the geometry-induced rigidity on: i) the mean curvature at the point of indentation, ii) the material properties of the shell and iii) the in-out differential pressure. The proposed predictive framework is in excellent agreement with our experiments, over a wide range of control parameters. The prominence of geometry in this class of problems points to the relevance and applicability of our results over a wide range of lengthscales.

1:27PM Q52.00012 S-cones in thin shells under indentation , ALICE NASTO, Massachusetts Institute of Technology, AMIN AJDARI, Northeastern University, ARNAUD LAZARUS, MIT, ASHKAN VAZIRI, Northeastern University, PEDRO REIS, MIT — We perform a hybrid experimental and numerical investigation of the localization of deformation in indented thin spherical elastic shells. Past the initial linear response, an inverted cap develops as a Pogorelov circular ridge. For further indentation, this ridge looses axis-symmetry and sharp points of localized curvature form. We refer to these localized objects as *s-cones* (for shell-cones), in contrast with their developable cousins in plates (d-cones). We quantify the effect of systematically varying the indenter's radius of curvature (from point to plate load) on the formation and evolution of s-cones. In our precision desktop-scale experiments we use rapid prototyped elastomeric shells and rigid indenters of various shape. The mechanical response is measured through load-displacement compression tests and the deformation process is further characterized through digital imaging. In parallel, the experimental results are contrasted against nonlinear Finite Element simulations. Merging these two complementary approaches allows us to gain further physical insight towards rationalizing this geometrically nonlinear process.

1:39PM Q52.00013 Folding and buckling pathways in spherical shells with soft spots , JAYSON PAULOSE, Harvard School of Engineering and Applied Sciences, Cambridge, MA 02138, DAVID NELSON, Department of Physics, Harvard University, Cambridge, MA 02138 — Thin elastic spherical shells subject to an external pressure undergo a buckling transition when the pressure reaches a critical value. Past the buckling instability, the shell typically takes on a shape with one or more inversions that focus the elastic deformation energy within narrow circular regions on the sphere. These inversions are associated with large volume changes and hysteresis, and their location is highly sensitive to very slight imperfections in the sphere. Recently, it has been demonstrated [1] that natural pollen grains have evolved soft sectors in their hard outer walls which guide them toward particular folding pathways when their internal volume is reduced due to dessication, thus avoiding sudden and uncontrolled changes in shape. Motivated by these results, we study the effect of circular soft spots on the buckling of otherwise uniform spherical shells. Through a combination of scaling arguments and numerical simulations, we demonstrate that the shell can be tuned to follow distinct buckling pathways by varying the size and stiffness of the soft spot. [1] E. Katifori *et al*, *Proc. Natl. Acad. Sci. USA* **107**, 7635 (2010)

1:51PM Q52.00014 Buckliballs: Buckling-Induced Pattern Transformation of Structured Elastic Shells , KATIA BERTOLDI, JONGMIN SHIM, SEAS, Harvard Univ, CLAUDE J. PERDIGOU, MIT, ELIZABETH R. CHEN, University of Michigan at Ann Arbor, PEDRO M. REIS, MIT — We present a class of continuum shell structures, the buckliball, which, undergo a structural transformation induced by buckling under pressure loading. The geometry of the buckliball comprises a spherical shell patterned with a regular array of circular voids. Moreover, we show that the buckling-induced pattern transformation is possible only with five specific hole arrangements. These voids are covered with a thin membrane, thereby making the ball air tight. Beyond a critical internal pressure, the thin ligaments between the voids buckle leading to a cooperative buckling cascade of the skeleton of the ball. Both precision desktop-scale experiments and finite element simulations are used to explore the underlying mechanics in detail and proof of concept of the proposed structures. We find excellent qualitative and quantitative agreement between experiments and simulations. This pattern transformation induced by a mechanical instability opens the possibility for reversible encapsulation, over a wide range of length scales.

2:03PM Q52.00015 Wrinkling of a collapsing viscous bubble , JAMES BIRD, Boston University, HOWARD STONE, Princeton University, JOHN BUSH, Massachusetts Institute of Technology — Thin-sheets of sufficiently viscous liquid can behave similar to elastic sheets and buckle under certain external forces. A classic example is the "parachute instability" for which a ruptured viscous bubble wrinkles as it relaxes, with the explanation for the wrinkles being based on the liquid film falling under its own weight. In this talk we revisit the viscous bubble-bursting experiments and demonstrate that gravity is responsible for neither the collapse nor the resulting wrinkling instability. Using a combination of experiments and theory, we highlight the importance of capillary forces and elucidate their role in the wrinkling instability.

Wednesday, February 29, 2012 2:30PM - 5:42PM –
Session T41 DFD: Swimming, Motility and Locomotion 156B

2:30PM T41.00001 Undulatory swimming on a free surface[1] , RAMIRO GODOY-DIANA, SOPHIE RAMANANARIVO, OLIVIA GANN, BENJAMIN THIRIA, PMMH UMR7636 CNRS; ESPCI ParisTech; UPMC; U. Diderot Paris 7 — A wide variety of swimmers in nature use body undulations to generate a propulsive force, in part owing to the relative insensitivity of the principle of undulatory swimming to the value of the Reynolds number $Re = UL/\nu$, which measures the relative importance of viscous and inertial forces in the flow considered (U and L being the typical speed and length of the animal, and ν the kinematic viscosity of the surrounding fluid). Here we study a flexible filament forced to oscillate by imposing a harmonic motion to one of its extremities (using magnetic interactions) and propelling itself at the surface of a water tank. This experiment serves as a canonical model for studying the interactions between an elastic structure undergoing complex deformations and the surrounding fluid.

[1]We acknowledge support from the French National Research Agency through project No. ANR-08-BLAN-0099 and of EADS Foundation through project "Fluids and elasticity in biomimetic propulsion"

2:42PM T41.00002 Geometry, Curvature, and Locomotion , ROSS HATTON, HOWIE CHOSET, Carnegie Mellon University — Many animals and robots locomote by undulating their bodies in traveling waves. Together with the generally inextensible nature of such systems, the large deformations involved in these motions introduce significant nonlinearities into their analysis. As a result, the equations of motion for these systems are often treated as black boxes – the displacement resulting from a given input (e.g., wave amplitude) can be calculated, but the relationship between the inputs and the net displacement over a period of the wave is hidden inside the nonlinearities. Drawing on results from the geometric mechanics community, we have developed an analysis framework for high-deformation locomotion that looks inside this black box, based on three core principles: (1) Working in terms of body curvature provides a linear basis for describing nonlinear high-deformation shapes. (2) Lie bracket analysis (the exploitation of system nonlinearities through oscillatory inputs) captures the nonlinearity of the system interaction with the world. (3) Systematically optimizing the coordinate choice transforms the system nonlinearity into a form that can be geometrically analyzed over the space of body curvatures to characterize the system's ultimate locomotory capabilities.

2:54PM T41.00003 Optimizing turning for locomotion , LISA BURTON, Massachusetts Institute of Technology, ROSS HATTON, HOWIE CHOSET, Carnegie Mellon University, A.E. HOSOI, Massachusetts Institute of Technology — Speed and efficiency are common and often adequate metrics to compare locomoting systems. These metrics, however, fail to account for a system's ability to turn, a key component in a system's ability to move a confined environment and an important factor in optimal motion planning. To explore turning strokes for a locomoting system, we develop a kinematic model to relate a system's shape configuration to its external velocity. We exploit this model to visualize the dynamics of the system and determine optimal strokes for multiple systems, including low Reynolds number swimmers and biological systems dominated by inertia. Understanding how shape configurations are related to external velocities enables a better understanding of biological and man made systems. Using these tools, we can justify biological system motion and determine optimal shape configurations for robots to maneuver through difficult environments.

3:06PM T41.00004 Effect of confinements: Bending in Paramecium , AJA EDDINS, Engineering Science and Mechanics - Virginia Tech, SUNG YANG, Department of Nano-bio Materials and Electronics, GIST, Republic of Korea, CORRIE SPOON, SUNGHWAN JUNG, Engineering Science and Mechanics - Virginia Tech — Paramecium is a unicellular eukaryote which by coordinated beating of cilia, generates metachronal waves which causes it to execute a helical trajectory. We investigate the swimming parameters of the organism in rectangular PDMS channels and try to quantify its behavior. Surprisingly a swimming Paramecium in certain width of channels executes a bend of its flexible body (and changes its direction of swimming) by generating forces using the cilia. Considering a simple model of beam constrained between two walls, we predict the bent shapes of the organism and the forces it exerts on the walls. Finally we try to explain how bending (by sensing) can occur in channels by conducting experiments in thin film of fluid and drawing analogy to swimming behavior observed in different cases.

3:18PM T41.00005 ABSTRACT WITHDRAWN –

3:30PM T41.00006 Enhanced swimming motion of nematode in a non-Newtonian fluid , JIN-SUNG PARK, Department of Physics and School of Engineering and Applied Sciences, Harvard University, DAEYEON KIM, JENNIFER SHIN, School of Mechanical, Aerospace and Systems Engineering, Division of Mechanical Engineering, Korea Advanced Institute of Science and Technology, DAVID WEITZ, Department of Physics and School of Engineering and Applied Sciences, Harvard University — Small organisms navigate their complex terrestrial substrates, which have the property of non-Newtonian complex fluids. Although a large body of literature exists on the locomotion of these organisms, the previous studies are mostly limited in simple Newtonian systems. Here we present experimental results on the locomotion of Caenorhabditis elegans (C. elegans), especially investigated in colloidal suspensions that exhibit the behavior of shear thinning fluid in the range of shear rate of undulating nematode. Interestingly, we observed that the swimming speed of nematodes was gradually increased with an increase of particle volume fraction in suspensions, and this enhanced motion of nematode is closely related to the shear thinning in the fluid viscosity.

3:42PM T41.00007 Hydrodynamic Optimality in the Bacterial Flagellum , SAVERIO SPAGNOLIE, Brown University, ERIC LAUGA, University of California, San Diego — Most bacteria swim through fluids by rotating helical flagella which can take one of 12 distinct polymorphic shapes, the most common of which is the normal form used during forward swimming runs. To shed light on the prevalence of the normal form in locomotion, we have gathered all available experimental measurements of the various polymorphic forms and computed their intrinsic hydrodynamic efficiencies. The normal helical form is found to be the most efficient of the 12 polymorphic forms by a significant margin–a conclusion valid for both the peritrichous and polar flagellar families, and robust to a change in the effective flagellum diameter or length. Hence, although energetic costs of locomotion are small for bacteria, fluid mechanical forces may have played a significant role in the evolution of the flagellum.

3:54PM T41.00008 Characterisation of metachronal waves on the surface of the spherical colonial alga *Volvox carteri* , DOUGLAS BRUMLEY, MARCO POLIN, CONSTANT MOREZ, RAYMOND GOLDSTEIN, TIMOTHY PEDLEY, University of Cambridge — *Volvox carteri* is a spherical colonial alga, consisting of thousands of biflagellate cells. The somatic cells embedded on the surface of the colony beat their flagella in a coordinated fashion, producing a net fluid motion. Using high-speed imaging and particle image velocimetry (PIV) we have been able to accurately analyse the time-dependent flow fields around such colonies. The somatic cells on the colony surface may beat their flagella in a perfectly synchronised fashion, or may exhibit metachronal waves travelling on the surface. We analyse the dependence of this synchronisation on fundamental parameters in the system such as colony radius, characterise the speed and wavelength of the observed metachronal waves, and investigate possible models to account for the exhibited behaviour.

4:06PM T41.00009 Collective dynamics of active suspensions in confined geometries , DENIS BARTOLO, ESPCI-Paris Diderot University, ERIC LAUGA, UCSD, JEAN-BAPTISTE CAUSSIN, ENS Lyon — We discuss the collective dynamics of suspensions of self-propelled particles confined in confined geometries. First, we revisit the conventional description of the hydrodynamic couplings between swimmers living in thin films or in shallow channels. We show that these hydrodynamic interactions are chiefly set by the particle size and shape irrespective of the microscopic propulsion mechanism. Second, we use kinetic theory to study the phase behavior of dilute suspensions. Finally, we exploit these results to show that the hydrodynamic interactions destabilize isotropic suspensions of polar particles, thereby yielding spontaneous collective motion at large scales. In contrast, suspensions of apolar particles only display weakly cooperative motion at small scales. We also investigate the case of aligned suspensions. Their behavior is very similar to the bulk phase of dipolar swimmer. They display generic instabilities at all scales. Comparisons of our theoretical findings with experiments on artificial swimmers will be shown.

4:18PM T41.00010 Giant number fluctuations in self-propelled particles without alignment[1] , YAOUEN FILY, SILKE HENKES, Syracuse University, M. CRISTINA MARCHETTI, Syracuse University and Syracuse Biomaterials Institute — Giant number fluctuations are a ubiquitous property of active systems. They were predicted using a generic continuum description of active nematics, and have been observed in simulations of Vicsek-type models and in experiments on vibrated granular layers and swimming bacteria. In all of these systems, there is an alignment interaction among the self-propelled units, either imposed as a rule, or arising from hydrodynamic or other medium-mediated couplings. Here we report numerical evidence of giant number fluctuations in a minimal model of self-propelled disks in two dimensions in the absence of any alignment mechanism. The direction of self-propulsion evolves via rotational diffusion and the particles interact solely via a finite range repulsive soft potential. It can be shown that in this system self propulsion is equivalent to a non Markovian noise whose correlation time is controlled by the amplitude of the orientational noise.

[1]Supported by the NSF through grants DMR-0806511 and DMR-1004789. The computations were carried out on SUGAR, a cluster supported by NSF-PHY-1040231.

4:30PM T41.00011 Chemotactic Self-Organization of Bacteria in Three-Dimensions , YEVGENIY KALININ, DAVID GRACIAS, Chemical and Biomolecular Engineering, Johns Hopkins University — Self-assembly with cellular building blocks represents an important yet relatively unexplored area of research. In this talk, we describe the self-assembly of motile cells using three-dimensional (3D) patterns of chemical (such as chemoattractants) that guide cellular and organization. These 3D chemical patterns are created when chemicals are released via diffusion from lithographically patterned self-assembled polyhedral containers. We show that a number of conceptually different strategies can be utilized for chemical patterns creation. In one such strategy, the overall shape of the container can be chosen to closely match the desired 3D spatial profile. As a part of a different strategy, we discuss how the chemical patterns can be engineered by specific placement of pores on the polyhedral containers. Combining these two strategies allows chemicals to be released in a variety of spatial patterns. To demonstrate applicability of our concept to in vitro organization of living cells in specific 3D geometries, we describe chemotactic self-organization of E. coli bacteria in a variety of well-defined shapes and space curves. We link the parameters that characterize the patterns of cells and the patterns of chemicals and describe how one can engineer the spatial shape of the multicellular constructs.

4:42PM T41.00012 Collective Dynamics of a Laboratory Insect Swarm , NICHOLAS OUELLETTE, DOUGLAS KELLEY, NIDHI KHURANA, Dept. of Mech. Eng., Yale University — Self-organized collective animal behavior is ubiquitous throughout the entire biological size spectrum. But despite broad interest in the dynamics of animal aggregations, little empirical data exists, and modelers have been forced to make many assumptions. In an attempt to bridge this gap, we report results from a laboratory study of swarms of the non-biting midge *Chironomus riparius*. Using multicamera stereoimaging and particle tracking, we measure the three-dimensional trajectories and kinematics of each individual insect, and study their statistics and interactions.

4:54PM T41.00013 Dimensional transitions for coupled rotational/translational diffusion in powered nanorotors[1] , AMIR NOURHANI, Chem. Eng. Dpt., Penn State Univ, PAUL LAMMERT, Phys. Dpt., Penn State Univ, ALI BORHAN, Chem. Eng. Dpt., Penn State Univ, VINCENT CRESPI, Phys. Dpt., Penn State Univ — Small colloidal particles in fluids are well-known to engage in rotational and translational Brownian motion. Over the past several years, experimentalists have developed a new class of colloidal particles which exhibit autonomous powered motion due to consumption of chemical fuels. Two such classes of nanomotor that have been developed are linear and rotary motors. Nanorotors engage in cyclical motions due to asymmetries in the distribution of force on the surface of the particles. We have analyzed the diffusion of powered rotary motors, considering how the addition of a powered component to their motion affects their diffusional properties.

[1]Supported by MRSEC at Penn State

5:06PM T41.00014 Swimming of bio-inspired micro robots in circular channels , SERHAT YESILYURT, FATMA ZEYNEP TEMEL, Sabanci University — In recent years, bio-inspired micro swimming robots have been attracting attention for use in biomedical tasks such as opening clogged arteries, carrying out minimally invasive surgical operations, and carrying out diagnostic tasks. There have been a number of experimental and modeling studies that address swimming characteristics of micro swimmers with helical tails attached to magnetic heads that rotate and move forward in rotating external magnetic fields. We carried out experimental studies with millimeter long helical swimmers in glass tubes placed in between Helmholtz coils, and demonstrated that swimming speed increases linearly with the frequency of the external field up to the step-out frequency. In order to study interaction of the swimmer with the circular boundary we used a computational fluid dynamics model. In simulations we compared swimming speeds of robots with respect to the frequency of the external magnetic field, wavelength and amplitude of the helical tail, and distance to the channel wall. According to simulation results, as the swimmer gets closer to the boundary swimming speed and efficiency improve. However step-out frequency decreases near the wall due to increased torque to rotate the swimmer.

5:18PM T41.00015 ABSTRACT WITHDRAWN —

5:30PM T41.00016 Bristle-Bots: a model system for locomotion and swarming , LUCA GIOMI, NICO HAWLEY-WELD, L. MAHADEVAN, Harvard University — The term *swarming* describes the ability of a group of similarly sized organisms to move coherently in space and time. This behavior is ubiquitous among living systems: it occurs in sub-cellular systems, bacteria, insects, fish, birds, pedestrians and in general in nearly any group of individuals endowed with the ability to move and sense. Here we address the problem of the origin of collective behavior in systems of self-propelled agents whose only social capability is given by aligning contact interactions. Our model system consists of a collection of Bristle-Bots, simple automata made from a toothbrush and the vibrating device of a cellular phone. When Bristle-Bots are confined in a limited space, increasing their number drives a transition from a disordered and uncoordinated motion to an organized collective behavior. This can occur through the formation of a swirling cluster of robots or a collective dynamical arrest, according to the type of locomotion implemented in the single devices. It is possible to move between these two major regimes by adjusting a single construction parameter.

Thursday, March 1, 2012 8:00AM - 11:00AM —

Session V52 GSNP DFD: Focus Session: Extreme Mechanics - Biological Systems and Structures 153C

8:00AM V52.00001 Micro-actuation through swelling and tissue engineering , NICHOLAS FANG, MIT — No abstract available.

8:36AM V52.00002 Plant tendrils: Nature's hygroscopic springs , SHARON GERBODE, Harvey Mudd College, JOSHUA PUZEY, ANDREW MCCORMICK, L. MAHADEVAN, Harvard University — Plant tendrils are specialized climbing organs that have fascinated biologists and physicists alike for centuries. Initially straight tendrils attach at the tip to an elevated rigid support and then winch the plant upward by coiling into a helical morphology characterized by two helices of opposite handedness connected by a helical perversion. In his renowned treatise on twining and tendril-bearing plants, Charles Darwin surmised that coiled tendrils serve as soft, springy attachments for the climbing plant. Yet, the true effect of the perverted helical shape of a coiled plant tendril has not been fully revealed. Using a combination of experiments on Cucurbitaceae tendrils, physical models constructed from strained rubber sheets, and numerical models of helical perversions, we have uncovered that tendril coiling occurs via anisotropic shrinkage of a strip of specialized cells in the interior of the tendril. Furthermore, variations in the mechanical behavior of tendrils as they become drier and "woodier" adds a new twist to the story of tendril coiling.

8:48AM V52.00003 Radial force development during root growth measured by photoelasticity , EVELYNE KOLB, PMMH-UMR 7636 ESPCI, 10 rue Vauquelin, 75231 Paris Cedex 5, France; Université Pierre et Marie Curie - Paris 6, 75230 Paris cedex 05, France, CHRISTIAN HARTMANN, IRD-UMR 211 "BIOEMCO," 46 rue d'Ulm, 75230 Paris cedex 05, France, PATRICIA GENET, CNRS-UMR 7618, 46 rue d'Ulm, 75230 Paris cedex 05, France; Université Paris Diderot - Paris 7, 75205 Paris cedex 13, France — The mechanical and topological properties of a soil like the global porosity and the distribution of void sizes greatly affect the development of a plant root, which in turn affects the shoot development. In particular, plant roots growing in heterogeneous medium like sandy soils or cracked substrates have to adapt their morphology and exert radial forces depending on the pore size in which they penetrate. We propose a model experiment in which a pivot root (chick-pea seeds) of millimetric diameter has to grow in a size-controlled gap δ (δ ranging 0.5-2.3 mm) between two photoelastic grains. By time-lapse imaging, we continuously monitored the root growth and the development of optical fringes in the photoelastic neighbouring grains when the root enters the gap. Thus we measured simultaneously and in situ the root morphological changes (length and diameter growth rates, circumnutation) as well as the radial forces the root exerts. Radial forces were increasing in relation with gap constriction and experiment duration but a levelling of the force was not observed, even after 5 days and for narrow gaps. The inferred mechanical stress was consistent with the turgor pressure of compressed cells. Therefore our set-up could be a basis for testing mechanical models of cellular growth.

9:00AM V52.00004 Digging Like Plants: Flexible Intruders in Granular Materials , DAWN WENDELL, KATHARINE LUGINBUHL, MIT, DIEGO SOLANO, Northeastern University, PEKO HOSOI, MIT — Inspired by plant root growth in granular media, we report on the effects of flexibility on the mechanical work required to dig through granular systems. In the case where the digger is significantly thinner than the grain diameter, increased flexibility in one-dimension leads to savings of nearly 50%. A simple numerical model based solely on the variability of forces in the granular substrate and the flexibility of the digger gives similar results to those observed in experiments.

9:12AM V52.00005 Helical Buckling of Plant Roots: Mechanics and Morphology , JESSE SILVERBERG, Department of Physics, Cornell University, ROSLYN NOAR, Department of Plant Pathology, North Carolina State University, MICHAEL PACKER, Department of Physics, Cornell University, MARIA HARRISON, Boyce Thompson Institute, Cornell University, CHRIS HENLEY, ITAI COHEN, Department of Physics, Cornell University, SHARON GERBODE, School of Engineering and Applied Sciences, Harvard University — How do plant roots respond to heterogeneities in their environment as they grow? Using a simple model system consisting of a layered hydrogel, we present a controlled mechanical barrier to the roots allowing us to perturb their growth. Interestingly, we find a localized helical root morphology which forms prior to the root passing through the gel layer interface. We interpret this geometry as a combination of a purely mechanical buckling caused by continued root elongation modified by the growth medium and a simultaneous twisting near the root tip. We study the morphology of the helical deformation as the modulus of the gel is varied using 3D time-lapse imaging and demonstrate that its shape scales with gel stiffness as expected by a simple model based on the theory of buckled rods. Our results demonstrate that mechanics is sufficient to account for the shape and its variations. In addition, we hypothesize that the twisted growth near the root tip arises from a touch-activated growth response that we call thigmotorsion.

9:24AM V52.00006 Dislocations and Grain Boundaries in Optimally-Packed, Twisted Filament Bundles , AMIR AZADI, Department of Physics, University of Massachusetts, Amherst, GREGORY GRASON, Department of Polymer Science and Engineering, University of Massachusetts, Amherst — From the collagen fiber to the parallel-actin bundle, twisted and rope-like assemblies of filamentous molecules are common and vital structural elements in cells and tissue of living organisms. We study the intrinsic frustration occurring in these materials between the two-dimensional organization of filaments in cross-section and out-of-plane interfilament twist in bundles based on the non-linear continuum elasticity theory of columnar materials. We find that interfilament twist generates in-plane stresses that couple favorably to the presence of topological defects, edge dislocations, in the cross-sectional packing, thereby restructuring the ground state filament packing of twisted bundles. The stability of dislocations increases with increases in both the degree of twist and lateral bundle size. We show that in ground states of large bundles, multiple dislocations pile up into linear arrays, radial grain boundaries, whose number and length grows with bundle twist. Remarkably, the "polycrystalline" texture of these optimal packings of twisted bundles show a striking similarity to models of the "almost crystalline" cross-section of collagen fibers.

9:36AM V52.00007 Mechanical Behavior of Bio-inspired Model Suture Joints , YANING LI, Department of Mechanical Engineering, ERICA LIN, CHRISTINE ORTIZ, Department of Materials Science and Engineering, MARY BOYCE, Department of Mechanical Engineering, BOYCE GROUP/MIT COLLABORATION, ORTIZ GROUP/MIT COLLABORATION — Suture joints of varying degrees of geometric complexity are prevalent throughout nature as a means of joining structural elements while providing locally tailored mechanical performance. Here, micromechanical models of general trapezoidal waveforms of varying hierarchy are formulated to reveal the role of geometric complexity in governing stiffness, strength, toughness and corresponding deformation and failure mechanisms. Physical constructs of model composite suture systems are fabricated via multi-material 3D printing (Object Connex500). Tensile tests are conducted on samples covering a range in geometry, thus providing quantitative measures of stiffness, strength, and failure. The experiments include direct visualization of the deformation and failure mechanisms and their progression, as well as their dependence on suture geometry, showing the interplay between shear and tension/compression of the interfacial layers and tension of the skeletal teeth and the transition in failure modes with geometry. The results provide quantitative guidelines for the design and tailoring of suture geometry to achieve the desired mechanical properties and also facilitate understanding of suture growth and fusion, and evolutionary phenotype.

9:48AM V52.00008 Morphogenesis of protrusions from confined lipid bilayers mediated by mechanics , MARINO ARROYO, Universitat Politecnica de Catalunya-BarcelonaTech, MARGARITA STAYKOVA, Princeton University, MOHAMMAD RAHIMI, Universitat Politecnica de Catalunya-BarcelonaTech, HOWARD A STONE, Princeton University — Biological membranes adopt a wide range of shapes that structure and give functionality to cells, compartmentalizing the cytosol, forming organelles, or regulating their area. The formation, stabilization, and remodeling of these structures is generally attributed to localized forces or to biochemical processes (insertion of proteins, active compositional regulation). Noting that in the crowded intra and extra-cellular environments membranes are highly constrained, we explore to what extent can mechanics explain the shape of protrusions out of confined membranes. For this purpose, we developed an in-vitro system coupling a lipid bilayer to the strain-controlled deformation of an elastic sheet (Staykova et al, PNAS 108, 2011). We show that upon contracting the elastic support, tubular or spherical protrusions grow out of the adhered membrane, which can be reversibly controlled with strain and osmolarity without resorting to localized forces or chemical alterations of the bilayer. The morphologies produced by our minimal system are ubiquitous in cells, suggesting mechanics may be a simple and generic organizing principle. We can understand most of our observations in terms of a phase diagram accounting for elasticity, adhesion, and the limited amount of area and volume available.

10:00AM V52.00009 Thin-shell model for faceting of multicomponent elastic vesicles , RASTKO SKNEPNEK, MONICA OLVERA DE LA CRUZ, Northwestern University — We use a discretized version of a thin elastic shell model to show that a two-component elastic vesicle can lower its energy by faceting into a wide variety of polyhedral shapes. The elastic shell model allows us to completely remove effects of the topological defects necessarily present in spherical topology. Therefore, we show that the faceting mechanism of multicomponent elastic vesicles is fundamentally different than the familiar defect-driven buckling into icosahedra. We present a detailed gallery of faceted shapes and discuss how the interplay between bending and stretching energies leads to faceting. Present work extends our recent study of the faceting of a two-component shell in the presence of topological defects [1]. [1] G. Vernizzi, R. Sknepnek, M. Olvera de la Cruz, Proc. Natl. Acad. Sci. USA 108, 4292 (2011).

10:12AM V52.00010 Charge Effects on Mechanical Properties of Elastomeric Proteins , RAVI KAPPIYOOR, Department of Engineering Science and Mechanics, Virginia Tech, Blacksburg, VA 24061, USA, GANESH BALASUBRAMANIAN, Eduard-Zintl-Institute für Anorganische und Physikalische Chemie, Technische Universität Darmstadt, 64287 Darmstadt, Germany, DANIEL DUDEK, ISHWAR PURI, Department of Engineering Science and Mechanics, Virginia Tech, Blacksburg, VA 24061, USA — Several biological molecules of nanoscale dimensions, such as elastin and resilin, are capable of performing diverse tasks with minimal energy loss. These molecules are efficient in that the ratio of energy output to energy consumed is very close to unity. This is in stark contrast to some of the best synthetic materials that have been created. For example, it is known that resilin found in dragonflies has a hysteresis loss of only 0.8% of the energy input while the best synthetic rubber made to date, polybutadiene, has a loss of roughly 20%.We simulate tensile tests of naturally occurring motifs found in resilin (a highly hydrophilic protein), as well as similar simulations found in reduced-polarity counterparts (i.e. the same motif with the charge on each individual atom set to half the natural value, the same motif with the charge on each individual atom set to zero, and a motif in which all the polar amino acids have been replaced with nonpolar amino acids). The results show a strong correlation between charge and extensibility. In order to further understand the effect of properties such as charge on the system, we will run simulations of elastomeric proteins such as resilin in different solvents.

10:24AM V52.00011 Denaturation of Circular DNA: Supercoils, overtwist and condensation[1] , ALKAN KABAKCIOGLU, Koc University, AMIR BAR, DAVID MUKAMEL, Weizmann Institute of Science — The statistical mechanics of DNA denaturation under fixed linking number is qualitatively different from that of the unconstrained DNA. Past work suggests that the nature of this constrained melting transition is sensitive to the mechanism that relaxes the torsional stress induced on the bound portions by the loops. Quantitatively different melting scenarios are reached from two alternative assumptions, namely, that the denatured loops are formed in expense of 1) overtwist, 2) supercoils. Recent work has shown that the supercoiling mechanism results in a BEC-like picture where a macroscopic loop appears at T_c and grows steadily with temperature while no such phenomenon has been reported for the overtwisting case. By extending an earlier result, we show here that a macroscopic loop appears in the overtwisting scenario as well. We calculate its size as a function of temperature and show that the fraction of the total sum of microscopic loops decreases above T_c, with a cusp at the critical point.

[1]Supported by TUBITAK through the grant TBAG-110T618

10:36AM V52.00012 Mechanics of short rod-like molecules in tension , PRASHANT PUROHIT, University of Pennsylvania — Rod like macromolecules such as actin, DNA etc., are most commonly stretched using optical tweezers or fluid flow. In this presentation we will describe the mechanics of short rod like molecules in tension. The mechanics is dominated by the competition between tensile forces (exerted by fluid flow, or by a device, such as, optical tweezers) and the thermal fluctuations of the molecule. For molecules whose contour length is comparable to the persistence length we show that the boundary conditions play major role in determining the mechanical behavior. We use the equipartition theorem of statistical mechanics to obtain expressions for the amplitude of the transverse fluctuations of the molecule and its force-extension relation for various boundary conditions. We then apply our theory to an experiment on short fluctuating actin filaments trapped by various means. We estimate the tension in these filaments by fitting our theory to the measured values of transverse fluctuations as a function of the position along the filament.

10:48AM V52.00013 Turning by buckling: a cheap evolutionary strategy for turning among marine bacteria , KWANGMIN SON, JEFFREY GUASTO, ROMAN STOCKER, MIT — Marine bacteria have long been known to swim forward and backward ('run and reverse') by controlling the rotational direction of a 20 nm helical flagellum. Recent detailed observations have shown that these bacteria can also make sharp, $\sim 90^{\circ}$ turns, an astounding feature for a micron-scale organism with just one degree of freedom under its control. We demonstrate that a buckling instability originating from the flexible linkage ('hook') between the body and the flagellum is responsible for the reorientation. Using high-magnification (40∼100X) observations based on high-speed video microscopy (420∼1000 fps), we captured the extreme deformation of the flagellum and the hook involved in this process. The mechanical properties of the hook are finely tuned to the hydrodynamic loads experienced by the cell: the hook becomes unstable only when the compressive load during the onset of forward swimming exceeds the threshold for Euler buckling. Combining the data with a model of buckling of thin structures, we show that bacteria take advantage of the flexibility of the flagellum and the hook to generate a turn, which may represent the evolutionarily cheapest bacterial strategy to actively change direction.

Thursday, March 1, 2012 11:15AM - 2:15PM –

Session W50 DPOLY DFD: Focus Session: Micro and Nano Fluidics I: Devices and Applications

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11:15AM W50.00001 Self-Sorting of Deformable Particles in a Microfluidic Circuit[1] , MARCO A. CARTAS-AYALA, MOHAMMED RAAFAT, ROHIT KARNIK, MIT — Sorting of cells, droplets, and particles based on physical characteristics including size and deformability is important for bioseparation, diagnostics, and two-phase microfluidics. While several methods have been developed to sort particles based on size, few techniques exist for sorting of particles based on deformability. Here, we present a microfluidic circuit that enables self-sorting of deformable particles based on the hydraulic resistance that the particle induces in a microchannel, which directly relates to the particle deformability. The present method employs a feed-forward circuit that biases a microfluidic Y-junction based on the hydraulic resistance induced by the particle as it enters a sensing channel. Since particles encountering a symmetric junction follow the branch with the higher flow rate, the resulting modulation of fluid flow at the junction switches the particle into one of two output channels depending on the resistance induced by the particle. Since hydraulic resistance can be influenced by particle-wall interactions, it also opens possibilities for functionalizing the sensing channel for sorting based on specific interactions. This technique may find use in cell sorting and analysis and in two-phase microfluidics.

[1]This work was partially supported by CONACYT (Mexican Science and Technology Council), grant 205899.

11:27AM W50.00002 Accelerating Yeast Prion Biology using Droplet Microfluidics[1] , LLOYD UNG, ASSAF ROTEM, Harvard School of Engineering and Applied Sciences, DANIEL JAROSZ, Whitehead Institute for Biomedical Research, MANOSHI DATTA, Whitehead Institute for Biomedical Research, MIT Computational and Systems Biology, SUSAN LINDQUIST, Whitehead Institute for Biomedical Research, Howard Hughes Medical Institute, MIT Department of Biology, DAVID WEITZ, Harvard School of Engineering and Applied Sciences, Department of Physics — Prions are infectious proteins in a misfolded form, that can induce normal proteins to take the misfolded state. Yeast prions are relevant, as a model of human prion diseases, and interesting from an evolutionary standpoint. Prions may also be a form of epigenetic inheritance, which allow yeast to adapt to stressful conditions at rates exceeding those of random mutations and propagate that adaptation to their offspring. Encapsulation of yeast in droplet microfluidic devices enables high-throughput measurements with single cell resolution, which would not be feasible using bulk methods. Millions of populations of yeast can be screened to obtain reliable measurements of prion induction and loss rates. The population dynamics of clonal yeast, when a fraction of the cells are prion expressing, can be elucidated. Furthermore, the mechanism by which certain strains of bacteria induce yeast to express prions in the wild can be deduced. Integrating the disparate fields of prion biology and droplet microfluidics reveals a more complete picture of how prions may be more than just diseases and play a functional role in yeast.

[1]LU acknowledges funding from NSERC

11:39AM W50.00003 Microfluidic devices for droplet injection , DONALD AUBRECHT, ILKE AKARTUNA, DAVID WEITZ, Harvard University — As picoliter-scale reaction vessels, microfluidic water-in-oil emulsions have found application for high-throughput, large-sample number analyses. Often, the biological or chemical system under investigation needs to be encapsulated into droplets to prevent cross contamination prior to the introduction of reaction reagents. Previous techniques of picoinjection or droplet synchronization and merging enable the addition of reagents to individual droplets, but present limitations on what can be added to each droplet. We present microfluidic devices that couple the strengths of picoinjection and droplet merging, allowing us to selectively add precise volume to our droplet reactions.

11:51AM W50.00004 Microfluidic devices for label-free separation of cells through transient interaction with asymmetric receptor patterns[1] , S. BOSE, R. SINGH, M.H. HOLLATZ[2], C.-H. LEE, MIT, J. KARP, Brigham & Women's Hospital, R. KARNIK, MIT — Cell sorting serves an important role in clinical diagnosis and biological research. Most of the existing microscale sorting techniques are either non-specific to antigen type or rely on capturing cells making sample recovery difficult. We demonstrate a simple; yet effective technique for isolating cells in an antigen specific manner by using transient interactions of the cell surface antigens with asymmetric receptor patterned surface. Using microfluidic devices incorporating P-selectin patterns we demonstrate separation of HL60 cells from K562 cells. We achieved a sorting purity above 90% and efficiency greater than 85% with this system. We also present a mathematical model incorporating flow mediated and adhesion mediated transport of cells in the microchannel that can be used to predict the performance of these devices. Lastly, we demonstrate the clinical significance of the method by demonstrating single step separation of neutrophils from whole blood. When whole blood is introduced in the device, the granulocyte population gets separated exclusively yielding neutrophils of high purity (<10% RBC contamination). To our knowledge, this is the first ever demonstration of continuous label free sorting of neutrophils from whole blood. We believe this technology will be useful in developing point-of-care diagnostic devices and also for a host of cell sorting applications.

[1]Funding: NSF CAREER award 0952493 (R.K.), NIH grants HL-095722 and HL-097172 (J.M.K.)
[2]Current affiliation: California Institute of Technology, Pasadena, USA

12:03PM W50.00005 Role of Structural Asymmetry in Controlling Drop Spacing in Microfluidic Ladder Networks

, WILLIAM WANG, JEEVAN MADDALA, SIVA VANAPALLI, RAGHUNATHAN RENGASAMY, Texas Tech University — Manipulation of drop spacing is crucial to many processes in microfluidic devices including drop coalescence, detection and storage. Microfluidic ladder networks —where two droplet-carrying parallel channels are connected by narrow bypass channels through which the motion of drops is forbidden—have been proposed as a means to control relative separation between pairs of drops. Prior studies in microfluidic ladder networks with vertical bypasses, which possess fore-aft structural symmetry, have revealed that pairs of drops can only undergo reduction in drop spacing at the ladder exit. We investigate the dynamics of drops in microfluidic ladder networks with both vertical and slanted bypasses. Our analytical results indicate that unlike symmetric ladder networks, structural asymmetry introduced by a single slanted bypass can be used to modulate the relative spacing between drops, enabling them to contract, synchronize, expand or even flip at the ladder exit. Our experiments confirm all the behaviors predicted by theory. Numerical analysis further shows that ladders containing several identical bypasses can only linearly transform the input drop spacing. Finally, we find that ladders with specific combinations of vertical and slanted bypasses can generate non-linear transformation of input drop spacing, despite the absence of drop decision-making events at the bypass junctions.

12:15PM W50.00006 Synchronized Reinjection and Coalescence of Droplets in Microfluidics

, MANHEE LEE, Department of Physics, Harvard University, JESSE COLLINS, DONALD AUBRECHT, SHINHYUN KIM, TINA LIN, ASSAF ROTEM, School of Engineering and Applied Sciences, Harvard University, LAURA SOLOMON, College of Engineering, Temple University, DAVID WEITZ, School of Engineering and Applied Sciences, Harvard University, VINOTHAN MANOHARAN, Department of Physics & School of Engineering and Applied Sciences, Harvard University, DAVID A. WEITZ COLLABORATION — In droplet-based microfluidics, one of the essential techniques is controlled addition of desired materials into the droplets. This is best achieved through the coalescence of pairs of droplets, and therefore various methods of coalescence have been developed over the last decade. However, the coalescence of two different droplets made independently in different devices still remains a challenging problem, primarily because it is difficult to synchronize the reinjection of the different droplets before their coalescence. In addition, typical coalescers require some specific conditions such as uniform droplet-droplet distances and constant flow rate, which hinders the flexible use of coalescers in practical applications. Here we present a straightforward method for synchronizing reinjection of two kinds of droplets and coalescing them. We employ a home-made emulsion collector operated by hydrostatic pressure to reinject droplets into a device, where two kinds of droplets are driven into two opposing T-junction alternatively and then pairs of droplets are merged at the new coalescer proposed here. We use the technique to create droplets with a controlled number of colloidal particles inside, so that we can observe their self-assembly into a cluster.

12:27PM W50.00007 Probing cell mechanical properties with microfluidic devices

, AMY ROWAT, University of California, Los Angeles — Exploiting flow on the micron-scale is emerging as a method to probe cell mechanical properties with 10-1000x advances in throughput over existing technologies. The mechanical properties of cells and the cell nucleus are implicated in a wide range of biological contexts: for example, the ability of white blood cells to deform is central to immune response; and malignant cells show decreased stiffness compared to benign cells. We recently developed a microfluidic device to probe cell and nucleus mechanical properties: cells are forced to deform through a narrow constrictions in response to an applied pressure; flowing cells through a series of constrictions enables us to probe the ability of hundreds of cells to deform and relax during flow. By tuning the constriction width so it is narrower than the width of the cell nucleus, we can specifically probe the effects of nuclear physical properties on whole cell deformability. We show that the nucleus is the rate-limiting step in cell passage: inducing a change in its shape to a multilobed structure results in cells that transit more quickly; increased levels of lamin A, a nuclear protein that is key for nuclear shape and mechanical stability, impairs the passage of cells through constrictions. We are currently developing a new class of microfluidic devices to simultaneously probe the deformability of hundreds of cell samples in parallel. Using the same soft lithography techniques, membranes are fabricated to have well-defined pore distribution, width, length, and tortuosity. We design the membranes to interface with a multiwell plate, enabling simultaneous measurement of hundreds of different samples. Given the wide spectrum of diseases where altered cell and nucleus mechanical properties are implicated, such a platform has great potential, for example, to screen cells based on their mechanical phenotype against a library of drugs.

1:03PM W50.00008 Droplet Microfluidics for Virus Discovery

, ASSAF ROTEM, Department of Physics and SEAS Harvard University, SHELLEY COCKRELL, Department of Biological Sciences University of Pittsburgh, MIRA GUO, Department of Physics and SEAS Harvard University, JAMES PIPAS, Department of Biological Sciences University of Pittsburgh, DAVID WEITZ, Department of Physics and SEAS Harvard University, WEITZ LAB TEAM, PIPAS LAB TEAM — The ability to detect, isolate, and characterize an infectious agent is important for diagnosing and curing infectious diseases. Detecting new viral diseases is a challenge because the number of virus particles is often low and/or localized to a small subset of cells. Even if a new virus is detected, it is difficult to isolate it from clinical or environmental samples where multiple viruses are present each with very different properties. Isolation is crucial for whole genome sequencing because reconstructing a genome from fragments of many different genomes is practically impossible. We present a Droplet Microfluidics platform that can detect, isolate and sequence single viral genomes from complex samples containing mixtures of many viruses. We use metagenomic information about the sample of mixed viruses to select a short genomic sequence whose genome we are interested in characterizing. We then encapsulate single virions from the same sample in picoliter volume droplets and screen for successful PCR amplification of the sequence of interest. The selected drops are pooled and their contents sequenced to reconstruct the genome of interest. This method provides a general tool for detecting, isolating and sequencing genetic elements in clinical and environmental samples.

1:15PM W50.00009 Creating 3D chemical gradients with self-folding microfluidic networks

, MUSTAPHA JAMAL, YEVGENIY KALININ, AASIYEH ZARAFSHAR, DAVID GRACIAS, Chemical and Biomolecular Engineering, Johns Hopkins University — We describe the reversible self-folding of polymeric films into intricate three-dimensional (3D) microfluidic networks and investigate their utility as bio-inspired synthetic vasculature for in vitro tissue culture models. Our fabrication methodology relies on patterning of channels inside the films at the planar microfabrication stage followed by programmable self-folding of the two-dimensional patterned structures. Here self-folding action is enabled by stress gradients which develop in the films due to differential ultraviolet cross-linking and subsequent solvent conditioning. We achieved wafer-scale assembly of micropatterned geometries including helices, polyhedra and corrugated sheets. To demonstrate utility of such self-folded microfluidic devices we present localized chemical delivery of biochemicals in 3D to discrete regions of cells cultured on the curved self-assembled surfaces and in a thick, surrounding hydrogel. We believe that the devices can be used to mimic such natural self-assembled systems as leaves and tissues. Reference: M. Jamal et al., Nature Communications (2011; in press).

1:27PM W50.00010 Control of Mass Transport and Chemical Reaction Kinetics in Ultrasmall Volumes

, CHARLES COLLIER, ORNL — This talk will describe means for triggering chemical reactions for studying reaction kinetics under extreme confinement with sub-millisecond temporal resolution, including on-demand generation and fusion of femtoliter (10^{-15} L) volume water-in-oil droplets, and triggering reactions in femtoliter chambers microfabricated in poly(dimethylsiloxane) (PDMS). We demonstrated a reversible chemical toggle switch, which lays the groundwork for exploring more complex chemical and biochemical reaction sequences triggered and monitored in real time in discrete ultrasmall reactors, such as sequential and coupled enzymatic reactions. We are also developing methods to vary confinement and macromolecular crowding in ultrasmall, water-in-oil droplets and chambers micromolded in PDMS as biomimetic reaction vessels containing minimal synthetic gene circuits, in order to better understand how confinement, reduced dimensionality and macromolecular crowding affect molecular mechanisms involved in the operation and regulation of genetic circuits in living cells.

1:39PM W50.00011 Thin Polymer Films as Microvalves in Microfluidic Devices , CLEMENCE VERGNE, FABRICE MONTI, PATRICK TABELING, UMR 7083 CNRS ESPCI, YVETTE TRAN, LUCIE DEVYS, UMR 7615 CNRS ESPCI, MMN TEAM, PPMD TEAM — We report on a novel technology allowing the integration of microvalves and micropumps in lab-on-a-chips made of either soft or hard materials. The approach is based on the grafting of responsive hydrogels onto the microchannel walls. These gels undergo large volume variations by absorbing or expelling water when subjected to external stimuli (here, temperature is used as the stimulus). The hydrogel thin films we study here are chemical polymer networks that are covalently bound to the surface. The first step of the elaboration of that valves is the development of the surface-attached hydrogel thin films. The objective is to obtain hydrogel films with a wide range of thicknesses. The second step is the completion of the microfluidic system by bonding a channel on the active surface. The polymer used is thermoresponsive, at room temperature the swollen gel forms a thick layer, measuring typically several micrometers. When the system is heated above the LCST (Low Critical Solution Temperature), the gel collapses, forming a submicrometric film. In this work we introduce two different applications. In the first situation, the gel layer constitutes a variable resistance. In the second situation the polymer entirely closes the channel after swelling, thus forming a valve.

1:51PM W50.00012 Nanofluidic Transistor Circuits[1] , HSUEH-CHIA CHANG, LI-JING CHENG, YU YAN, ZDENEK SLOUKA, SATYAJYOTI SENAPATI, University of Notre Dame — Non-equilibrium ion/fluid transport physics across on-chip membranes/nanopores is used to construct rectifying, hysteretic, oscillatory, excitatory and inhibitory nanofluidic elements. Analogs to linear resistors, capacitors, inductors and constant-phase elements were reported earlier (Chang and Yossifon, BMF 2009). Nonlinear rectifier is designed by introducing intra-membrane conductivity gradient and by asymmetric external depletion with a reverse rectification (Yossifon and Chang, PRL, PRE, Europhys Lett 2009-2011). Gating phenomenon is introduced by functionalizing polyelectrolytes whose conformation is field/pH sensitive (Wang, Chang and Zhu, Macromolecules 2010). Surface ion depletion can drive Rubinstein's microvortex instability (Chang, Yossifon and Demekhin, Annual Rev of Fluid Mech, 2012) or Onsager-Wien's water dissociation phenomenon, leading to two distinct overlimiting I-V features. Bipolar membranes exhibit an S-hysteresis due to water dissociation (Cheng and Chang, BMF 2011). Coupling the hysteretic diode with some linear elements result in autonomous ion current oscillations, which undergo classical transitions to chaos. Our integrated nanofluidic circuits are used for molecular sensing, protein separation/concentration, electrospray etc.

[1]This work is supported by NSF CBET 1060652 and NSF EFRI 0937997.

2:03PM W50.00013 The Lab-on-a-Disc: Miniature Counterpart to the Lab-on-a-CD for Driving Chip-Based Microcentrifugation , LESLIE YEO, NICK GLASS, RICHARD SHILTON, PEGGY CHAN, JAMES FRIEND, Micro/Nanophysics Research Laboratory, RMIT University — The Lab-on-a-CD concept has opened up the powerful possibility of carrying out a range of microfluidic operations simply by using a compact disc (CD) player to spin a disc on which microchannels are fabricated. Nevertheless, the bulk rotation of the entire CD structure is cumbersome, expensive and unreliable - the antithesis of microfluidic philosophy. Fluid transfer on and off the chip can also be difficult. We have instead developed a miniaturized centrifugal microfluidic platform for lab-on-a-chip applications that employs surface acoustic waves to drive the rotation of a 10 mm SU-8 disc on which microfluidic structures are patterned. Unlike its macroscopic Lab-on-a-CD counterpart, the Lab-on-a-Disc does not require moving parts, and is inexpensive, disposable, and significantly smaller both in terms of the disc itself and the portable palmtop battery-operated circuit used to power the chip-sized device. In the first proof of concept, we show the capability of the Lab-on-a-Disc platform to drive capillary-based valving, mixing and size-based concentration/separation of aqueous particle suspensions in microchannels on the disc. To the best of our knowledge, the miniature Lab-on-a-Disc concept is the first microcentrifugation platform small enough to comprise a handheld device.

Thursday, March 1, 2012 11:15AM - 2:15PM –

Session W52 GSNP DFD: Focus Session: Extreme Mechanics - Fluid-Structure Interactions and Swelling 153C

11:15AM W52.00001 Capillary rise between exible walls[1] , JOSÉ BICO, THOMAS CAMBAU, ETIENNE REYSSAT, PMMH-ESPCI — We report experimental work on capillary rise of a liquid in a cell formed by parallel plates, one of which is flexible. We show that above a critical width, the cell collapses under the negative capillary pressure in the liquid. This collapse allows the liquid to rise virtually without limit between the plates. The height of the rising front is found to increase with time as $t^{1/3}$, a characteristic of capillary imbibition in a wedge.

[1]funding: ANR MecaWet-Paris 7 University-CNRS-ESPCI

11:27AM W52.00002 Motion of a rigid sphere through an elastic tube , THOMAS CAMBAU, JOSE BICO, ETIENNE REYSSAT, PMMH ESPCI PARISTECH — The transport of soft objects through small rigid channels is a common problem in the biological world : red blood cells are deformed when passing through small capillaries and polymer coils can make their way through minute pores. We study the opposite model problem of a rigid sphere moving in a narrower elastic tube. Geometry, mechanical properties of the tube and friction or lubrication conditions determine the dynamics of the entrapped sphere. We present experimental results on this problem, together with scaling law analysis.

11:39AM W52.00003 Equilibrium and stability of an elastic meniscus[1] , MARCO RIVETTI, ARNAUD ANTKOWIAK, Institut Jean le Rond d'Alembert, UPMC & CNRS — A liquid-air interface touching a solid wall gives rise to a liquid meniscus, whose shape has been well known for two centuries and results from the balance between capillarity and gravity. We investigate the case in which a portion of the liquid interface has been replaced by a soft strip, adding the elastic ingredient to this physical problem. We experimentally study the equilibrium configurations, from small to high non-linear deformations, and we compare to a 2D theoretical model. Stability of the system involving 3D corrections is also addressed.

[1]This work is supported by ANR grant ANR-09-JCJC-0022- 01 and "La Ville de Paris - Programme Emergence."

11:51AM W52.00004 Capillary-Induced Self-Organization of Soft Pillar Arrays into Moiré Patterns by Dynamic Feedback Process , SUNG KANG, NING WU, ALISON GRINTHAL, JOANNA AIZENBERG, School of Engineering and Applied Sciences, Harvard University — We report a self-organized pattern formation of polymer nanopillar arrays by dynamic feedback: two nanopillar arrays collectively structure a sandwiched liquid and pattern the menisci, which bend the pillars into Moiré patterns as it evaporates. Like the conventional Moiré phenomenon, the patterns are deterministic and tunable by mismatch angle, yet additional behaviors—chirality from achiral starting motifs and preservation of the patterns after the surfaces are separated—appear from the feedback process. Patterning menisci based on this mechanism provides a simple, scalable approach for making a series of complex, long-range-ordered structures. Reference: Sung H. Kang, Ning Wu, Alison Grinthal, and Joanna Aizenberg, Phys. Rev. Lett., **107**, 177802 (2011).

12:03PM W52.00005 Study of waving of grass using a soap film model , RAVI SINGH, Brown University, MAHESH BANDI, Okinawa Institute of Science and Technology, L. MAHADEVAN, Harvard University, AMALA MAHADEVAN, Woods Hole Oceanographic Institution, SHREYAS MANDRE, Brown University — Wind blowing over a grass field incites synchronized response from the grass blades, which appear as waves. This effect is called Mo-nami in a terrestrial setting, while in an aquatic setting it is termed as Ho-nami. We use a combination of experimental observations, numerical simulations and theoretical analysis to understand this effect. The experiment is conducted in two-dimensional realization of these phenomena in a gravity driven soap film tunnel. Nylon filaments attached to the boundaries of the soap film play the role of the grass. We provide a preliminary characterization of this analog model for the synchronized oscillations of grass.

12:15PM W52.00006 Direct measurements of flow and deformation of a free reed , PETER BUCHAK, University of Massachusetts Amherst, JOHN BUSH, Massachusetts Institute of Technology — The free reed, responsible for producing sound in a family of air-driven musical instruments, is an example of a coupled fluid-structure system engineered to vibrate efficiently at a controllable frequency. In Western free reed instruments, a flexible metal plate is clamped at one end above a slot cut into a rigid support plate. This geometry allows a constant driving pressure to produce and sustain large-amplitude vibrations. The mechanism behind this has been discussed by several investigators. However, it has yet to be verified experimentally with direct measurements of the flow speed. We present simultaneous measurements of the reed motion and the flow speed in the downstream jet, which enable characterization of the relationship between the finite-amplitude deformation of the reed and the flow.

12:27PM W52.00007 Control and Manipulation of Fluid Flow Using Elastic Deformations , BEHROUZ TAVAKOL, DOUGLAS HOLMES, Virginia Tech, GUILLAUME FROEHLICHER, HOWARD STONE, Princeton University — In this work, we utilize elastic deformations within a flexible microfluidic device via mechanical actuation to control and direct fluid flow. The device consists of a microchannel with a flexible arch prepared by buckling a thin elastic film. The deflection of the arch can be predicted and controlled using the classical theory of Euler buckling. We controlled the fluid flow rate by coupling the elastic deformation of the arch to the gap within the microchannel, and matched these experimental results analytically with a perturbation of lubrication theory and with computational simulations. These results illustrate an experimental design paradigm for the preparation of portable microchannels for chemical mixing, self-healing, and in situ diagnostics.

12:39PM W52.00008 Curling paper , ETIENNE REYSSAT, PMMH-ESPCI, L. MAHADEVAN, Harvard University — As many soft materials, paper is mechanically sensitive to humidity. Owing to its hygroscopic cellulose-based structure, it is known to wrinkle when subject to humidity fluctuations. Here, we present experimental results on the more extreme deformations observed when a sheet of tracing paper is put on a bath of water. After contact with the liquid surface, water diffuses into the hygroscopic material from below and induces differential swelling, resulting in the curling of the paper. Within seconds, a spectacular roll-up motion follows. We explain the observed shapes and curling dynamics.

12:51PM W52.00009 Walking and jumping spores , PHILIPPE MARMOTTANT, University of Grenoble and CNRS, Lab. Interdisciplinaire de Physique, France — The Equisetum plants, more commonly called "horsetail," emit 50-microns spores that are spherical in shape and present four hygroscopic arms. Under high humidity, the arms are retracted. But under lower humidity, less than 70%, the four arms deploy beautifully. With time-lapse image recordings, we show that under repeated cycles of dry and high humidity, the spores behave as random walkers, since they move by about their size in a different direction at every cycle. The process is apparently stochastic because of the complex shape of the arms and hysteretic friction of the arms on the ground. For some spores, a decrease in humidity level results in very fast jumps, the spores taking off at a typical velocity of a meter per second, as recorded on high-speed camera. With these jumps, they reach centimetric elevations, much larger than their size. The physical mechanism at the root of these "Levy-flight" jumps is still under investigation. The walking and jumping phenomena thus provide motility, which we believe is helpful for the understanding of the biological dispersion of the spores. It could also bring biomimetic inspiration to engineer new motile elastic structures.

1:03PM W52.00010 Mechanic instabilities of swelling gels , MARTINE BEN AMAR, JULIEN DERVAUX, Ecole Normale Supérieure — While the study of gels takes undoubtedly its roots within the field of physico-chemistry, the interest for gels has flourished and they progressively became an important object in the study of the mechanics of polymeric materials and volumetric growth, rising some fascinating problems, some of them remaining unsolved. Because gels are multiphase objects, their study represents an important step in the understanding of the mechanics of complex soft matter as well as for the process of shape generation in biological bodies. I will present here experiments and models of swelling gels mainly in the cylindrical geometry which mimic various growth instabilities from tumors up to the morphogenesis of tubular organs.

1:15PM W52.00011 Patterns formed by swelling-induced folding of films[1] , SACHIN VELANKAR, VICTORIA LAI, University of Pittsburgh, RICHARD VAIA, Wright Patterson Air Force Base — The solvent swelling of a thin polymer film attached to a rigid substrate is known to induce a creasing pattern on the free surface of the film. Here we show that if the film is weakly attached to the substrate, the swelling-induced compressive stress nucleates buckle delamination of the film from the substrate. Surprisingly, the buckles do not have a sinusoidal profile, instead, the film near the delamination buckles slides towards the buckles causing growth of sharp folds of high aspect ratio. The folds persist even after the solvent evaporates. Such fold formation depends on the size of the region of the film exposed to solvent. A very small region of exposure (realized by placing a small drop of solvent on the film) does not induce delamination. Remarkably, with moderate sized drops, the delamination and folding occurs around the perimeter of the drop, thus culminating in a corral with tall walls. We quantify the parameters (drop volume, film thickness) which demarcate the transitions between no fold formation, corral formation, and multiple fold formation.

[1]Funding support from AFOSR Grant number FA9550-10-1-0329 is acknowledged.

1:27PM W52.00012 Swelling-Driven Shaping of Thermally Responsive Photo-Patterned Gel Sheets , MYUNGHWAN BYUN, JUNGWOOK KIM, RYAN HAYWARD, Polymer Science and Engineering Department, University of Massachusetts Amherst, JAMES HANNA, CHRISTIAN SANTANGELO, Physics Department, University of Massachusetts Amherst — Swelling-mediated shaping of patterned non-Euclidean plates offers a powerful route to design and engineer complex 3-D structures, with possible applications in biomedicine, robotics, and tunable micro-optics. We have studied the behavior of poly(N-isopropyl acrylamide) (PNIPAm) copolymers containing pendent benzophenone units that allow the degree of crosslinking to be tuned by varying the dose of ultraviolet light. A halftone (gray) gel lithography approach, wherein two photomasks enable patterning of highly-crosslinked domains within a lightly-crosslinked matrix, is shown to provide effectively continuous variations in swelling in truly two-dimensional patterns. We show how this technique can be harnessed to form complex, reversibly actuating, 3-D structures through patterned growth.

1:39PM W52.00013 Dynamical Actuation and Pattern Formation with Local Swelling in Microgels[1] , HOWON LEE, KIN HUNG FUNG, NICHOLAS FANG, MIT — In this invited talk, we present a set of study on swelling-induced actuation and pattern formation in hydrogels of three dimensional microstructures. For example, rapid actuation of a micro hydrogel device is observed by exploiting swelling-induced snap-buckling. Utilizing its fast actuation speed, the device can even jump by itself upon wetting. It is demonstrated that elastic energy is effectively stored and quickly released from the device by incorporating elastic instability. In our experiment, the micro device could generate a snapping motion within 12 milliseconds, releasing power at a rate of 34 mW/g. We also captured the evolution circumferential buckling of tubular shaped microgels. Inhomogeneous stress develops as gel swells under mechanical constraints, which gives rise to buckling instability. A simple analytical model is developed using elastic energy to predict stability and post-buckling patterns upon swelling. Our experiment demonstrates that circumferential buckling of desired mode can be created in a prescribed manner. Our study on the mechanics of three-dimensionally microstructured gels might provide new insights for in morphogenesis in tissue engineering, and provide new gateways in many emerging fields such as soft robotics and tunable matamaterials.

[1]partially supported by NSF and LLNL LDRD

1:51PM W52.00014 Separating Viscoelasticity and Poroelasticity of Gels with Different Length and Time Scales , ANIRUDH MOHAN, XUANHE ZHAO, Soft Active Materials Laboratory, Duke University, SOFT ACTIVE MATERIALS LABORATORY, DUKE UNIVERSITY TEAM — Viscoelasticity and poroelasticity commonly coexist in polymer gels. We propose a method capable of separating the viscoelasticity and poroelasticity of gels in various mechanical tests. The viscoelastic characteristic times and the poroelastic diffusivities of a gel can define intrinsic material length scales of the gel. The experimental setup can give sample length scales, over which the solvent migrates in the gel. By setting the sample lengths to be much larger or smaller than the material lengths, the viscoelasticity and poroelasticity of the gel will manifest at different time scales in a test. Therefore, the viscoelastic and poroelastic properties of the gel can be probed separately at different time scales of the test.

2:03PM W52.00015 A constitutive theory for visco-hyperelastic gels , SHAWN CHESTER, Lawrence Livermore National Laboratory — Many gels operate in chemically saturated environments in a variety of applications. Most constitutive theories for gels are formulated using large deformation hyperelasticity coupled with fluid transport. However, in most cases the mechanical response of such gels show hysteresis and other dissipative effects which are not accounted for in present constitutive theories. We have recently developed a three dimensional continuum level theory to describe the coupled fluid permeation and large deformation response of visco-hyperelastic materials. In this work, we apply our theory and numerical simulation capability to study the indentation response among others of visco-hyperelastic gels.

Thursday, March 1, 2012 2:30PM - 5:30PM –
Session X43 DBIO DFD: Invited Session: Bacterial Swimming and Chemotaxis 157AB

2:30PM X43.00001 Bacterial Swimming and Accumulation at the Fluid Boundaries , JAY TANG, Physics Department, Brown University — Micro-organisms often reside and thrive at the fluid boundaries. The tendency of accumulation is particularly strong for flagellated bacteria such as *Escherichia coli*, *Vibro alginolyticus*, and *Caulobacter crescentus*. We measured the distribution of a forward swimming strain of *Caulobacter crescentus* near a solid surface using a three-dimensional tracking technique based on darkfield microscopy and found that the swimming bacteria accumulate heavily within micrometers from the surface, even though individual swimmers are not trapped long enough to display circular trajectories. We attributed this accumulation to frequent collisions of the swimming cells with the surface, causing them to align parallel to the surface as they continually move forward. The extent of accumulation at the steady state is accounted for by balancing alignment caused by these collisions with the rotational Brownian motion of the micrometer-sized bacteria. We performed simulations based on this model, which reproduces the measured results. Additional simulations demonstrate the dependence of accumulation on swimming speed and cell size, showing that longer and faster cells accumulate more near a surface than shorter and slower ones do. Our ongoing experimental effort also includes observation of similar phenomena at the interfaces of either water-oil or water-air, noting even stronger trapping of the swimming bacteria than near a solid surface. These studies reveal a rich range of fluid physics for further analysis.

3:06PM X43.00002 Bacterial Motility Patterns and Their Chemotaxis Behaviors , XIAOLUN WU, University of Pittsburgh — No abstract available.

3:42PM X43.00003 Periplasmal Physics: The Rotational Dynamics of Spirochetal Flagella , GREG HUBER, University of Connecticut Health Center, and University of Connecticut Storrs — Spirochetes are distinguished by the location of their flagella, which reside within the periplasm: the tiny space between the bacterial cell wall and the outer membrane. In *Borrelia burgdorferi* (the causative agent of Lyme Disease), rotation of the flagella leads to cellular undulations that drive swimming. Exactly how these shape changes arise due to the forces and torques acting between the flagella and the cell body is unknown. By applying low-Reynolds number hydrodynamic theory to the motion of an elastic flagellum rotating in the periplasm, we show that the flagella are most likely separated from the bacterial cell wall by a lubricating layer of fluid. We obtain analytical solutions for the force and torque on the rotating flagellum through lubrication analysis, as well as through scaling analysis, and find results are in close agreement numerical simulations. (Joint work with J. Yang and C.W. Wolgemuth.)

4:18PM X43.00004 Microfluidics for bacterial chemotaxis , MINGMING WU, Biological and Environmental Engineering Department, Cornell University, Ithaca, NY 14853 — The emerging microfluidic technology opens up new opportunities for bacterial chemotaxis studies. In this talk, I will present our efforts in correlating molecular level events with cellular phenotypes in bacterial chemotaxis using microfabricated device. I will present results of bacterial chemotaxis in both single and dual chemical gradients. In single gradient experiments, we demonstrated that bacteria sense the chemical concentration at a logrithmic scale, similar to sensory system in higher organism. In dual gradient experiments, we showed that the number ratio of the two different types of receptor plays a critical role in bacteria's chemotactic decision making process. Experimental results based on single cell analysis will be presented. This work is supported by the National Science Foundation and the Cornell Nanobiotechnology Center.

4:54PM X43.00005 Directional swimming in bacteria: active and passive gradient responses , ROMAN STOCKER[1], MIT — The ability to swim directionally is paramount for bacteria, in their quest for nutrients and favorable microhabitats. This ability depends on both active and passive responses to gradients. Here we bring an example from each case, based on novel microfluidic experiments that quantify the swimming behavior of bacteria. First, we describe their active response to oxygen gradients - or aerotaxis - and show the unexpected consequences of competing oxygen gradients with nutrient gradients. Then, we present the first observations of directional swimming by bacteria in response to fluid velocity gradients - or rheotaxis. Combining experiments with mathematical modeling we demonstrate that, unlike in larger organisms such as fish, rheotaxis in bacteria is passive, resulting from a previously undetected torque that originates from the chirality of the bacterial flagellum.

[1]Co-authors: Kwangmin Son, Yutaka Yawata, Marcos, Henry Fu, and Thomas Powers

Thursday, March 1, 2012 2:30PM - 5:30PM –

Session X50 DPOLY DFD: Focus Session: Micro and Nano Fluidics II: Structured or Active Surfaces and Electrotransport 162B

2:30PM X50.00001 Dynamics of self-oscillating cilia designed from active polymer gels , PRATYUSH DAYAL, AMITABH BHATTACHARYA, OLGA KUKSENOK, ANNA C. BALAZS, University of Pittsburgh — Using theory and simulations, we design active synthetic surfaces which are capable of replicating functionalities of biological cilia. In order to design such exquisite biomimetic systems we harness unique properties of polymer gels that undergo photosensitive Belousov-Zhabotinsky (BZ) reaction. Powered by internalized BZ reaction these polymer gels swell and de-swell autonomously by chemo-mechanical transduction and therefore are ideal materials for designing our system. In order to simulate the dynamics of the BZ cilia in surrounding fluid we have developed a nonlinear hybrid 3D model which captures elasto-dynamics of polymer gel and diffusive exchange of BZ reagents between the gel and the fluid. Here we show that the geometrical arrangement of cilia and the distribution of BZ activator in the fluid determine the dynamic response of the cilia. We further show that using light as an external stimulus we can sequentially modulate height of individual cilium and thereby create the "piano effect". Finally, we demonstrate that synchronized oscillations in the cilia result from the distribution of BZ-activator in the surrounding fluid. Our findings can be used to design active surfaces which can be remotely tuned depending upon the magnitude of external stimuli.

2:42PM X50.00002 Using actuated synthetic cilia to enhance microscale heat transport , ZACHARY G. MILLS, ALEXANDER ALEXEEV, Georgia Institute of Technology — We used three dimensional computer simulations to examine heat transport in a microchannel that encompasses a periodic array of actuated synthetic cilia. The channel was filled with a viscous fluid and its walls were maintained at different temperatures. Elastic synthetic cilia were attached to the bottom channel wall and were actuated by a periodic external force applied horizontally to their free ends. To model this multi-component system, we employed a thermal lattice Boltzmann model coupled with the lattice spring model. We probed how the beating cilia affect the heat transfer between channel walls, and how the thermal transport coefficient changes depending on the oscillating frequency and the relative distance between actuated filaments. Our findings could be useful for developing new methods for temperature control in microscale devices.

2:54PM X50.00003 Transport of Micro-particles by Active Cilia Arrays , AMITABH BHATTACHARYA, Department of Chemical Engineering, University of Pittsburgh, GAVIN BUXTON, Department of Science, Robert Morris University, O. BERK USTA, Center for Engineering in Medicine, Massachusetts General Hospital, ANNA. C. BALAZS, Department of Chemical Engineering, University of Pittsburgh — Biological organisms are known to use hair-like filaments called cilia to manipulate and transport particles. The coordinated motion of cilia is known to be effective at propelling surrounding fluid. In this work, we show that adhesive interaction between the actuated cilia and particulates can be crucial towards controlling particle transport. We model transport of a microscopic particle via a regular array of beating elastic cilium, whose tips experience an adhesive interaction with the particle's surface. At optimal adhesion strength, the average particle velocity is maximized. Using simulations spanning a range of cilia stiffness, particle radius, and cilia-particle adhesion strength, we explore the parameter space over which the particle can be "released," "propelled" or "trapped" by the cilia. We use a low-order model to predict parameters for which the cilia are able to attach themselves to the particle. We also study the effect of varying the particle size and stiffness on its transport properties. This is the first study that shows how both stiffness and adhesion strength are crucial for manipulation of particles by active cilia arrays.

3:06PM X50.00004 Fluid flows around nanoelectromechanical resonators , O. SVITELSKIY, V. SAUER, N. LIU, D. VICK, K.M. CHENG, M.R. FREEMAN, W.K. HIEBERT, University of Alberta Physics Department and National Institute for Nanotechnology, Edmonton AB Canada — To explore properties of fluids on a nanosize scale, we fabricated by a standard top down technique a series of nanoelectromechanical resonators (cantilevers and bridges) with widths w and thicknesses t from 100 to 500 nm; lengths l from 0.5 to 12 micron; and resonant frequencies f from 10 to 400 MHz. For the sake of purity of the experiment, the undercut in the widest (w=500 nm) devices was eliminated using the focused ion beam. To model the fluidic environment the devices were placed in the atmosphere of compressed gases (He, N_2, CO_2, Ar, H_2) at pressures from vacuum up to 20 MPa, and in liquid CO_2; their properties were studied by the real time stroboscopic optical interferometry. Thus, we fully explored the Newtonian and non-Newtonian flow damping models. Observing free molecular flow extending above atmospheric pressure, we find the fluid relaxation time model to be the best approximation throughout, but not beyond, the non-Newtonian regime, and both, vibrating spheres model and the model based on Knudsen number, to be valid in the viscous limit.

3:18PM X50.00005 Dynamic Similarity Principle for Nanoscale Resonant Devices in Gaseous Environments , CARYN BULLARD, MICHAEL ROUKES, California Institute of Technology, JOHN SADER, JIANCHANG LI, PAUL MULVANEY, The University of Melbourne — The mechanical performance of cantilevers on the nanoscale operating in atmosphere is dominated by gas damping. However, theoretical modeling of gas-solid interactions on the nanoscale is non-trivial due to the non-continuum nature of the gas flow. In addition, these gas-structure interactions can significantly affect the sensitivity of these devices. Instead of using numerical simulations to determine the gas flow and consequently, gas damping, of a nanoscale device, we used a general dynamic similarity principle to determine the gas damping of a nanoscale device by measuring the gas damping of a scaled up prototype device.

3:30PM X50.00006 Computational modeling of traveling wave electrophoresis[1] , ROBERT CORRELL, JARROD SCHIFFBAUER, LLOYD CARROLL, West Virginia University — Traveling wave electrophoresis (TWE) is a microfluidic separation technique in which electrodes flanking a microchannel apply a traveling potential wave along the channel. Charged particles, including small molecules, proteins, and nanoparticles are differentially transported along the channel at a rate dependent on their mobility. TWE is ideally suited for application in lab-on-a-chip and field deployed sensor systems. In order to fully exploit this technology, a series of computational models have been developed, including 1-dimensional and 2-dimensional models. These models allow for testable predictions of single-particle motion, and the effects of factors such as Ph and concentration upon separation efficiency. Efforts to include diffusive components within the model, and to consider the motion of bands, rather than single particles will be discussed.

[1] This work is funded through NSF CBET-1066730 and the NSF RII award EPS-1003907, for which the WV EPSCoR Office and the WVU Research Corporation provided matching funds.

3:42PM X50.00007 Activated wetting dynamics in the presence of mesoscopic surface disorder , KRISTINA DAVITT, Laboratoire de Physique Statistique - ENS, MICHAEL PETTERSEN, Washington and Jefferson College, ETIENNE ROLLEY, Laboratoire de Physique Statistique - ENS — Although disorder is commonly used to explain contact angle hysteresis, it is often neglected when considering wetting dynamics. When viscous forces are negligible, contact-line velocity is modelled by the Molecular Kinetic Theory [1], which predicts an activated motion driven by molecular jumps on preferential adsorption sites. We believe that in the presence of mesoscopic disorder, this model can be reinterpreted and that the activation length is no longer molecular-sized but is related to depinning events on the surface. This hypothesis is supported by a study of the wetting of cesium by liquid hydrogen in which it was shown that the activation length is of the order of the expected roughness [2]. However, no systematic study between the activation area and the length scale of the disorder has previously been made. We study wetting dynamics on metal films evaporated under different conditions, allowing us to obtain films with lateral grain sizes ranging from 10 to 200 nm. We find that the activation area deduced from wetting experiments is coherent with these sizes; however, its precise relation to the scale of disorder is not clear.

[1] T.D. Blake and J.M. Haynes, J. Colloid Interface Sci. 30, 421 (1969)
[2] E. Rolley and C. Guthmann, PRL 98, 166105 (2007)

3:54PM X50.00008 Experimental test of Schrodinger's first-passage-time theory using colloids in micro-channels

, SUNGCHEOL KIM, XINSHENG LING, Brown University — We report an experimental study of the first-passage-time problem of driven diffusion in micro-channels. Fluorescent microspheres of 190nm diameter are confined in channels of 1.0 micron in width and 1.0 micron depth and driven by an applied longitudinal electric field. The images are acquired by a fluorescent microscope. The time dependence of the particle positions is tracked using particle tracking algorithms. The first passage times at different electric field values are extracted from the real-time data and compared with the exact solution given by Schrodinger for the 1D biased diffusion equation with one absorbing boundary condition.

4:06PM X50.00009 Liquid-impregnated surfaces: overcoming the limitations of superhydrophobic surfaces for robust non-wetting and anti-icing surface

, J. DAVID SMITH, RAJEEV DHIMAN, ERNESTO REZA-GARDUNO, GARETH MCKINLEY, ROBERT COHEN, KRIPA VARANASI, None — In this work we address fundamental limitations of superhydrophobic surfaces for non-wetting and anti-icing applications by impregnating them with a hydrophobic liquid. The impregnating liquid serves as a barrier to the penetration of impinging water droplets and forces preferential condensation and frost formation on texture tops. We predict the thermodynamically stable wetting states based on a free energy analysis, and model the behavior of rolling droplets on liquid-impregnating surfaces. We conducted droplet impact and roll-off experiments to assess the robustness of liquid-impregnateding micro- and nano-scale textured surfaces and found that their ability to shed droplets was improved dramatically. Furthermore, environmental scanning electron microscope experiments demonstrated that frost formation as well as condensation occurs preferentially on these surfaces thereby limiting ice contact to texture tops only. Ice adhesion strength was quantified using a custom-built adhesion testing apparatus to demonstrate greatly enhanced anti-icing performance of the liquid-impregnating surfaces compared to superhydrophobic surfaces.

4:18PM X50.00010 Using Superhydrophobic Surfaces and Optical Caustics to Detect Nanoparticle Aggregation

, ANTONIO GARCIA, JAMES LINDSAY, ERIC GILMORE, None — A 3-D envelope of refracted light known as an optical caustic, can be formed by shaping an aqueous drop on a superhydrophobic surface which is used to generate a signal that is very sensitive to changes in particle size. When the sample being detected is suspended in the drop, slow evaporation induces movement that segregates smaller from larger particles, enhancing the speed of detection via induced aggregation. While the unique properties of optical caustics have been used in engineering science to evaluate stress distributions and contact between material components, they have not been widely used in diagnostics or biological analyses. This paper demonstrates how this method can track aggregation of gold nanoparticles for rapid detection of molecular disease markers using immunoassays.

4:30PM X50.00011 Droplet condensation and growth on nanotextured surfaces impregnated with an immiscible liquid

, SUSHANT ANAND, ADAM PAXSON, JONATHAN SMITH, RAJEEV DHIMAN, KRIPA VARANASI, Massachusetts Institute of Technology — For effective dropwise condensation, a surface that sheds droplets easily is desirable due to the enhancement in accompanying heat transfer. Incorporating nano-textures on the surface can enhance the droplet shedding or spreading. We demonstrate that droplet shedding can be further influenced by impregnating the nano-textured surface with a liquid which is immiscible with respect to the droplet. In this study, the dynamics of dropwise condensation on such immiscible liquid impregnated nano-textured surfaces have been investigated in pure quiescent water vapor conditions. Condensation experiments were conducted using an Environmental Scanning Electron Microscope by controlling the chamber water vapor pressure and substrate temperature. We show preferential sites for condensation and different modes under which droplets grow, depending upon the surface chemistry, surface texture, and the impregnating liquid properties. Concurrently, we show an evolution of apparent contact angles during the condensation process on the impregnated surfaces.

4:42PM X50.00012 Molecular diffusion and tensorial slip at surfaces with periodic and random nanoscale textures[1]

, NIKOLAI PRIEZJEV, Michigan State University — The influence of periodic and random surface textures on the flow structure and effective slip length in Newtonian fluids is investigated by molecular dynamics (MD) simulations. This study is motivated by the possibility to generate transverse flows in microfluidics devices to enhance mixing and separation processes. We consider a situation where the typical pattern size is smaller than the channel height and the local boundary conditions at wetting and nonwetting regions are characterized by finite slip lengths. In case of anisotropic textures, the interfacial diffusion coefficient of fluid molecules near heterogeneous surfaces correlates well with the effective slip length as a function of the shear flow direction with respect to the texture orientation. In addition, it was found that the angular dependence of the effective slip length obtained from MD simulations is in good agreement with hydrodynamic predictions provided that the pattern size is larger than several molecular diameters. These findings lend support for the microscopic justification of recently introduced tensor formulation of the effective slip boundary conditions in the case of noninertial flows of Newtonian fluids over smooth surfaces with nanoscale anisotropic textures.

[1]Funding from NSF (CBET-1033662) is gratefully acknowledged.

4:54PM X50.00013 Wetting as a basis for a highly selective colorimetric indicator for organic liquids[1]

, IAN BURGESS, School of Engineering and Applied Sciences, Harvard University, KEVIN RAYMOND, NATALIE KOAY, Wyss Institute for Biologically Inspired Engineering, Harvard University, ANNA SHNEIDMAN, MATHIAS KOLLE, MARKO LONCAR, JOANNA AIZENBERG, School of Engineering and Applied Sciences, Harvard University — We present a colorimetric indicator for organic liquids that couples distinct macroscopic color patterns to minute differences in liquids' intrinsic wettability to a surface. We find that when a liquid percolates through the pores of large-area, defect-free silica inverse-opal films, a highly consistent re-entrant geometry leads to sharply defined threshold wettability for liquid infiltration, occurring at intrinsic contact angles near 20°. The structure also acts as a 3D photonic crystal, producing bright iridescent color that disappears when infiltrated with liquid, coupling the highly selective wetting observed to an easy-to-visualize colorimetric response. Combining a percolation model and FDTD optical simulations, we estimate the selectivity of the colorimetruic response. In addition, we present a technique to generate precisely controlled spatial patterns of surface chemistry throughout the porous network. This lets us tailor the wettability threshold to specific liquids across a continuous range. Using these techniques, we demonstrate the applicability of this indicator to colorimetrically distinguish: i) ethanol-water mixtures varying by only 2.5% in concentration; ii) hexane, heptane, octane, nonane, and decane; and iii) samples of gasoline (regular unleaded) and diesel.

[1]Supported by the AFOSR Award # FA9550-09-1-0669-DOD35CAP.

5:06PM X50.00014 Drag Measurements in Laminar Flows over Superhydrophobic Porous Membranes

, OZGUR OZSUN, VICTOR YAKHOT, KAMIL L. EKINCI, Boston University — An anomalous hydrodynamic response has recently been observed in oscillating flows on mesh-like porous superhydrophobic membranes.[1] This effect was attributed to a stable Knudsen layer of gas at the solid-liquid interface. In this study, we investigate laminar channel flow over these porous superhydrophobic membranes. We have fabricated surfaces with solid area fraction ϕ_s, which can maintain intimate contact with both air and water reservoirs on either side. Typical structures have linear dimensions of 1.5 mm $\times$ 15 mm $\times$ 1 μm and pore area of 10 μm $\times$ 10 μm. The surfaces are enclosed with precisely machined plastic microchannels, where pressure driven flow of DI water is generated. Pressure drop across the microchannels is measured as a function of flow rate. Slip lengths are inferred from the Poiseuille relation as a function of ϕ_s and compared to that of similar standard superhydrophobic surfaces, which lack intimate contact with an air reservoir.

[1]S. Rajauria, O. Ozsun, J. Lawall, V. Yakhot, and K. L. Ekinci, Phys. Rev. Lett. 107, 174501 (2011)

5:18PM X50.00015 Thermo-super-hydrophobic effect , JERZY M. FLORYAN, The University of Western Ontario — Super-hydrophobic effect involves capture of gas bubbles in pores of solid wall. These bubbles separate moving liquid from the solid surface resulting in a substantial reduction of shear drag experienced by the liquid. The super-hydrophobic effect requires presence of two phases and thus drag reduction can be accomplished only for liquids. Thermo-super-hydrophobic effect takes advantage of the localized heating to create separation bubbles and thus can work with single phase flow systems. Analysis of a simple model problem shows that this effect is very strong in the case of small Re flows such as those found in micro-channels and can reduce pressure drop down to 50% of the reference value if the heating pattern as well as the heating intensity are suitable chosen. The thermo-super-hydrophobic effect becomes marginal when Re increases above a certain critical value.

Thursday, March 1, 2012 2:30PM - 5:18PM –

Session X52 GSNP DFD: Focus Session: Extreme Mechanics - Fracture, Friction, and Frequencies 153C

2:30PM X52.00001 Geometry of Tearing: crack propagation in brittle sheets[1] , BENOIT ROMAN, JOSE BICO, PMMH CNRS/ESPCI/UPMC/Paris7 - Paris France, ENRIQUE CERDA, EUGENIO HAMM, FRANCISCO MELO, VICTOR ROMERO, Departamento de Fisica, Universidad de Santiago de Chile — We experiment the fracture of thin object everyday when trying to open a packaging. From a physics point of vew, the propagation of cracks in thin brittle elastic sheets appears to be remarkably reproducible, with very regular crack path. We will present some examples where the crack path can be predicted using classical arguments in fracture and geometrical tools: this is another example where geometry plays a central role in the mechanics of thin sheets.

[1]We thank ANR MecaWet

2:42PM X52.00002 Spiral and croissant crack in drying thin films , JOEL MARTHELOT, BENOIT ROMAN, JOSE BICO, PMMH ESPCI ParisTech, ETIENNE BARTHEL, JEREMIE TEISSEIRE, DAVY DALMAS, SVI CNRS Saint Gobain, FRANCISCO MELO, USACH — Drying mud or crazing in ceramics glaze leads to familiar hierarchical cracks network where a new crack connects perpendicularly to older ones. We report unusual spirals and croissants crack patterns in methylsiloxane drying thin films moderately adhering on a substrate. Such cracks are also observed in a very different situation when magnetron sputtering multilayers are under external tension. The amplitude and wavelength of the pattern are robusts and are orders of magnitude larger than the thickness of the layer. The propagation of the spiral and croissant cracks occurs in a narrow range of adhesion energy between the film and the substrate and strain in the film. We will show how the propagation is driven by a cooperation between fracture and adhesion.

2:54PM X52.00003 Rupture of a highly stretchable acrylic dielectric elastomer , GEORGE PHARR, Harvard University, JEONG-YUN SUN, Seoul National University and Harvard University, ZHIGANG SUO, Harvard University — Dielectric elastomers have found widespread application as energy harvesters, actuators, and sensors. In practice these elastomers are subject to large tensile stretches, which potentially can lead to mechanical fracture. In this study, we have examined fracture properties of the commercial acrylic elastomer VHB 4905. We have found that inserting a pre-cut into the material drastically reduces the stretch at rupture from $\lambda_{rup} = 9.43\pm1.05$ for pristine samples down to only $\lambda_{rup} = 3.63\pm0.45$ for the samples with a pre-cut. Furthermore, using "pure-shear" test specimens with a pre-crack, we have measured the fracture energy and stretch at rupture as a function of the sample geometry. The stretch at rupture was found to decrease with sample height, which agrees with an analytical prediction. Additionally, we have measured the fracture energy as a function of stretch-rate. The apparent fracture energy was found to increase with stretch-rate from $\Gamma \approx 1500$ J/m^2 to $\Gamma \approx 5000$ J/m^2 for the investigated rates of deformation. This phenomenon is due to viscoelastic properties of VHB 4905, which result in an apparent stiffening for sufficiently large stretch-rates.

3:06PM X52.00004 How does adhesion impact the formation of telephone cord buckles? , ETIENNE BARTHEL, JEAN-YVON FAOU, SERGEY GRACHEV, CNRS / Saint-Gobain, GUILLAUME PARRY, SIMAP — Compressively stressed thin films with low adhesion frequently buckle into telephone cords. Although telephone cord buckles have been studied for decades, no complete understanding of their origin and propagation has so far been presented. Here, using Finite Element Analysis, we have coupled non-linear plate deformation with a cohesive zone model to simulate the kinematics of a propagating telephone cord buckle. On the experimental side, we have developped model thin films with a precise adjustment of both adhesion and residual stresses. From the comparison of the simulations with some experimental observations, we propose a generic mechanism for the formation of telephone cord buckles. Proper inclusion of the dependence of interfacial toughness upon mode mixity proved to be central to the success of the approach so that this clarification of the mechanism of telephone cord formation promises better understanding of interfacial toughness through the analysis of buckle morphology.

3:18PM X52.00005 Nonlinear modal interactions in a microcantilever[1] , HIDDE WESTRA, HERRE VAN DER ZANT, WARNER VENSTRA, Kavli Institute of Nanoscience, Delft University of Technology — We study the nonlinear interactions between vibrational modes in a microcantilever. The flexural-flexural, torsional-torsional and torsional-flexural modal interactions are investigated theoretically and experimentally. In a cantilever, the nonlinearity arising from geometrical and inertial effects couples the different modes. The motion of one mode influences the resonance frequency of the other modes. We show that depending on the amplitude of one mode, both frequency stiffening and weakening of the other mode occurs. The modal interactions in clamped-clamped beam resonators is recently studied, and several applications have been proposed. Microcantilevers are frequently used in instrumentation, and the modal interactions presented here enable such schemes, including Q-factor tuning and self-detection.

[1]The authors acknowledge financial support from the Dutch funding organization FOM (Physics for Technology)

3:30PM X52.00006 Effects of Roughness and Inertia on Precursors to Frictional Sliding[1] , MARK O. ROBBINS, K. MICHAEL SALERNO, Johns Hopkins University — Experiments show that when a PMMA block on a surface is normally loaded and driven by an external shear force, contact at the interface is modified in discrete precursor slips prior to steady state sliding.[1] Our simulations use an atomistic model of a rough two-dimensional block in contact with a flat surface to investigate the evolution of stress and displacement along the contact between surfaces. The talk will show how local and global stress conditions govern the initiation of interfacial cracks as well as the spatial extension of the cracked region. Inertia also plays an important role in determining the number and size of slips before sliding and influences the distribution of stresses at the interface. Finally, the geometry of surface asperities also influences the interfacial evolution and the total friction force. The relationship between the interfacial stress state and rupture velocity will also be discussed. [1] S.M. Rubinstein, G. Cohen and J. Fineberg, PRL 98, 226103 (2007)

[1]Supported by AFOSR FA9550-0910232

3:42PM X52.00007 Scratch test as a fracture process: from soft to hard materials , ANGE-THERESE AKONO, Dept of Civil and Environmental Engineering, Massachusetts Institute of Technology, Cambridge, MA, USA, PEDRO MIGUEL REIS, Dept of Civil and Environmental Engineering & Dept of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA, USA, NICHOLAS XAVIER RANDALL, CSM Instruments, Needham, MA, USA, FRANZ-JOSEF ULM, Dept of Civil and Environmental Engineering, Massachusetts Institute of Technology, Cambridge, MA, USA — The scratch test consists of driving a probe, at a certain depth, through a material and is most likely the oldest technique for the mechanical characterization of materials. Although it is widely used in strength testing, the presence of residual chips during the process suggests that a fracture mechanism is at play. We investigate the link between the material fracture properties, the probe geometry and the resulting forces using a combination of precision experiments and Linear Elastic Fracture Mechanics analysis. An analytical model is developed that is applicable both at the macro and micro scale, and that can take into account different probe geometries. Rationalizing the mechanics involved allows us to introduce a novel experimental technique to accurately determine the fracture toughness from scratch tests. Application of this technique to mechanical testing on metals, polymers and ceramics yields values for the fracture toughness that are in excellent agreement with conventional methods such as the three-point bending test, albeit in a way that is less destructive and more scalable. As such, our method to determine materials fracture properties represents an important new development in the field of mechanical micro-characterization.

3:54PM X52.00008 Sliding on a Nanotube: Interplay of Friction, Deformations and Defects , HSIANG-CHIH CHIU, SUENNE KIM, School of Physics, Georgia Institute of Technology , ERIO TOSATTI, International School for Advanced Studies (SISSA), and CNR-IOM Democritos, CHRISTIAN KLINKE , Institute of Physical Chemistry, University of Hamburg, ELISA RIEDO, School of Physics, Georgia Institute of Technology — Carbon nanotubes (CNT) have applications as composite material reinforcements and components in nanodevices due to their exceptional physical properties. However, CNTs have structural defects that can change their mechanical properties. For applications, CNTs have to be in contact with other surfaces, thus it is important to understand how defects change their frictional properties. Here, we show that defects can impact the frictional properties of supported Arc Discharge (AD) and Chemical Vapor Deposition (CVD) grown CNTs by sliding an AFM tip along (longitudinal) and across (transverse) the CNT axis. Larger friction coefficient is found during transverse sliding due to a lateral CNT deformation (called hindered rolling) that causes extra friction dissipation which is absent during longitudinal sliding.[1] A friction anisotropy, defined as the ratio of shear strength measured during both sliding directions, can be as high as 13.7 for AD CNTs but less than 6 for CVD CNTs. Extra defects in CVD CNTs couple both sliding motions, resulting in more energy dissipation and higher longitudinal friction. A simple analytical model is developed to explain the observed experimental behavior. Our finding provides a better understanding of tribological properties of individual CNT at the nanoscale. [1] M. Lucas et al., Nature Mater. 8, 876 (2009)

4:06PM X52.00009 Graphene Morphology on Nano-Patterned Electronic Substrates , GUANGXU LI, CIHAN YILMAZ, XIAOHONG AN, SIVASUBRAMANIAN SOMU, SWASTIK KAR, AHMED BUSNAINA, KAI-TAK WAN, Northeastern University, DEPARTMENT OF MECHANICAL AND INDUSTRIAL ENGINEERING COLLABORATION, NSF NANOSCALE SCIENCE AND ENGINEERING CENTER FOR HIGH-RATE NANOMANUFACTURING COLLABORATION, DEPARTMENT OF PHYSICS COLLABORATION — In order to get high quality of graphene for the application in electronic devices, good transfer of graphene prepared by mechanical exfoliation or chemical vapor deposition is always required and substrate with flat surface is preferred to avoid the crack and destruction of the thin sheets. Here, we studied the graphene morphology on nano-patterned electronic substrates by transferring graphene grown from chemical vapor deposition onto the gold nano pillar patterns on silicon substrate. The adhesion between the graphene and the gold surface makes the flexible thin membrane conform to the substrate geometry and form a series of blisters. By measuring the blister radius and height, the adhesion energy of graphene and gold substrate can be deduced. In the meantime, the morphology of graphene on the pillar patterns was found to strongly related to the adhesion energy, the height and separation of pillars. By changing these parameters, the blisters may decrease size or expand to coalesce. The critical separation between pillars and the critical height of pillars were predicted to avoid the coalescence of the blisters when the adhesion energy was fixed. The results obtained here can be useful to increase the performance and the durability of the graphene based device.

4:18PM X52.00010 Graphene Blister Adhesion Mechanics[1] , NARASIMHA BODETTI, STEVEN KOENIG, JIANLIANG XIAO, SCOTT BUNCH, MARTIN DUNN, University of Colorado — We describe graphene blister configurations to study the elasticity of mono- and multi-layer graphene as well as the adhesion of the blister to an SiO2 substrate. We create blisters by depositing graphene on a chip containing etched cavities of a prescribed volume. The chip is placed in a high-pressure chamber where the cavities are charged to a prescribed pressure. When the chip is removed from the chamber the pressure difference across the membrane causes it to bulge, while the number of gas molecules in the chamber remains constant. As the pressure is increased the membrane continues to bulge and at a critical pressure can delaminate (in a stable or unstable manner) permitting extraction of the adhesion energy from a combination of theory and measurements of the deformed blister configuration. We describe these experiments and develop a thermodynamic model of the system that identifies interesting nonlinear effects as the membranes deform including instabilities, delamination, and adhesion hysteresis, depending on the configurational parameters. We use the theory and experiments together to determine for the first time the adhesion energy between graphene and SiO2, as well as explore the interesting mechanics that occur.

[1]National Science Foundation, DARPA

4:30PM X52.00011 Novel method for simulation of structural post buckling , RACHMADIAN WULANDANA, Dept. of Mechanical Engineering and Materials Science, University of Pittsburgh, Pittsburgh, PA, SACHIN VELANKAR, Dept. of Chemical and Petroleum Engineering, University of Pittsburgh, Pittsburgh, PA — A new FEM-based method for simulating the onset of buckling instabilities and the post-buckling evolution is developed. The method consists of creating a random spatial perturbation of the elastic modulus and applying a step-by-step loading to approach the critical state and beyond. Prior to buckling, the non-uniform modulus triggers micro bending and lateral deformation. As the compressive load progresses, the micro displacement grows non-linearly causing the system to be biased toward the mode that minimizes energy. The system buckles in that mode and the post-buckling deformation can be examined. The technique has been applied to several buckling cases. The results show quantitative agreement with theory and experiments. For problems with continuously-distributed buckling modes and critical values that are close from one to another, the method is able to automatically select the correct critical configuration. Unlike other perturbation methods that are inspired by either Eigen vectors or experimental data, the current method does not need a priori knowledge of the expected buckling mode. This is especially useful in complex problems (e.g. wrinkling of stretched films) for which linear eigenvalue analysis cannot predict the critical conditions.

4:42PM X52.00012 Buckling morphologies of crystalline shells with frozen defects , EE HOU YONG, Harvard University, PROF L. MAHADEVAN (HARVARD UNI.) COLLABORATION — The crumpling of spherical crystalline lattices where the topological defects are frozen is studied. The geometry of the crumpled membrane is found to depend on the set of topological defects and more exotic defect sets can result in crumpled shapes resembling that of the Platonic and Archimedean solids. The phase diagram of the crumpled spheres can be categorized by two dimensionless numbers h/R (aspect ratio) and R/a (lattice ratio), where h is the thickness of the shell, R is the radius of the initial sphere and a is the average bond length of the triangulation. The shapes of the crumpled membrane can be understood using rotationally invariant quantities formed from spherical harmonics coefficients and a Landau free energy can be written, involving quadratic and cubic rotational invariants. Shells with different topological defects have qualitatively different hysteresis behaviors and the transitions appear to be first order in general.

4:54PM X52.00013 Do tidal stresses trigger large earthquakes early? , BRADEN BRINKMAN, MICHAEL LEBLANC, University of Illinois at Urbana-Champaign, JONATHAN UHL, None, YEHUDA BEN-ZION, University of Southern California, KARIN DAHMEN, University of Illinois at Urbana-Champaign — The effect of tidal or other periodic stresses on the timing of large earthquakes is a hotly debated topic in geophysics and rock-friction or granular physics communities. I discuss a simple probabilistic model which captures the main qualitative features of several rock-friction or granular experiments and may resolve some outstanding discrepancies between different experimental results. With sufficiently accurate measurements, quantitative predictions for real experiments are possible, including the number of measured events needed to detect correlations between periodic stresses and large slip events for given amplitudes and frequencies.

5:06PM X52.00014 Tattoo-Like Strain Gauges Based on Silicon Nano-Membranes , NANSHU LU, University of Texas at Austin, LU RESEARCH GROUP TEAM — This talk reports the in vivo measurement of tissue deformation through adhesive-free, conformable lamination of a tattoo-like elastic strain gauge consisted of piezoresistive silicon nano-membranes strategically integrated with tissue-like elastomeric substrates. The mechanical deformation in soft tissues cannot yet be directly quantified due to the lack of enabling tools. While stiff strain gauges for structural health monitoring have long existed, biological tissues are soft, curvilinear and highly deformable in contrast to civil or aerospace structures. An ultra-thin, ultra-soft, tattoo-like strain gauge that can conform to the convoluted surface of human body and stay attached during locomotion will be able to directly quantify tissue deformation without affecting the mechanical behavior of the tissue. While single crystalline silicon is known to have the highest gauge factor and best elastic response, it is intrinsically stiff and brittle. To achieve strain gauges with high compliance, high stretchability and reasonable sensitivity, single crystalline silicon nano-membranes will be transfer-printed onto polymeric support through carefully engineered stamps. The thickness and length of the Si strip will be chosen according to theoretical and numerical mechanics analysis which takes into account for the tradeoff between stretchability and sensitivity.

Friday, March 2, 2012 8:00AM - 11:00AM –

Session Y50 DPOLY DFD: Focus Session: Micro and Nano Fluidics III: Microtransport and Thermophysical Properties 162B

8:00AM Y50.00001 Cavitation in confined water: ultra-fast bubble dynamics , OLIVIER VINCENT, PHILIPPE MARMOTTANT, CNRS and University of Grenoble, Lab. Interdiscplinaire de Physique, France — In the hydraulic vessels of trees, water can be found at negative pressure. This metastable state, corresponding to mechanical tension, is achieved by evaporation through a porous medium. It can be relaxed by cavitation, i.e. the sudden nucleation of vapor bubbles. Harmful for the tree due to the subsequent emboli of sap vessels, cavitation is on the contrary used by ferns to eject spores very swiftly. We will focus here on the dynamics of the cavitation bubble, which is of primary importance to explain the previously cited natural phenomena. We use the recently developed method of artificial tress, using transparent hydrogels as the porous medium. Our experiments, on water confined in micrometric hydrogel cavities, show an extremely fast dynamics: bubbles are nucleated at the microsecond timescale. For cavities larger than 100 microns, the bubble "rings" with damped oscillations at MHz frequencies, whereas for smaller cavities the oscillations become overdamped. This rich dynamics can be accounted for by a model we developed, leading to a modified Rayleigh-Plesset equation. Interestingly, this model predicts the impossibility to nucleate bubbles above a critical confinement that depends on liquid negative pressure and corresponds to approximately 100 nm for 20 MPa tensions.

8:12AM Y50.00002 Multiphase flow within 3D porous media , SUJIT DATTA, DAVID WEITZ, Department of Physics, Harvard University — Multiphase flow through porous media is important for a diverse range of processes including aquifer remediation, CO2 sequestration, and oil recovery. Despite its enormous importance, exactly how flow proceeds within a porous medium is unknown; the opacity of the medium typically precludes direct imaging of the flow. Here, we present an experimental technique to directly visualize multiphase flow within porous media. Using this approach, we show how heterogeneity strongly affects flow behavior during the drainage of porous media.

8:24AM Y50.00003 Modeling capillary filling of micropores with nanoparticle-filled binary fluid , YONGTING MA, AMITABH BHATTACHARYA, OLGA KUKSENOK, University of Pittsburgh, Pittsburgh, PA 15261, DENNIS PERCHAK, Kodak Research Laboratories, Rochester, NY 14650, ANNA C. BALAZS, University of Pittsburgh, Pittsburgh, PA 15261 — We examine the behavior of binary fluids containing nanoparticles that are driven by capillary forces to fill well-defined pores of microchannels. To carry out these studies, we use a hybrid computational approach that combines the lattice Boltzmann model for binary fluids and a Brownian dynamics model for the nanoparticles. The hybrid model allows us to capture the interactions between the binary fluids and the nanoparticles, as well as model the interactions among the fluid, the nanoparticles and the pore walls. We show that the nanoparticles dynamically alter both the interfacial tension between the two fluids and the contact angle on the pore walls; this, in turn, strongly affects the dynamics of the capillary filling. We demonstrate that by tailoring the properties of the nanoparticles, such as their affinity to the fluid components and their interaction with the pore walls, one can effectively control both the filling velocities and the deposition of nanoparticles on the pore walls. Our findings provide fundamental insights into the dynamics of this complex system, as well as potential guidelines for technological processes involving capillary filling with nanoparticles in microchannels with differing geometries.

8:36AM Y50.00004 Label-free Screening of Multiple Cell-surface Antigens Using a Single Pore , KARTHIK BALAKRISHNAN, UC Berkeley Department of Mechanical Engineering, MATTHEW CHAPMAN, UC Berkeley Biophysics Graduate Group, ANAND KESAVARAJU, UC Berkeley Department of Bioengineering, LYDIA SOHN, UC Berkeley Department of Mechanical Engineering — Microfluidic pores have emerged as versatile tools for performing highly sensitive measurements. Pore functionalization can result in slower particle transit rates, thereby providing insight into the properties of particles that travel through a pore. While enhancing utility, functionalizing with only one species limits the broader applicability of pores for biosensing by restricting the insight gained in a single run. We have developed a method of using variable cross-section pores to create unique electronic signatures for reliable detection and automated data analysis. By defining a single pore into sections using common lithography techniques, we can detect when a cell passes through a given pore segment using resistive-pulse sensing. This offers such advantages as 1) the ability to functionalize each portion of a pore with a different antibody that corresponds to different cell surface receptors, enabling label-free multianalyte detection in a single run; and 2) a unique electronic signature that allows for both an accelerated real-time analysis and an additional level of precision to testing. This is particularly critical for clinical diagnostics where accuracy and reliability of results are crucial for healthcare professionals upon which to act.

8:48AM Y50.00005 Tracking rotation and translation simultaneously in confined liquids , SUBHALAKSHMI KUMAR, SUNGCHUL BAE, STEVE GRANICK, University of Illinois, Urbana Champaign — At the same spatially-resolved spots when fluid is confined to molecularly-thin spacings between atomically-smooth mica crystals, we track simultaneously, using fluorescence correlation spectroscopy and time correlated single photon counting, the translational and rotational diffusion of small dyes suspended in octamethylcyclotetrasiloxane (OMCTS). The spatially-resolved quantification of both dynamical quantities gives insight, as it does in bulk glasses, into the origins of dynamical heterogeneity in confined fluids.

9:00AM Y50.00006 Neutron Scattering Applications for Characterizing Phase Behavior and Dynamics of Confined Fluids in Nanoporous Materials , YURI MELNICHENKO, Biology and Soft Matter Division, Oak Ridge National Laboratory — Fluid-solid interactions in natural and engineered porous solids underlie variety of technological processes, including sequestration of anthropogenic greenhouse gases, hydrogen storage, membrane separation, and catalysis. The size, distribution and interconnectivity of pores, the chemical and physical properties of the solid and fluid phases collectively dictate how fluid molecules migrate into and through the micro- and mesoporous media, adsorb and ultimately react with the solid surfaces. Due to the high penetration power and relatively short wavelength of neutrons, small-angle neutron scattering (SANS) as well as quasi elastic neutron scattering (QENS) techniques are ideally suited for *in situ* studies of the structure and phase behavior of confined fluids under pressure as well as for evaluating structure of pores in engineered and natural porous systems. It has been demonstrated recently that SANS and USANS can also be used for evaluating the volume of closed pores as a function of pore sizes in the range from micrometer to sub-nanometer pores. In this talk I will overview some recent developments in the SANS and QENS methodology and give several examples of how it can be used for in-situ studies of the adsorption and dynamics of carbon dioxide and methane in porous fractal silica and carbon aerogels as well as characterizing the abnormal densification of hydrogen in activated carbons at ambient temperatures.

9:12AM Y50.00007 A mathematical model for the transport of a solute through a porous-walled tube , IAN GRIFFITHS, REBECCA SHIPLEY, Mathematical Institute, University of Oxford — Predicting the distribution of solutes or particles in flows within porous-walled tubes is essential to inform the design of cross-flow filtration devices. Here we use Taylor-dispersion theory to derive a radially averaged model for solute transport in a tube with porous walls, where the wall Darcy permeability may vary both spatially and in time. Crucially, this model includes solute advection via both radial and axial flow components, as well as diffusion, and the advection, diffusion and uptake coefficients in the averaged equation are explicitly derived. The model is used to explore the specific example of a hollow-fibre membrane bioreactor for tissue engineering applications - here membrane fouling and cell population expansion mean that the effective membrane permeability is intrinsically coupled to both fluid flow and nutrient transport. We conclude by presenting design considerations that promote spatially uniform cell population growth.

9:24AM Y50.00008 Biased and flow driven Brownian motion in periodic channels[1] , S. MARTENS, A. STRAUBE, Humboldt-University Berlin, G. SCHMID, University Augsburg, L. SCHIMANSKY-GEIER, Humboldt-University Berlin, P. HÄNGGI, University Augsburg — In this talk we will present an expansion of the common Fick-Jacobs approximation to hydrodynamically as well as by external forces driven Brownian transport in two-dimensional channels exhibiting smoothly varying periodic cross-section. We employ an asymptotic analysis to the components of the flow field and to stationary probability density for finding the particles within the channel in a geometric parameter. We demonstrate that the problem of biased Brownian dynamics in a confined 2D geometry can be replaced by Brownian motion in an effective periodic one-dimensional potential $\Psi(x)$ which takes the external bias, the change of the local channel width, and the flow velocity component in longitudinal direction into account. In addition, we study the influence of the external force magnitude, respectively, the pressure drop of the fluid on the particle transport quantities like the averaged velocity and the effective diffusion coefficient. The critical ratio between the external force and pressure drop where the average velocity equals zero is identified and the dependence of the latter on the channel geometry is derived. Analytic findings are confirmed by numerical simulations of the particle dynamics in a reflection symmetric sinusoidal channel.

[1]This work has been supported by the VW Foundation via project I/83903 (L.S.-G., S.M.) and I/83902 (P.H., G.S.). P.H. acknowledges the support the excellence cluster "Nanosystems Initiative Munich" (NIM).

9:36AM Y50.00009 ABSTRACT WITHDRAWN —

9:48AM Y50.00010 Crossover from the Hydrodynamic to the Kinetic Regime in Confined Nanoflows[1] , CHARLES LISSANDRELLO, VICTOR YAKHOT, KAMIL L. EKINCI, Department of Mechanical Engineering, Boston University — We present an experimental study of a confined nanoflow. The nanoflow is generated in a simple fluid by a sphere oscillating in the proximity of a flat solid wall. Varying the oscillation frequency, the confining length scale and the fluid mean free path over a broad range provides a detailed map of the flow. We use this experimental map to construct a scaling form, which seamlessly describes the nanoflow in both the hydrodynamic and the kinetic regimes. Furthermore, our scaling form unifies previous theories based on the slip boundary condition and the effective viscosity.

[1]Support from the US NSF (through grants ECCS-0643178, CMMI-0970071, and DGE-0741448) is acknowledged.

10:00AM Y50.00011 Viscosity of ultrathin water films confined between oxide surfaces – ab initio and classical molecular dynamics simulations[1] , PETER J. FEIBELMAN, GARY S. GREST, Sandia National Laboratories, NEIL HARIA, CHRISTIAN D. LORENZ, King's College London — We compare estimates based on ab initio (DFT/PBE) and on classical molecular dynamics simulations of the viscosity of 2, 3 and 5-layer water films confined between hydrophilic kaolinite surfaces. Results were obtained by constraining the confining surfaces to move in +x and -x directions at equal speeds of 1-200 m/sec and loads up to 1 GPa. In neither simulation approach did the calculated viscosity of the confined water exceed that of bulk water by more than an order of magnitude. Thus neither supports the idea that nano-confinement dramatically enhances water's viscosity.

[1]Supported by the DOE Office of Basic Energy Sciences, Division of Materials Science and Engineering. Sandia is operated by the Lockheed Martin Co. for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL8500

10:12AM Y50.00012 Submicron flows of polymer solutions , HUGUES BODIGUEL, AMANDINE CUENCA, Université of Bordeaux - LOF — We study flow properties of high molecular weight polymer solutions below the micron scale. Fluorescence photobleaching is used as a non-invasive technique to evaluate the velocity of pressure-driven flows in channels from 100 to 4000 nm height. We observe a striking reduction of the effective viscosity of polyacrylamide solutiuons in the semi-dilute regime. This effect increases with molecular weight and concentration. Using a Rabinovitch-like approach, we correlate the data at different thicknesses to obtain the wall slip velocity and the flow curve at sub-microscale. Those properties are also evaluated using particle imaging velocimetry close to similar surfaces and standard rheometry. Comparing the measurements in bulk and in confined geometries, we conclude that the observed viscosity reduction can not be solely explained by slippage. We discuss the possible reasons of this effect that are size-dependant filtration and shear-thinning enhancement due to the confinement.

10:24AM Y50.00013 Nanomechanics and dynamics of confined water and other liquids[1] , PETER HOFFMANN, Wayne State University, SHAH KHAN, Wayne State University/ University of Peshawar — From oil recovery to molecular biology, nanoconfined water plays an important role in many areas of research. However, the mechanics and dynamics of nanoconfined water are not well understood. Over the last ten years, a number of groups have measured the mechanics of confined water using atomic force microscopy (AFM) or surface force apparatus (SFA) - often with contradictory results. At Wayne State University, we have developed high resolution AFMs for ultra-small amplitude, linear measurements of the mechanics and dynamics of confined liquids. We have shown that water shows a distinct slow-down in dynamics under confinement (PRB 2004), co-discovered a dynamic "solidification" in a model liquid (Langmuir 2006), and showed that normal and shear stiffness are closely related in confined liquids (Rev. Sci. Instr. 2008). Recently, we found dynamic solidification also in water layers (PRL 2010), a finding that explains the contradictory findings in earlier measurements and points to surprisingly complex behavior in this seemingly simple system. Here we will review these findings, as well as present new findings that show the profound effects of ion concentration on these dynamical effects, as well as measurements of colloidal systems, which illustrate that some findings at the molecular scale can be understood from purely geometric considerations and are not dependent on molecular-scale interactions.

[1] P. M. H. acknowledges funding through the National Science Foundation, Grant No. DMR-0804283.

10:36AM Y50.00014 Investigation of Nanoscale Structure Using Spin-Echo Small-Angle Neutron Scattering (SESANS) , XIN LI, ROGER PYNN, ADAM WASHINGTON, Indiana University, WEI-REN CHEN, KUNLUN HONG, GREGORY SMITH, Oak Ridge National Laboratory, YUN LIU, National Institute of Standards and Technology — Spin-Echo Small-Angle Neutron Scattering (SESANS) is a new technique for probing structural correlations in real space over distances ranging from ∼20 nm to several microns. The measured SESANS correlation function is a projection of the normal Patterson correlation function on to a particular spatial direction. A framework to theoretically calculate this correlation function is laid out, followed by a general discussion of the features of the SESANS correlation function for colloidal systems with different interaction potentials. Our calculations for a system of monodisperse spherical particles, show that SESANS is much more sensitive to the intercolloid potential than conventional Small Angle Neutron Scattering. We have used SESANS to study the correlations between 300-nm-diameter surfactant-stablized poly(methyl methacrylate) (PMMA) spheres suspended in a good solvent, with and without an added polymeric depletant. Below a PMMA volume fraction of ∼30% we find good agreement between the experimental data and theoretical prediction based on the Percus-Yevick approximation. With a small amount of polymer added to the suspension (less than 0.2% by weight of 110 kD polymer), the short-range correlations between PMMA spheres are enhanced because of the presence of polymer depletant. The magnitude of the change is roughly as expected on the basis of calculations of a mixture of spherical particles of different sizes.

10:48AM Y50.00015 Non local rheology and near wall fluctuations in microgel jammed suspensions , PATRICK TABELING, CHOONGYEOP LEE, FABRICE MONTI, MICHEL CLOITRE, ESPCI — We study flows of concentrated suspensions of soft nanoparticles in microchannels, over smooth hydrophilic and hydrophobic surfaces, using nano-PTV and μPIV techniques. With hydrophobic walls, the flow curves are in good agreeement with bulk rheology. With hydrophilic walls, substantial deviations from bulk rheology are observed. In the meantime, large velocity oscillations close to the wall are detected. We couple these observations by introducing a local rheology based on an energy barrier. As a whole, our work confirms the existence of non local rheological behavior in glassy systems.

Friday, March 2, 2012 11:15AM - 2:15PM – Session Z43 GSNP DFD: Invited Session: Applications of Jamming 157AB

11:15AM Z43.00001 Robotics using sand , HEINRICH JAEGER, Univ of Chicago — No abstract available.

11:51AM Z43.00002 Shocks in fragile matter , VINCENZO VITELLI, Instituut Lorentz for Theoretical Physics — Non-linear sound is an extreme phenomenon typically observed in solids after violent explosions. But granular media are different. Right when they unjam, these fragile and disordered solids exhibit vanishing elastic moduli and sound speed, so that even tiny mechanical perturbations form supersonic shocks. Here, we perform simulations in which two-dimensional jammed granular packings are continuously compressed, and demonstrate that the resulting excitations are strongly nonlinear shocks, rather than linear waves. We capture the full dependence of the shock speed on pressure and compression speed by a surprisingly simple analytical model. We also treat shear shocks within a simplified viscoelastic model of nearly-isostatic random networks comprised of harmonic springs. In this case, anharmonicity does not originate locally from nonlinear interactions between particles, as in granular media; instead, it emerges from the global architecture of the network. As a result, the diverging width of the shear shocks bears a nonlinear signature of the diverging isostatic length associated with the loss of rigidity in these floppy networks.

12:27PM Z43.00003 Controlling the jamming transition of sheared hard spheres , THOMAS HAXTON, Lawrence Berkeley National Laboratory — Many applications require understanding how disordered materials flow under an external load such as a shear stress. Since external loads drive systems out of equilibrium, their behavior cannot be described solely in terms of equilibrium parameters like temperature and pressure. However, simulations and experiments show that sheared spherical particles possess an *effective* temperature that relates low-frequency fluctuations of various observable quantities to their associated response functions. Here, we show that the mobility of a mixture of sheared hard spheres is largely controlled by the dimensionless ratio of effective temperature to pressure, $T_{\rm eff}/p\sigma^3$, where σ is the sphere diameter. We define the effective temperature as the consistent value that relates the amplitudes of low-frequency shear stress and density fluctuations to their associated response functions. We find that the relaxation time τ characterizing the mobility depends on $T_{\rm eff}/p\sigma^3$ according to two distinct mechanisms in two distinct regimes. In the *solid response* regime, the behavior at fixed packing fraction ϕ satisfies $\tau\dot{\gamma} \propto \exp(-cp\sigma^3/T_{\rm eff})$, where $\dot{\gamma}$ is the strain rate and c depends weakly on ϕ, suggesting that the effective temperature controls the average local yield strain. In the *fluid response* regime, τ depends on $T_{\rm eff}/p\sigma^3$ as it depends on $T/p\sigma^3$ in equilibrium. This regime comprises a large part of the hard-sphere jamming phase diagram including both near-equilibrium conditions where $T_{\rm eff}$ is similar to the kinetic temperature $T_{\rm kin}$ and far-from-equilibrium conditions where $T_{\rm eff} \neq T_{\rm kin}$. In particular, the dynamic jamming transition is largely controlled by the fluid-response mechanism; like equilibrium hard spheres, sheared hard spheres can flow only if low-frequency fluctuations are large enough compared to the pressure. By presenting our results in terms of the dimensionless jamming phase diagram, we show how these mechanisms likely apply to systems with soft repulsive interactions.

1:03PM Z43.00004 Density-Temperature-Softness Scaling of the Dynamics of Glass-forming Soft-sphere Liquids[1] , MAGDALENO MEDINA-NOYOLA, Instituto de Física, Universidad Autónoma de San Luis Potosí — We employ the principle of dynamic equivalence between soft-sphere and hard-sphere fluids [Phys. Rev. E **68**, 011405 (2003); Phys. Rev. Lett. **107**, 155701 (2011)] to describe the interplay of the effects of varying the density n, the temperature T, and the softness (characterized by a softness parameter ν^{-1}) on the dynamics of glass-forming soft-sphere liquids in terms of simple scaling rules. The main prediction is the existence of a dynamic universality class associated with the hard sphere fluid, constituted by the soft-sphere systems whose dynamic parameters, such as the α-relaxation time and the long-time self-diffusion coefficient, depend on n, T, and ν only through the reduced density $n^* \equiv n\sigma_{HS}^3(n,T,\nu)$, where the effective hard-sphere diameter $\sigma_{HS}(n,T,\nu)$ is determined by the Andersen-Weeks-Chandler condition for soft-sphere–hard-sphere structural equivalence. A number of scaling properties observed in recent experiments and simulations involving glass-forming fluids with repulsive short range interactions are found to be a direct manifestation of this general dynamic equivalence principle. The self-consistent generalized Langevin equation (SCGLE) theory of colloid dynamics [Phys. Rev. E **76**, 041504, 062502 (2007)] is shown to accurately capture these scaling rules. The non-equilibrium extension of this theory [Phys. Rev. E **82**, 061503, 061504 (2010)] is employed to describe the manifestation of this scaling on the aging of instantaneously-quenched soft-sphere liquids.

[1]Work supported by the Consejo Nacional de Ciencia y Tecnología (CONACYT, México), through Grants No. 84076 and 132540, and through the Red Temática de Materia Condensada Blanda.

1:39PM Z43.00005 Active Jamming: Self-propelled particles at high density[1] , SILKE HENKES, Syracuse University — What determines the mechanical properties of dense collections of active particles? The answer to this question is highly relevant to a wide range of physical and biological phenomena from tissue formation to the dynamics of vibrated granular layers. We present a numerical study of the phases and dynamics of a dense collection of self-propelled particles with soft repulsive interactions and polar alignment in a two-dimensional confined geometry. The phase diagram consists of a polar liquid phase at low packing fraction and high self-propulsion speed, and an active jammed phase at high density and low self-propulsion speed. The liquid phase exhibits local alignment and giant number fluctuations typical of the Vicsek class of models. The dynamics of the jammed phase is dominated by oscillations along the low frequency modes of the underlying packing. We show analytically that at long times the energy is carried entirely by the lowest available excitations of the system. Recent experiments on epithelial cell monolayers using force traction microscopy have revealed stress distributions that resemble those observed in granular materials. We measure and compare the local stresses in our active system, with added attraction, to both granular materials and the tissue experiments.

[1]This work was done in collaboration with Yaouen Fily and M. Cristina Marchetti and supported by the NSF through grants DMR-0806511 and DMR-1004789. The computations were carried out on SUGAR, a cluster supported by NSF-PHY-1040231.

Friday, March 2, 2012 11:15AM - 2:15PM –

Session Z50 DPOLY DFD: Focus Session: Micro and Nano Fluidics IV: Emulsions and Complex Fluids 162B

11:15AM Z50.00001 Active Emulsions: Synchronization of Chemical Oscillators , SETH FRADEN, Brandeis University — We explore the dynamical behavior of emulsions consisting of nanoliter volume droplets of the oscillatory Belousov-Zhabotinsky (BZ) reaction separated by a continuous oil phase. Some of the aqueous BZ reactants partition into the oil leading to chemical coupling of the drops. We use microfluidics to vary the size, composition and topology of the drops in 1D and 2D. Addition of a light sensitive catalyst to the drops and illumination with a computer projector allows each drop to be individually perturbed. A variety of synchronous regimes are found that systematically vary with the coupling strength and whether coupling is dominated by activatory or inhibitory species. In 1D we observe in- and anti-phase oscillations, stationary Turing patterns in which drops stop oscillating, but form spatially periodic patterns of drops in the oxidized and reduced states, and more complex combinations of stationary and oscillatory drops. In 2D, the attractors are more complex and vary with network topology and coupling strength. For hexagonal lattices as a function of increasing coupling strength we observe right and left handed rotating oscillations, mixed oscillatory and Turing states and finally full Turing states. Reaction – diffusion models based on a simplified description of the BZ chemistry and diffusion of messenger species reproduce a number of the experimental results. For a range of parameters, a simplified phase oscillator model provides an intuitive understanding of the complex synchronization patterns.

"Coupled oscillations in a 1D emulsion of Belousov–Zhabotinsky droplets," Jorge Delgado, Ning Li, Marcin Leda, Hector O. Gonzalez-Ochoa, Seth Fraden and Irving R. Epstein, *Soft Matter*, **7**, 3155 (2011).

11:51AM Z50.00002 Double Emulsion Templated Celloidosomes[1] , LAURA R. ARRIAGA, Department of Physics and Division of Engineering and Applied Science, Harvard University, Cambridge, MA 02138, SAMANTHA M. MARQUEZ, Maggie L. Walker Governor's School, 1000N. Lombardy St. Richmond, VA 23220, SHIN-HYUN KIM, CONNIE CHANG, JIM WILKING, Department of Physics and Division of Engineering and Applied Science, Harvard University, Cambridge, MA 02138, FRANCISCO MONROY, Department of Physical Chemistry, Complutense University, 28040 Madrid, Spain, MANUEL MARQUEZ, YNano LLC 14148 Riverdowns S. Dr. Midlothian, VA 23113, DAVID A. WEITZ, Department of Physics and Division of Engineering and Applied Science, Harvard University, Cambridge, MA 02138 — We present a novel approach for fabricating celloidosomes®, which represent a hollow and spherical three-dimensional self-assembly of living cells encapsulating an aqueous core. Glass- capillary microfluidics is used to generate monodisperse water-in-oil-in-water double emulsion templates using lipids as stabilizers. Such templates allow for obtaining single but also double concentric celloidosomes. In addition, after a solvent removal step the double emulsion templates turn into monodisperse lipid vesicles, whose membrane spontaneously phase separates when choosing the adequate lipid composition, providing the adequate scaffold for fabricating Janus-celloidosomes. These structures may find applications in the development of bioreactors in which the synergistic effects of two different types of cells selectively adsorbed on one of the vesicle hemispheres may be exploited.

[1]Laura R. Arriaga would like to thank Real Colegio Complutense for finnancial support

12:03PM Z50.00003 Viscoelastic Flow Instabilities of Worm-like Micellar Solutions in Microfluidic Devices , THOMAS OBER, GARETH MCKINLEY, Massachusetts Institute of Technology — Worm-like micellar (WLM) fluids are a unique class of complex fluids whose large deformation rate rheology is not fully understood. By combining mechanical pressure measurements, μ-PIV and spatially-resolved measurements of flow-induced birefringence, we study the behavior of WLM solutions undergoing large deformation rates in microfluidic rectilinear and converging geometries, whose small characteristic dimensions facilitate experiments at high elasticity number (i.e. low inertia). In our experiments, we observe the extensional flow of a shear-banding WLM fluid in a planar hyperbolic contraction. We classify the flow regimes and observe the onset of spatio-temporally unsteady flow often referred to as "elastic turbulence." We use pressure drop measurements to calculate the apparent extensional viscosity of both Newtonian fluids and WLM fluids. We also investigate the onset of elastically driven instabilities in flows nominally without streamwise curvature in a high aspect ratio straight channel. These latter experiments are aimed at determining if elastically-driven turbulence in dilute polymer solutions can be initiated and sustained in pressure-driven rectilinear flows.

12:15PM Z50.00004 Elastic instability in straight channels , ANNIE COLIN, HUGUES BODIGUEL, JULIEN BEAUMONT, University Bordeaux 1 — Polymer solutions exhibit purely elastic flow instabilities even in the absence of inertia. The almost ubiquitous ingredient of such an elastic instability is the curvature of streamlines: polymers that have been extended along curved streamlines are taken by fluctuations across shear rate gradient in the unperturbed state which, in turn, couples the hoop stresses acting along the curved streamlines to the radial and axial flows and amplifies the perturbation. It has been tacitly assumed for over 30 years that in line with this instability scenario, visco-elastic parallel shear flows are stable, since the streamlines are straight. Recently, Saarloos and coworkers [1] derived a general instability criterion, which shows that these flows invariably exhibit a nonlinear instability. At this stage only a few studies support and validate this analysis [2]. In this work, we take advantage of microfluidic devices and study the flow of highly elastic polymers and surfactant solutions in a straight microchannel located after a constriction. The velocity of the solution is measured using Particle Imaging Velocimetry. The amplitude of the perturbation is controlled by the shape of the constriction. Using such devices, we present a comprehensive flow diagram in the parameter plane amplitude of the perturbation, Weissenberg number. 1/ Bernard Meulenbroek at all J. Non-Newtonian Fluid Mech. 116 (2004) 235–268 2/ Daniel Bonn et all Phys Rev E 84, 045301(R) (2011)

12:27PM Z50.00005 Microfluidic Fabrication of Functional Capsules with ultra-thin membranes[1] , SHIN-HYUN KIM, ALIREZA ABBASPOURRAD, DAVID WEITZ, Harvard University — We have developed a new emulsification technique to produce monodisperse double-emulsion drops with an ultra-thin middle layer through a one-step emulsification. A biphasic flow, consisting of sheath of one fluid flowing along the capillary wall and surrounding a second fluid flowing through center of the capillary, is created in a form of either a jet or drops, which is emulsified into double-emulsion drops with ultra-thin middle layer. The ultra-thin middle phases provide stability to the double-emulsion drops by putting the fluid in the middle phase in the lubrication regime. We have employed such stable double-emulsion drops to make functional microcapsules using evaporation-induced consolidation. Simplest form is microcapsules with homogenous membrane. Using biodegradable polymers such as PLA or PLGA as a membrane material, we can achieve a long-term release of various bioactives from the capsules as the membrane degrades by hydrolysis. Heterogeneous membrane can also be prepared by using polymer blends. For example, a polymer blend of PMMA and PLA with small interaction parameter makes heterogeneous structure at nanoscale, while a polymer blend of PS and PLA with large interaction parameter makes their phase separation at one micrometer scale.

[1]This work was supported by Amore-Pacific, the NSF (DMR-1006546) and the Harvard MRSEC (DMR-0820484).

12:39PM Z50.00006 Coupled oscillations in a 1D emulsion of Belousov–Zhabotinsky droplets[1] , NING LI, Brandeis University, JORGE DELGADO, University of Guanajuato, HECTOR GONZALEZ OCHOA, San Luis Potosi Institute of Scientific Research and Technology (IPICyT), MARCIN LEDA, Institute of Physical Chemistry (Polish Academy of Science), SETH FRADEN, IRVING EPSTEIN, Brandeis University, BRANDEIS UNIVERSITY TEAM — We experimentally and computationally study the dynamics of interacting oscillating Belousov–Zhabotinsky (BZ) droplets of 100 micron diameter separated by perfluorinated oil and arranged in a one-dimensional array. A microfluidic chip is used for mixing the BZ reactants, forming monodisperse droplets by flow-focusing and directing them into a hydrophobized 100 micron diameter capillary. In order to make quantitative comparison with theory, we use photosensitive $Ru(bipy)_3$ catalyzed BZ droplets and set both boundary and initial conditions of arrays of small numbers of oscillating BZ droplets with a programmable illumination source. The coupling strength is a function of malonic acid concentration and varying coupling strength leads to the generation of different dynamical attractors. In many cases, simulations agree well with experiments.

[1]Funded by MRSEC.

12:51PM Z50.00007 Double emulsion templated monodisperse phospholipid liposomes incorporating Doxorubicin hydrochloride , MINGTAN HAI, University of Science and Technology Beijing/Harvard University, DAVID WEITZ, Harvard University — We present a novel approach for fabricating monodisperse phospholipid liposomes incorporating water soluble anticancer drug Doxorubicin hydrochloride using controlled w/o/w double emulsions as templates. Glass-capillary microfluidics is used to generate monodisperse w/o/w double emulsion templates and double emulsion droplet size is from 20 to 100 um according to different flow rates. We show that the high uniformity in size and shape of the templates are maintained in the final phospholipid liposomes after a solvent removal step by Nikon eclipse microscopy. The lipid bilayers encapsulating anticancer drug inside is retained after the emulsion drops are converted to vesicles. The liposomes vesicles are promising water soluble anticancer drug delivery vehicles.

1:03PM Z50.00008 Drops of Yield-Stress Liquid Impacting a Solid Surface , QIN XU, HEINRICH JAEGER, James Frank Institute and Department of Physics, The University of Chicago — We use high-speed video to investigate the drop impact process for yield-stress fluids under different initial conditions. Unlike Newtonian fluids, the impact dynamics of yield-stress liquids are greatly affected by the their viscoelasticity, which can be attributed to either a surface stress or bulk material properties. To explore these two different mechanisms, we perform impact experiments for two model fluids: liquid metals and particle suspensions, which both exhibit significant yield-stress in rheology. By controlling surface oxidation (for liquid metals) and packing density (for suspensions), we quantitatively vary the yield-stress within several orders of magnitude. In this way, we draw a direct comparison between the two fluids at various impact velocities to clarify the role of different sources of yield stress. Also, we build up an approach to bridge impact dynamics with rheological measurements.

1:15PM Z50.00009 Oscillatory shear of non-colloidal fiber suspensions , ALEXANDRE FRANCESCHINI, EMMANOUELA FILIPPIDI, NYU, Dept Phys, Ctr Soft Matter Res, New York, NY 10003 USA, ELIZABETH GUAZZELLI, Aix Marseille Univ U1, IUSTI, CNRS, UMR Polytech Marseille 6595, F-13453 Marseille 13, France, DAVID PINE, NYU, Dept Phys, Ctr Soft Matter Res, New York, NY 10003 USA — Concentrated suspensions of non-colloidal fibers under slow periodic strain undergo a phase transition from an absorbing state to an active fluctating state. Fiber trajectories are reversible in the absorbing state and irreversible in the fluctuating state. The activity, measured by the translational diffusivity between successive periods, vanishes in the absorbing state but reaches a finite value in the fluctuating state. We show that the transition is controlled by a collision cross-section, which is a function of the strain amplitude, concentration and fiber orientation. Over the course of an experiment, the activity drives the orientation toward the vorticity, subsequently reducing the cross section. We evaluate the influence of the control parameter decay on the phase transition and then focus on the fluctuating state dynamics.

1:27PM Z50.00010 Dynamics in Semidilute Rod Suspensions , PRAMUKTA KUMAR, DAN BLAIR, JEFFREY URBACH, Department of Physics, Georgetown University — While shear-thinning in semidilute suspensions of rod-like particles has been widely observed, the underlying mechanisms are often unclear. We have developed a model system of fluorescent SU-8 rods suspended in a Glycerol/Ethylene-Glycol solution. This model system exhibits an order of magnitude difference in apparent viscosity at low shear rates as compared to high shear rates while showing no discernible difference in structure. Using a coupled confocal microscope and rheometer instrument along with fiber identification and particle tracking routines, we directly image and quantify the 3D structure and dynamics of our model system under shear flow in order to determine how particle interactions could be generating the observed shear thinning. In particular we look at how interactions modify Jeffery's orbits in semidilute suspensions as compared to the motion of an isolated rod or ellipsoid.

1:39PM Z50.00011 The filed effect on local temperature distribution in natural convection in a magnetic fluid , JUN HUANG, WEILI LUO, University of Central Florida — Previously, we have reported the magnetic field effect on the flow front of natural convection in magnetic fluids. In this work we present the local temperature distribution as a function of applied field, from which flow patterns are constructed. We will also report, and discuss the possible mechanism for, a crossover field, above which the field dependence diminishes.

1:51PM Z50.00012 Mixing dynamics of slurry in rotating drum , KIWING TO[1], Institute of Physics, Academia Sinica, CHUN CHUNG LIAO[2], SHU-SAN HSIAU[3], Department of Mechanical Engineering, National Central University — We study the effects of interstitial fluid viscosity on the rates of dynamical processes in a thin rotating drum half-filled with monodisperse glass beads. The rotating speed is fixed at the rolling regime such that a continuously flowing layer of beads persists at the free surface. While the characteristic speed of a bead in the flowing layer decreases with the fluid viscosity, the mixing rate of the beads is found to increase with the fluid viscosity. These findings are consistent to a simple model related to the thickness of the flowing layer.

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[3]Jhongli, Taiwan 32001, R.O.C.

2:03PM Z50.00013 Bubble production using a Non-Newtonian fluid in microfluidic flow focusing device , YI-LIN WANG, National Taiwan University of Science and Technology, THOMAS WARD, CHRISTINE GRANT, North Carolina State University — We experimentally study the production of micrometer-sized bubbles using microfluidic technology and a flow-focusing geometry. Bubbles are produced by using a mixture containing aqueous polyacrylamide of concentrations ranging from 0.01-0.10% by weight and several solution also containing a sodium-lauryl-sulfate (SLS) surfactant at concentrations ranging 0.01-0.1% by weight. The fluids are driven by controlling the static pressure above a hydrostatic head of the liquid while the disperse phase fluid static pressure is held constant (air). In the absence of surfactant the bubble production is discontinuous. The addition of surfactant stabilizes the bubble production. In each type of experiment, the bubble length ℓ, velocity U and production frequency ω are measured and compared as a function of the inlet pressure ratio. The bubbles exhibit a contraction in their downstream length as a function of the polymer concentration which is investigated.