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Monday, March 15, 2010 8:00AM - 11:00AM –
Session A12 DFD: Microfluidics I: Electrokinesis and Transport B110-B111

8:00AM A12.00001 Flow Regimes and Parametric Competitions in Nanochannel Flows CHONG LIU, ZHIGANG LI, Department of Mechanical Engineering, The Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong — Nanoscale fluid flow systems involve both micro- and macroscopic parameters, which compete with each another and lead to different flow regimes. In this work, we investigate the competitions of four fundamental parameters, including the fluid-fluid, fluid-wall binding energies, temperature of the system, and driving force. By illustrating the fluid flux as a function of a dimensionless number, which represents the effective surface effect on the fluid, we show that the fluid motion in nanochannels falls into different regimes. For small fluid-fluid self-binding energy, there are three flow regimes; as the dimensionless number increases, the flux undergoes a transition from fluid-wall binding energy independent to temperature independent. If the fluid-wall binding energy is of the order of room temperature, there is a critical value for the dimensionless number, which divides the flow into weak and strong fluid-wall interaction regimes. Each of these regimes is associated with a distinct mechanism which reveals the competitions of the parameters.

8:12AM A12.00002 Microfluidic Chemical Concentration Switching at Taylor's Limit[1] , EBERHARD BODENSCHATZ, ALBERT BAE, LASSP, Cornell University, Ithaca and MPI for Dynamics and Selforganization, Goettingen, CARSTEN BETA, Institute for Physics and Astronomy, University of Potsdam and MPI for Dynamics and Selforganization, Goettingen — In this talk, we will discuss the time for switching chemical concentrations in microfluidic devices. The limits of rapid switching are analyzed based on the theory of dispersion by Taylor and Aris and compared to both experiments and numerical simulations. We conclude by comparing the performance of various switching techniques.

[1]This work was supported by the Deutsche Forschungsgemeinschaft (SPP 1128) and the Max Planck Gesellschaft.

8:24AM A12.00003 Film Relaxation and Pressure-Saturation Hysteresis in a Wedge-shaped Microfluidic Channel[1] , YIHONG LIU, Purdue University, LAURA PYRAK-NOLTE, DAVID NOLTE — Wetting-phase films play important roles in the fluid distribution and pressure-saturation behavior of porous media, but are often difficult to quantify because of their complex geometry. We used fluorescent confocal microscopy to image three-dimensional water-films in 40 μm deep wedge-shaped microfluidic channel. The microfluidic channels were fabricated from photoresist on a cover glass using two methods to achieve different wall roughness: a) two-photon laser machining, and b) UV-illumination. From the confocal images, we experimentally acquired the movement and transformation of the films and the time-dependent volume, thickness, and length of the films at controlled pressures. We also observe hysteresis in the capillary pressure vs. saturation behavior in this simple geometry when performing imbibition and drainage scanning. The wetting film, as an extension of the wetting phase, strongly increases the interaction area of the wetting phase (water) with the non-wetting phase (air) and the solid phase (channel), which contributes irreversible effects to hysteresis mechanisms.

[1]Acknowledgment: ARRA & the National Science Foundation (0911284-EAR).

8:36AM A12.00004 Fluidic rectification due to asymmetric concentration polarization at nano-microfluidic interface , JARROD SCHIFFBAUER, KATHLEEN RESCHKE, West Virginia University, BORIS ZALTZMAN, Ben Gurion Univerisity, BOYD EDWARDS, West Virginia University, ISAAK RUBINSTEIN, Ben Gurion Univerisity, WILL BOOTH, AARON TIMPERMAN, West Virginia University — A simple 1D locally electroneutral (LEN) electro-diffusive model explains steady-state fluidic rectification in terms of asymmetry in the diffusion layers flanking a charge-selective element such as a porous membrane or nano-pore. The selectivity in such systems is a function of the diffusion layer asymmetry and applied voltage. Rectification is experimentally demonstrated in a microfluidic system utilizing a charge selective membrane with symmetric nanopores where the asymmetry of the diffusion layers is attributed to the geometric asymmetry in the fluidic portion of the system. Results for devices with different cross-sections on either side of the membrane verify that increasing asymmetry in the geometry, hence diffusion layers, increases the strength of the observed rectification as predicted by the theory.

8:48AM A12.00005 Photo-manipulation of a liquid droplet by chromocapillary effect , ARNAUD SAINT-JALMES, Institut de Physique de Rennes - CNRS, ANTOINE DIGUET, Departement de Chimie, ENS-Paris, REINE-MARIE GUILLERMIC, Institut de Physique de Rennes , NOBUYUKI MAGOME, KENISHI YOSHIKAWA, Kyoto University, YONG CHEN, DAMIEN BAIGL, Departement de Chimie, ENS-Paris — Using simply light at different wavelengths, we show how an oil droplet floating on an aqueous solution can be trapped and rapidly moved along any desired shapes. The technique is based on the presence of a surfactant (adsorbed at the oil-water interface) which configuration and polarity change with the light wavelength. A partial illumination of the droplet, with either visible or UV light, is first used to create wavelength-dependent interfacial tension gradients, meaning that the gradient direction depends on the wavelength of the illumination. Such *chromocapillary* gradients are then able to induce interfacial flows, finally resulting in reversible droplet motions in directions depending on the light wavelength. By combining ultraviolet and visible light, we then made a chromocapillary trap to capture a droplet on the liquid surface. The trapped droplet can be dragged across the surface at 300 microns per second by moving the trap around. We discuss the potential use of chromocapillary effects in microfluidic devices and in light-responsive materials.

9:00AM A12.00006 Suppression of Brownian motion by electrodynamic confinement in aqueous solution , WEIHUA GUAN, MARK REED, Department of Electrical Engineering, Yale University, SONY JOSEPH, PREDRAG KRSTIC, Physics Division, Oak Ridge National Laboratory — Trapping and manipulating single molecule or colloid particles in aqueous solution provides the opportunity to study intrinsic individual characteristics rather than averaged ensemble properties. In this study, a planar aqueous electrodynamic trap on a chip is fabricated and studied. Individual charged particles can be trapped in aqueous solution by a "Paul trap" type rotating electric field. The trap utilizes the strong alternating electrophoretic force and dynamically traps charged particles in the center of the planar device. The trap is characterized by investigating the stable trapping region with its characteristic driving parameters. The impact of the Brownian noise on the stability of the trapping and on the root- mean-square (rms) value of the position fluctuations are investigated. Compared to conventional Paul trap which works in vacuum or gaseous phase, our electrodynamic trap demonstrates for the first time a successful aqueous trapping. This technique opens the possibility to spatially control the object in aqueous solution and can lead to lab-on-a-chip systems controlling single molecules.

9:12AM A12.00007 Two-dimensional mapping of dielectrophoresis force and AC electro-osmosis flow , JINGYU WANG, H.D. OU-YANG, Lehigh University — In an AC electric field, colloids in an aqueous suspension are subjected to different electrokinetic forces. Charged particles will experience a frequency dependent dielectrophoresis (DEP) force due to the polarizability response of the associated double layers, causing particle movement. At the cross-over frequency when the double layers cannot fully respond to the field, this force tends to zero. For free ions in solution, Coulomb forces exerted on them near the electrodes can produce fluid flows through AC-electro-osmosis (ACEO). As DEP and ACEO depend quadratically on the field strength, it is difficult to distinguish the contribution of each force exerted on a particle. To differentiate DEP and ACEO, we used optical tweezers to track individual particle motion to pin-point the DEP cross-over frequencies at locations where ACEO is negligible. We then mapped out the ACEO flow patterns at the cross-over frequency of zero DEP force. Moreover, as the cross-over frequency was a function of particle size, we were able to determine the scaling of the ACEO flow with the applied field frequency.

9:24AM A12.00008 Destruction of Emulsions by an AC Electric Field: Importance of Partial Merging[1] , ABDOU RACHID THIAM, NICOLAS BREMOND, JERÔME BIBETTE, LCMD-ESPCI-PECSA-CNRS — Electrocoalescence is basically the process of blending droplets by the application of an electric field. The approach is used in petroleum refineries for the separation of water in oil emulsions (that is, by coalescing water droplets), and more recently in biotechnology industry, for the fusion of micro reactors. In a first step, we will focus on the coalesce condition for two drops under a given electric field. Microfluidics offers a comfortable setup therefore, as we sought to span a range of initial conditions in terms of the distance between the droplets, their sizes, and also a region of the applied electric field. Thus, we could establish a stability diagram according to the initial conditions and droplets' composition, which displays three domains referred to as: coalescence, no coalescence and a third one of partial coalescence, where the droplets coalesce for a brief moment then separate right afterwards. We proceeded then by generalizing the setup to the case of a stream of droplets, and we found that the evolution of the stream can be predicted by the behaviour of the local pairs of droplets, as seen in the previous step. The main outcome of that study is the total destruction of an emulsion above a critical volume fraction for a given amplitude of electric field.

[1]LCMD-ESPCI-PECSA-CRNS

9:36AM A12.00009 Broadband Dielectric Response of Insulin and Bovine Serum Albumin in Solution , J. BOOTH, N. ORLOFF, Y. WANG, NIST, J. DENNIS, University of Colorado, I. TAKEUCHI, University of Maryland — We report on quantitative frequency-dependent permittivity measurements of nanoliter volumes of bovine serum albumin and insulin in solution, using microfluidic channels integrated with planar microwave frequency transmission lines. Our measurements yield quantitative values for the solution permittivity as a function of frequency for different values of protein concentration, over the broad freqeuncy range 45 MHz to 40 GHz. Analysis of these data based on dielectric mixing models allows us to extract quantitative values for the effective molecular permittivity of the aqueous proteins, as a function of frequency.

9:48AM A12.00010 Single-Molecule Denaturation Mapping of DNA in Nanofluidic Channels , WALTER REISNER, McGill University - Dept of Physics, NIELS LARSEN, Technical University of Denmark - Dept. of Micro- and Nanotechnology, ASLI SILAHTAROGLU, University of Copenhagen - Wihelm Johannsen Centre for Functional Genome Research, ANDERS KRISTENSEN, Technical University of Denmark - Dept. of Micro- and Nanotechnology, NIELS TOMMERUP, University of Copenhagen - Wihelm Johannsen Centre for Functional Genome Research, JONAS O. TEGENFELDT, Lund Univ./Univ, of Gothenburg - Dept of Physics, HENRIK FLYVBJERG, Technical University of Denmark - Dept. of Micro- and Nanotechnology — Nanochannel based DNA stretching can serve as a platform for a new optical mapping technique based on measuring the pattern of partial melting along the extended molecules. We partially melt DNA extended in nanofluidic channels via a combination of local heating and added chemical denaturants. The melted molecules, imaged via a standard fluorescence videomicroscopy setup, exhibit a nonuniform fluorescence profile corresponding to a series of local dips and peaks in the intensity trace along the stretched molecule. We show that this barcode is consistent with the presence of locally melted regions along the molecule and can be explained by calculations of sequence-dependent melting probability. Specifically, we obtain experimental melting profiles for T4, T7, lambda-phage and bacterial artificial chromosome DNA (from human chromosome 12) and compare these profiles to theory. In addition, we demonstrate that the BAC melting profile can be used to align the BAC to its correct position on chromosome 12.

10:00AM A12.00011 Channeling of DNA during Electrophoresis in a Sparse Ordered Post Array , JIA OU, JASEOL CHO, SAM CARPENTER, DAN OLSON, KEVIN DORFMAN, Dept. of Chemical Engineering and Materials Science, University of Minnesota — Microfabricated post arrays are a promising approach to separate long DNA by size. Simulation data suggest that, if the post array is ordered and sparse, then long DNA will move through the array with very few collisions and the separation will be lost. We tested this "channeling hypothesis" using 1 μm diameter post arrays with two different pitches: 3 μm and 7 μm. The mobility, dispersivity and videomicroscopy data for λ-DNA in a 3μm pitch array indicate that the DNA frequently collide with the posts over a wide range of electric fields. We demonstrate via simulations that the frequent collisions are due to the curved electric field lines. To detect the onset of channeling in the 7μm pitch array, which has a more uniform field, we compared the electrophoretic mobility of λ-DNA and a smaller plasmid, pUC19 (2,383 bp), that cannot make a rope-over-pulley collision. At low electric fields, these DNA are separated because the λ-DNA collides with the posts. The resolution is lost as the electric field increases due to the onset of channeling by the λ-DNA.

10:12AM A12.00012 DNA mobility in nanofluidic systems , ALENA KARPUSENKO, NC State University, SHUANG FANG LIM, ROBERT RIEHN — Nano-scale devices are attractive candidates for rapid and inexpensive biological analysis. Particular focus has been the analysis of DNA, studied in both nano-pores and nanofluidic channels. DNA is linearized and stretched to about 60 % of its contour length by confinement to channels with a cross-section of 100×100 nm^2 and hundreds of microns long. Here we study the motion of dsDNA through mazes of nanofluidic channels, and in particular the dependence of average drift velocities on the size and shape of the molecules. We find interesting relationships by comparing the average displacement for different molecules when driven by electric fields. We propose separation techniques for DNA molecules with different topologies using specific fluidic systems and driving schemes.

10:24AM A12.00013 Tube-like motion of ds-DNA in a nanoslit post array , PO-KENG LIN, Institute of physics, Academia Sinica, CHEN-HSIANG HUNG, National Taiwan University, CHIA-FU CHOU, YENG-LONG CHEN, Institute of physics, Academia Sinica — Polymer reptation motion has been observed in polymer trapped in a porous network with pore size smaller than the chain Kuhn length. In this study, we directly observe the tube-like motion of DNA confined in nano-height hexagonal micropost arrays, where the post spacing is much larger than the Kuhn length. The chain length Ndependence of DNA diffusivity D exhibits the two-dimensional reptation scaling D $\sim$ $N^{-1.5}$. The tube-like motion results from confinement-induced attraction between DNA and the microposts. We also systematically investigate the transition of DNA-wall interaction from repulsion to attraction.

10:36AM A12.00014 Bubble length affects bubble speed in a rough microfluidic channel , QUAN ZHANG, University of Chicago, KONSTANTIN TURITSYN, Los Alamos National Laboratory, TOM WITTEN, University of Chicago — We discuss the creeping motion of bubbles of different length in rough capillary tubes filled with carrier fluids. This extends the results of Bretherton[1] for an infinite-length bubble at small capillary number Ca in a circular tube. We first derive the asymptotic corrections to the speed owing to finite length. This dependence on length is exponentially small, with a decay length much shorter than the tube radius R. Then we discuss the effect of azimuthal roughness of the tube on the bubble speed. Tube roughness leads to a carrier fluid flow in the azimuthal plane; this flow controls the relaxation of the bubble shape to its infinite length limit. For long-wavelength roughness, we find that the above decay length becomes much longer and even comparable to R. This implies a much-enhanced dependence of the bubble velocity on length. A shorter bubble should then catch up with a longer bubble ahead of it in the same channel. This mechanism may explain catch-up effects seen experimentally.[2]

[1]F.P.Bretherton, 1961, J. Fluid Mech., 10, 166.

[2]R.Ismagilov, private communication.

10:48AM A12.00015 Vesicle extrusion in nanopores[1] , BÉLA JOÓS, MARTIN BERTRAND, SÉBASTIEN OUELLET, University of Ottawa — Monodisperse vesicles of nearly circular shape or liposomes are used as drug delivery systems. Their fabrication involves repeated passage of large vesicles through small pores. At each passage the vesicle ruptures and the fragments reform into smaller vesicles. We report on the last stages of the process where small liposomes are pushed by pressure differences into nano-sized pores, and we study the stress distribution along the lipid bilayer to determine the rupture lines. This is done by performing coarse grained Molecular Dynamics simulations. We have developed a technique to measure the stress in the membrane based on a tessellation of the surface which allows us to monitor the local area per lipid fluctuations. The results show subtle and complex flow phenomena. We can predict the final size distribution after many passages. Comparisons will be made with existing experimental data.

[1]Funded by the NSERC Canada.

Monday, March 15, 2010 8:00AM - 10:48AM –
Session A13 DFD GSNP: Convection and Crystal Growth B112

8:00AM A13.00001 Rotating turbulent convection at high Rayleigh and Taylor numbers , JOSEPH NIEMELA, SIMONE BABUIN, The Abdus Salam ICTP, KATEPALLI SREENIVASAN, New York University — We report heat transport measurements in a cylindrical convection apparatus rotating about the vertical axis. The aspect ratio was 1/2. The working fluid was cryogenic helium gas and the following parameter ranges applied: The Rayleigh number, Ra, varied in the range $10^{11} < Ra < 4.3 \times 10^{15}$, the Taylor number, Ta, in the range $10^{11} < Ta < 3 \times 10^{15}$, the convective Rossby number, Ro, in the range $0.4 < Ro < 1.6$, and the Prandtl number, Pr, in the range $0.7 < Pr < 5.9$. Boussinesq conditions applied quite closely. The heat transport for steady rotation, under all conditions of the present experiments, was smaller than that for the non-rotating case. When the rotation rate varied periodically in time a sharp transition to a state of significantly enhanced heat transport was observed for modulation Taylor numbers $Ta^* \gtrsim 10^{14}$, where Ta^* is based on the maximum of the modulation angular velocity.

8:12AM A13.00002 Concentration-dependent Onset of Natural Convection in Magnetic Fluids , YI LIU, JUN HUANG, ZHENYU ZHOU, WEILI LUO, University of Central Florida, CONDENSED MATTER MAGNETISM TEAM — The convective heat transfer in magnetic fluids was studied as a function of particle concentrations in a quasi-one dimensional cell with externally applied temperature difference across the sample. The local temperature distribution measured by eight thermal sensors indicates that the onset of the convection depends monotonically on the concentration of particles, suggesting the resistance to the fluid motion from the particles. From the time-dependent temperature profile we obtained the speed of the flow front to be in the order of 10^{-4} m/s. This work renders the possibility of studying the effect of applied fields to the convective flow.

8:24AM A13.00003 ABSTRACT WITHDRAWN –

8:36AM A13.00004 The field-dependent flow-front speed of natural convection in magnetic fluids , JUN HUANG, YI LIU, ZHENYU ZHOU, WEILI LUO, University of Central Florida — The flow front of natural convection in a magnetic fluid was studied in applied field with two configurations: one with temperature gradient, ∇T, parallel to the field gradient, ∇B, and the other with ∇T anti-parallel to ∇B. The temperature profiles inside the two quasi one-dimensional cells were used to analyze the speeds of flow fronts. We found that when ∇B is anti-parallel to ∇T, the flow speed is slower than that in zero field; while when ∇B is parallel with ∇T, the flow speed is faster than that in zero field. These results confirmed our earlier work that in the parallel configuration the field enhances, while in the anti-parallel configuration the field suppresses the convection.

8:48AM A13.00005 Probing Instability using Pattern Control in Rayleigh-Bénard Convection[1] , ADAM PERKINS, ROMAN GRIGORIEV, MICHAEL SCHATZ, Georgia Institute of Technology — Identifying and characterizing the mechanisms of instability in spatiotemporally complex systems is of extreme interest, both fundamentally and for real-world applications such as forecasting. We report on a new experimental approach to study instability in a paradigm of such pattern forming systems, Rayleigh-Bénard convection. The convective fluid absorbs incident infrared laser light, thereby altering the fluid flow. Rapid scanning of the light allows nearly simultaneous actuation at many spatial locations of the pattern. This approach is used to impose reproducibly a given convection pattern. Control is demonstrated by preparing repeatedly a pattern near a straight roll instability. Selected perturbations are applied to this ensemble and decay lifetimes are measured as the system relaxes to the base state. We find that decay lifetimes give a quantitative measure of distance from instability and observe expected critical slowing down as the instability boundary is approached. We also extract the spatial structure of the modes governing the instability and the corresponding growth rates.

[1]This work is supported by NSF.

9:00AM A13.00006 Convection Cells driven by Spontaneous Symmetry Breaking[1] , MICHEL PLEIMLING, BEATE SCHMITTMANN, R.K.P. ZIA, Virginia Polytechnic Institute and State University — A clear signature of far-from-equilibrium systems, convection cells are ubiquitous in nature. Typically, they are driven by external forces, like gravity (in combination with temperature gradients) or shear. Here, we show the existence of such cells in a simple (possibly the simplest) system involving only a temperature gradient. In particular, we study a two-dimensional Ising lattice gas in contact with two thermal reservoirs, one at infinite temperature and another at a finite T. When T drops below the critical temperature, phase separation emerges and creates convection cells.

[1]Supported in part by NSF-DMR-0705152 and NSF-DMR-0904999.

9:12AM A13.00007 ABSTRACT WITHDRAWN –

9:24AM A13.00008 Phase separation in fluids with chaotic advection , DANIEL BELLER, Brandeis University, BEN VOLLMAYR-LEE, SOHEI YASUDA, Bucknell University — When immiscible fluids are advected by an externally applied chaotic flow field, a nonequilibrium steady state arises from the competition between coarsening and the chaotic ripping-apart of domains. We simulate a two-dimensional binary fluid system advected by two different flow fields: a periodic alternating vortex flow and a periodic alternating sine flow. For each case, we examine the local degree of chaos in the flow field by computing finite-backward-time Lyapunov exponent values at each point in the system. We find that this Lyapunov exponent field is correlated with the advected fluids' local free energy density, which is inversely related to the local time-averaged size of phase-separated domains in the steady state. This raises the possibility of making universal predictions of steady-state characteristics based on Lyapunov analysis of the flow field.

9:36AM A13.00009 Passive-scalar separation using chaotic advection , ANDREW DUGGLEBY, PRADEEP RAO, Texas A&M University, MARK STREMLER, Virginia Tech — Separation of two substances with slightly different diffusivities using chaotic advection is explored for finite Reynolds numbers (up to Re$\sim$ 10) and high average Schmidt numbers ($\overline{\mathrm{Sc}} = (\mathrm{Sc}_1 + \mathrm{Sc}_2)/2 = 10^6$)) for a modified lid-driven cavity. In this approach, exponential stretching of material interfaces enhances diffusion and accelerates separation of concentrated molecules having slightly different diffusivities. At low Re the flow can be reversed and the separated molecules extracted. Using the exponential convergence afforded by the use of a 2D Fourier-Chebyshev spectral algorithm for streamfunction-vorticity formulation with passive scalar transport enables accurate tracking of exponential stretching of material lines in the flow and capturing of the sharp concentration gradients associated with large $\overline{\mathrm{Sc}}$. The two substances separate significantly faster than for simple diffusion. Application to real separation systems will be discussed.

9:48AM A13.00010 A (1 + 1)-dimensional model to study the kinetic roughening transition in molecular beam epitaxial growth[1] , CRISTÓVÃO DIAS, GCEP-Centro de Fisica da Universidade do Minho, 4710-057 Braga, Portugal, NUNO ARAÚJO, Computational Physics for Engineering Materials, IfB, ETH Zurich, Schafmattstr. 6, 8093 Zurich, Switzerland, ANTÓNIO CADILHE, T-1 Group, MS B268, Los Alamos National Laboratory, Los Alamos, NM 87545, USA — We present a novel model to study the molecular beam epitaxial growth which belongs to different universality classes depending on the values of the flux and temperature. In the present work, we take that thermally activated processes evolve by bond counting. The model exhibits different regimes that from the ballistic deposition limit (at particle low mobility) to layer-by-layer growth (at high particle mobility). Finally, we provide a detailed analysis of the properties of the model at the roughening transition.

[1]LA-UR 09-07639

10:00AM A13.00011 Sidebranching in the Dendritic Crystal Growth of Ammonium Chloride , ANDREW DOUGHERTY, FRANKLIN STINNER, Lafayette College — We report new measurements of the dendritic crystal growth of NH_4Cl from supersaturated aqueous solution. We report the first measurement of the capillary length d_0 to be approximately $2 \times 10^{-4} \mu$m. For growth at small dimensionless supersaturations Δ on the order of 0.005, we have estimated the stability constant σ^* to be approximately 0.008. The origin of the sidebranches in dendritic growth is not fully understood, but one model is that they result from the selective amplification of microscopic noise. We will 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)]. 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. Given the finite experimental resolution, no measurement of the tip region can be completely free of contamination from early sidebranches. We will discuss this and other experimental challenges that need to be overcome before we can understand the origin of sidebranches.

10:12AM A13.00012 Growth and Scaling Dynamics of Condensed Water Drops around a NaCl crystal nucleus[1] , WENCESLAO GONZÁLEZ-VIÑAS, RAMCHANDRA D. NARHE[2], JOSÉ M. GUADARRAMA[3], University of Navarra, DANIEL BEYSENS, CEA-ESEME, ESPCI-PMMH, France — We report experimental results on the evolution of condensed water drops in presence of a NaCl crystal nucleus on an ITO substrate. Initially, a drop of radius R starts to grow on the nucleus. At the same time, at distance r from the nucleus center, a condensation pattern is also growing. A region of inhibited condensation is present between the central drop and the pattern. The width of this region δ asymptotically decreases as $t^{-1/6}$. The mean size of drops in the condensation patterns follows a power law r^{γ}, where γ evolves in time and has an average value of 0.16$\pm$0.07. The role of surface diffusion on this system behavior is discussed.

[1]Partially supported by Departamento de Educación (Gobierno de Navarra) and by Spanish MEC (FIS2008-01126)
[2]This research was supported by Marie Curie International Incoming Fellowship within the 7^{th} European Community Framework program
[3]Supported by the Asociación de Amigos de la Universidad de Navarra

10:24AM A13.00013 Scaling of walls in crystals: Deformation, grain boundaries, and dislocation structures , YONG CHEN, WOOSONG CHOI, STEFANOS PAPANIKOLAOU, JAMES SETHNA, LASSP, Cornell University — Some experiments of dislocation cell wall structures evolving in deformed metals have observed fractal structures; others have been analyzed in terms of distributions of cell sizes and misorientations that appear non-fractal, but scale with increasing deformation. We analyze a continuum simulation of geometrically necessary dislocations, relaxing in time. In the absence of climb, we observe self-similar (fractal) cell-wall structures, which we exhibit via real-space renormalization group and analyze in terms of critical exponents for correlation functions of dislocation density, orientation, and plastic distortion. For the same simulation, we analyze the distribution of cell sizes and cell wall misorientations, compare to the corresponding experiments, and discuss how our conclusions depend on the application of external loading. In the presence of climb (roughly simulating grain boundary polygonization) we observe non-fractal scaling and polycrystalline behavior.

10:36AM A13.00014 Domain Structure Universality in the Asymmetric Cahn-Hilliard Equation , BENJAMIN VOLLMAYR-LEE, Bucknell University, ANDREW RUTENBERG, Dalhousie University, SOHEI YASUDA, Bucknell University — The Cahn-Hilliard equation, which describes phase separation dynamics with a locally conserved order parameter, is symmetric under interchange of the two equilibrium phases. We consider variations of the Cahn-Hilliard equation in which this symmetry is broken, either by introducing a concentration-dependent asymmetric mobility, or by modifying the double-well potential. We then simulate these modified systems to determine the influence of asymmetry on the domain structure. This study is motivated by our conjecture that the asymptotic, late time domain structure is determined by the asymptotic dynamics of domain walls. Analysis of the domain wall dynamics, in turn, predicts that mobility asymmetry should affect the domain structure and correlations but that the potential well asymmetry should not. A comparison to the simulation results will be presented.

Monday, March 15, 2010 11:15AM - 2:15PM –
Session B12 GSNP DFD: GSNP Graduate Student Prize and Liquid Crystals: Smectics B110-B111

11:15AM B12.00001 Random Packing Density of Platonic Solids , JESSICA BAKER, ARSHAD KUDROLLI, Department of Physics, Clark University — Motivated by the relation between particle shape and packing, we investigate the volume fraction occupied by faceted particles as a function of number of particle sides. Such particles are arguably better representative of natural sand than spheres. For simplicity, we focus on the highly symmetric five Platonic solids which are polygons with congruent sides, vertices and angles, and experimentally measure their packing densities. Plastic dice with 4, 6, 8, 12, and 20 sides are fluidized or shaken randomly to find configurations corresponding to the loosest stable packing and densest packing, respectively. We find that the packing fraction obtained by both protocols peak at the cube and then monotonically decrease below the corresponding values obtained for spheres. Interestingly, the overall trend is similar but systematically lower that the maximum volume fractions reported for frictionless platonic solid particles. The effect of friction of the particles and the shape of the boundary shape on observed packing fractions is also investigated.

11:27AM B12.00002 A Bayesian Approach to Detecting Amino Acid Covariance in Multiple Sequence Alignments , LUCY COLWELL, MICHAEL BRENNER, ANDREW MURRAY, Harvard University — Determining which residues of a protein control its biological function is a classical question in molecular biology. In particular, proteins can change their structure or function by mutating just a small set of residues. An attractive idea is that distinct sets of residues are responsible for different phenotypic properties, so that one property can be changed while another is not. Members of such a set mutate at similar points in a multiple sequence alignment and so are correlated. It has long been proposed that analysis of correlations in the mutation patterns of protein sequences may provide an important means of extracting functional information about proteins from sequence alignments. Here, we propose a methodology for incorporating functional and structural annotations of the sequences analyzed to improve the efficacy of algorithms at detecting such residue sets. We provide a Bayesian framework in which known biological properties of the sequences are used to define a prior probability that quantifies our belief that sequence positions with different conservation levels are associated with the phenotype of interest. Recent experimental data is used to demonstrate that applying these principles results in improved detection ability, allowing us to distinguish between pairs that demonstrate similar levels of correlation but are not of equal relevance to the phenotypic purpose being addressed.

11:39AM B12.00003 Coarse-grained computational studies of the assembly of viral capsids around a flexible polymer , OREN ELRAD, MICHAEL HAGAN, Brandeis University — During the replication of many viruses, hundreds to thousands of protein subunits assemble around the viral nucleic acid to form a protein shell called a capsid. Recent electron microscopy experiments on small ssRNA viruses have shown that their enclosed RNA adopts the icosahedral symmetry of the overall capsid structure. The process that leads to this ordered encapsulation of the RNA is unknown. In this talk, we will explore dynamical simulations of coarse grained models that represent capsid proteins assembling around a flexible polymer, which shed light on the mechanisms by which icosahedral order emerges. We will discuss geometric and kinetic factors that control assembly, including the limits on the length of RNA that can be efficiently packaged. We will also report on several forms of cooperative polymer-protein motions that contribute to efficient and robust assembly. Finally, we will discuss how the simulation predictions can be tested with imaging experiments, bulk assembly kinetics measurements, and recently developed single molecule techniques that monitor the assembly of individual capsids.

11:51AM B12.00004 Controlling Elastic Instabilities: From Complex Pattern Formation to Functionality , ELISABETTA MATSUMOTO, RANDALL KAMIEN, University of Pennsylvania — Exploiting elastic instability in thin films has proven a robust method for creating complex patterns and structures across a wide range of lengthscales. Even the simplest of systems, an elastic membrane with a lattice of pores, under stress, generates a plethora of complex patterns featuring long-range orientational order. Harnessing the underlying elastic instability allows for the rational design of materials with highly desirable properties: from a film with a switchable photonic bandgap to a material with a negative Poisson ratio. Within the framework of linear elasticity, we model the system as a lattice of interacting deformation elements, or "dislocation dipoles," which captures the configuration and orientational order present in any conceivable deformation of the system. In addition, when we promote this system to a curved surface, a novel set of features, patterns and broken symmetries appears.

12:03PM B12.00005 Extending the Scaling Laws of Plasticity , GEORGIOS TSEKENIS, KARIN DAHMEN, Physics Department, University of Illinois at Urbana-Champaign — Crystalline materials are known to deform in an intermittent way with avalanches. Power laws govern the statistics of the avalanche sizes, energies and times between avalanches. In this work we are studying the universal aspects of plasticity and dislocation dynamics. We employ a discrete dislocation dynamics simulation, which allows us to reproduce the distributions of avalanche sizes and energies of previous works. In addition, our model accounts for time explicitly. Thus we are able to extract distributions of dislocation slip avalanche durations and interevent times, which compare quite well with the experimental findings. We are also able to extract the power spectra of the dislocation activity that exhibit power law behavior as well. Furthermore, finite stress rate forces avalanches to occur concurrently in time and/or space and appears to lead to similar effects as previously studied for spin systems driven by an increasing magnetic field. The study of larger system sizes and slower stress rates and comparison to new experiments will give us deeper insight into the problem of plasticity as a nonequilibrium critical phenomenon.

12:15PM B12.00006 BREAK –

12:39PM B12.00007 Investigation of B7 Liquid Crystal Undulation Texture[1] , D. CHEN, M.A. GLASER, J.E. MACLENNAN, N.A. CLARK, Department of Phyasics, University of Colorado at Boulder, USA, E. KORBLOVA, D.M. WALBA, Department of Chemistry and Biochemistry, University of Colorado at Boulder, USA — In bent-core liquid crystals, the strong local preference for layering, coupled with the bent shape of the molecules, leads to two spontaneous symmetry-breaking instabilities: polar molecular orientational ordering and molecule tilt. These instabilities combine to produce chiral layered phases such as the B2 and B7 phases. In the B7 phase, layer undulation arise due to the formation of periodic polarization splay stripes [D. A. Coleman, *et al. Science* **301**, 1204 (2003)]. We have studied the topological defects in the B7 undulation texture obtained by freeze fracture transmission electron microscopy, and have observed dislocations and disclinations in the undulation texture analogous to those in the layered systems. Investigation of these defects gives insight into the B7 polarization splay stripe structure. A model is proposed to calculate the free energy of the defects.

[1]This work is supported by NSF MRSEC Grant DMR0820579 and NSF Grant DMR0606528.

12:51PM B12.00008 Discovery of a novel smectic-C* liquid crystal phase with six-layer periodicity[1] , SHUN WANG, LIDONG PAN, University of Minnesota, RONALD PINDAK, NSLS, BNL, ZENGQIANG LIU, St. Cloud State University , TINH NGUYEN, Centre de Recherche Paul Pascal, CNRS, Universite Bordeaux I, CHENG-CHER HUANG, University of Minnesota — We report the discovery of a new SmC*$_{d6}$liquid crystal phase with six-layer periodicity by resonant x-ray diffraction. Upon cooling, the new phase appears between the SmC*$_{\alpha}$ phase having a helical structure and the SmC*$d4$ phase with four-layer periodicity. This SmC*$_{d6}$ phase was identified in two mixtures which have an unusual reversed SmC*d4-SmC$*$phase sequence. The SmC*$_{d6}$phase shows a distorted clock structure. The existence of phases having liquid-like in-plane ordering with a "long-range" lock-in periodicity (now being extended to six layers) is one of the long-lasting questions in condensed matter. Major efforts are required to address the physical origin of long-range interactions and novel physical properties of the SmC*$_{d6}$phase.

[1]S. W. acknowledges support from DDF, U of Minnesota

1:03PM B12.00009 ABSTRACT WITHDRAWN –

1:15PM B12.00010 Polarization modulated orthogonal smectic phases[1] , CHENHUI ZHU, RENFAN SHAO, JOSEPH MACLENNAN, DONG CHEN, YONGQIANG SHEN, MATTHEW GLASER, NOEL CLARK*, Department of Physics, University of Colorado, R. AMARANATHA REDDY, DAVID WALBA, Department of Chemistry and Biochemistry, University of Colorado, PER RUDQUIST, Microtechnology and Nanoscience, Chalmers University of Technology, Sweden — Polar orthogonal phases of bent-core materials have long been predicted, and a field-induced $SmAP_F$ has been reported[1]. We have recently observed a stable $SmAP_F$ phase, obtained by design for an asymmetric bent-core mesogen with only one tail[2]. Here we report studies on a similar single-tail bent-core mesogen, W596, which suggest the new material possesses an I-$SmAP_F$'-$SmAP_F$-Crystal phase sequence on cooling, where the $SmAP_F$' phase is similar to the $SmAP_F$ phase except that the $SmAP_F$' phase is polarization modulated, leading to the formation of layer undulations, evidenced from the 1D periodic line patterns in freeze fracture transmission electron microscopy images, and x-ray reflections in addition to the main smectic layering reflection. Results of polarizing optical microscopy, electro-optic studies, and differential scanning calorimetry will also be presented. [1] Y. Shimbo, et al. PRL 97, 113901 (2006). [2] D. M. Walba, et al. 11th FLC Conference, 2007, p31.

[1]This work was supported by NSF MRSEC Grant No. DMR-0213918.

1:27PM B12.00011 Helical nanofilaments and the high chirality limit of smectics-A , GARETH ALEXANDER, University of Pennslyvania, ELISABETTA MATSUMOTO, University of Pennsylvania, RANDALL KAMIEN, University of Pennslyvania — Motivated by recent experiments on chirality in smectic systems of achiral bent core molecules [1], I shall describe our recent work on the theory of chiral smectic-A liquid crystals and argue that at sufficiently large chiralities the traditional twist grain boundary phase is augmented by a new texture [2]. This bulk texture is characterized by an array of parallel, coherently rotating helical nanofilaments, which represent the local optimal configuration for chiral smectics, laced together by a lattice of defects, in a fashion akin to the cholesteric blue phases. A mean field analysis of the properties of this nanofilament phase shows good qualitative agreement with the germaine features of the experiment, which can be improved upon by including the layer curvature energy, as well as bringing up several subtle aspects of the familiar analogy between smectics and superconductors. [1] L. E. Hough et al, Science 325, 456-460 (2009). [2] E. A. Matsumoto, G. P. Alexander, and R. D. Kamien, arXiv:0909.3529 [cond-mat.soft] (2009).

1:39PM B12.00012 Orientational order and topological defects in smectics , BRYAN CHEN, GARETH ALEXANDER, RANDALL KAMIEN, University of Pennsylvania — The homotopy theory of topological defects in liquid crystals fails to completely characterize disclinations in smectics, due to the broken translational symmetry. We provide an approach to enumerating topological defects that correctly accounts for the interaction between translations and rotations.

1:51PM B12.00013 Chromonic liquid crystals and their dispersion in polymers , JUNG PARK, XUXIA YAO, MOHAN SRINIVASARAO — Chromonic liquid crystals can self-assemble into an ordered complex fluid, potentially applicable for biosensor, polarizers, optical compensetors and organic solar cells. Different from common amphiphilic lyotropic mesophases, aggregation of the chromonic liquid crystals is thought to be isodesmic and without optimum aggregation size. We studied the aggregation behavior by Vis-spectroscopy, and the phase behavior by polarizing optical microscopy and differential scanning calorimetry. We also used capillary flow to achieve uniform planar alignment in a flat capillary, and measured polarized Raman scattering, from which the temperature and concentration dependence of order parameters, both <P200> and <P400>, and the orientation distribution were deduced. Order parameters increase as concentration increases and decrease as temperature increases. Polymer dispersed chromonic droplets with different director configurations were obtained by using different water soluble polymers and those anchoring phenomena were compared.

2:03PM B12.00014 Topological defects of lyotropic chromonic liquid crystals , XUXIA YAO, ALEJANDRO REY, JUNG PARK, MOHAN SRINIVASARAO — Lyotropic chromonic liquid crystals (LCLCs), an interesting and relatively poorly studied class of lyotropic liquid crystals, have gained increasing attention from 1980s. The studies of topological defects of LCLCs have been rarely reported in literature. We found LCLCs actually provide a good model system to study the defects, due to their unique properties. Defects, such as loops and point defects distributed on disclination line, etc., were created and controlled through symmetry-breaking phase transitions in some cells with special geometries. The dynamics of these defects was studied and more elastic properties of LCLCs were deduced.

Monday, March 15, 2010 2:30PM - 5:18PM –
Session D12 DFD DCMP: Colloidal Crystals, Suspensions and Films B110-B111

2:30PM D12.00001 Glassy Dislocation Relaxation in Colloidal Peanut Crystals , SHARON GERBODE, DESMOND ONG, UMANG AGARWAL, CHEKESHA LIDDELL, FERNANDO ESCOBEDO, ITAI COHEN, Cornell University — Previous studies of dislocations in crystals of colloidal dimers have revealed unusual restrictions on dislocation glide. In the current study, we induce defect formation in such crystals using an optically manipulated spherical intruder particle dragged through an otherwise pure dimer crystal grain. We find that the relaxation response of the perturbed crystal changes as a function of the size of the grain. For small grains, the crystal relaxes via unrestricted dislocation glide, while in larger grains, other slower relaxation mechanisms are utilized. Furthermore, we have uncovered a two-stage defect relaxation process in crystals of dimers, reminiscent of relaxation in glassy systems, in which an initial fast glide response is followed by a slower relaxation process where dislocations hop between caged configurations. We find that the relaxation decay of dislocations is consistent with the combination of a fast exponential decay followed by a slow logarithmic decay characterized by a timescale 5 orders of magnitude longer than that of the exponential decay. Together these results reveal an interesting new class of materials possessing crystalline order but whose defects are characterized by glassy behavior.

2:42PM D12.00002 Elastically Disordered Perfect Colloidal Crystals , DENIZ KAYA, N.L. GREEN, Department of Chemical Engineering , C.E. MALONEY, Deparment of Civil and Environmental Engineering , M.F. ISLAM, Departments of Chemical Engineering, Materials Science and Engineering, Carnegie Mellon University, Pittsburgh, PA, 15213 — We use spherical microgel colloidal particles to study lattice dynamics in a three-dimensional crystal using optical microscopy. We find that the local bond length fluctuations vary by as much as 75% from bond to bond despite less than 2% fluctuations in the equilibrium bond lengths. We show how to calculate the low-energy eigenmodes and the density of states in the presence of the strong heterogeneity. We find that the lowest energy eigenmodes are dominated by a few long-wavelength planewaves, and the density of states shows Debye-like behavior at low energy. This work has been partially supported by the NSF through Grants DMR-0619424 and DMR-0645596, by ACS-PRF and Alfred P. Sloan foundation.

2:54PM D12.00003 Formation and Phase Transformations of Helical Structures of Colloidal Spheres[1] , MATTHEW LOHR, University of Pennsylvania, AHMED ALSAYED, CNRS-Rhodia-UPenn UMI 3254, BRYAN CHEN, ZEXIN ZHANG, RANDALL KAMIEN, ARJUN YODH, University of Pennsylvania — We experimentally explore the ordering of thermal quasi-one dimensional helical structures of monodisperse spheres. Helical packings of thermoresponsive colloid particles are formed in glass microcapillaries and display evidence of long-range orientational order at high volume fractions. As volume fraction is decreased, these ordered packings transition to structurally disordered states. Orientational order parameters and susceptibilities demonstrate the abrupt nature of this crossover. Coexistence of ordered and disordered states is also exhibited at lower volume fractions, as well as coexistence of ordered domains with different pitch and chirality. Such coexistence lends credence to the notion of discontinuous transitions in these structures. We also present preliminary experimental work on producing and controlling the formation of ordered helical structures of unconfined colloids by tuning both short-range attractive and dipolar interactions between particles.

[1]This work supported by MRSEC grant DMR-0520020, NSF grant DMR-080488, and NASA grant NAG-2939.

3:06PM D12.00004 Melting of Colloidal-Crystal Films , YI PENG, ZIREN WANG, Hong Kong University of Science and Technology, AHMED ALSAYED, ARJUN YODH, University of Pennsylvania, YILONG HAN, Hong Kong University of Science and Technology — We studied the melting of multilayer colloidal crystals composed of diameter tunable microgel spheres with short-ranged repulsive interactions confined between two glass walls. Samples are annealed into large crystalline domains so that the finite size effects are negligible. Different melting behaviors were observed in three thickness regimes: 1. Thick films ($>$ 4-layer) melt from grain boundaries in polycrystals and from surfaces in single crystals. The liquid-solid coexistence regime decreases with the thickness and vanishes at 4 layers. 2. Thin films (2 to 4-layer) melt homogenously from both grain boundaries and surfaces. One-step melting is observed in 2-, 3- and 4-layer triangular and square lattices. 3. Monolayers melt in two steps with a middle hexatic phase.

3:18PM D12.00005 Exploring the role of strain in colloidal thin film crystallization , JOHN SAVAGE, RAJESH GANAPATHY, ITAI COHEN, Cornell University — We present results of experiments studying the effect of isotropic and directed strain on the dynamics of thin film crystallization in colloids with short-range attractive interaction. Our system consists of micron size colloidal particles and a tunable depletant allowing reversible control of the interaction with small temperature changes. We explore the role of strain on the dynamics of melting and freezing and the equilibrium structures formed under directed strain. We find that in comparison with previously performed experiments on flat unpatterned substrates, dynamics and equilibrium morphologies on such surfaces alter dramatically. For example, crystals formed on square lattices strained along one direction tend to become highly elongated along the other direction. We consider the competition of strain and surface tension during the nucleation process under these extreme conditions.

3:30PM D12.00006 Melting scenario for two-dimensional plasma crystals , V. NOSENKO, S.K. ZHDANOV, A.V. IVLEV, C.A. KNAPEK, G.E. MORFILL, Max-Planck Institute for extraterrestrial Physics, Garching, Germany — The solid-liquid phase transition in two-dimensional (2D) systems is not completely understood. Two most important (and competing) models of 2D melting are the dislocation theory of melting - the Kosterlitz-Thouless-Halperin-Nelson-Young (KTHNY) theory and the theory of grain-boundary-induced melting. We performed experimental study of melting in 2D crystalline lattices using complex plasma as a model system. Complex (dusty) plasmas consist of fine solid particles suspended in a weakly ionized gas. At our experimental conditions, the suspension forms a highly ordered 2D triangular lattice, where all particles can be traced using video microscopy. This lattice is very soft and can be readily melted using e.g. the radiation of a focused laser beam. We found an Arrhenius dependence of the defect concentration on the kinetic temperature in steady-state experiments, and show the evidence of metastable quenching in unsteady experiments, where the defect concentration follows a power-law temperature scaling. In all experiments, independent indicators suggest a grain-boundary-induced melting scenario.

3:42PM D12.00007 Phase separation in binary complex plasmas , ALEXEI IVLEV, ADAM WYSOCKI, CHRISTOPH RAETH, ROBERT SUETTERLIN, HUBERTUS THOMAS, GLENN JOYCE, HARTMUT LOEWEN, GREGOR MORFILL, MAX PLANCK INSTITUTE FOR EXTRATERRESTRIAL PHYSICS, 85741 GARCHING, GERMANY TEAM, HEINRICH-HEINE-UNIVERSITAET, 40225 DUESSELDORF, GERMANY COLLABORATION, ICARUS RESEARCH INC., BETHESDA, USA COLLABORATION — Complex plasmas are composed of a weakly ionized gas and charged microparticles and represent an ideal system to investigate multicomponent mixtures. Microparticles usually acquire high negative charges determined by the balance of absorption of the surrounding electrons and ions, and interact via the Yukawa potential. The effective screening length characterizing the interactions is typically two orders of magnitude larger than the particle size, and can be varied from a few tenths to a few interparticle distances. This allows us to span the interaction regimes from short-range to many-body. Recent experiments performed with binary complex plasma under microgravity conditions onboard the ISS revealed different regimes of the phase separation. The interparticle interactions in complex plasmas are characterized by a positive nonadditivity which always stimulates the phase separation. For typical experimental conditions the regime of the spinodal decomposition is easily achievable.

3:54PM D12.00008 Fabrication of polymer-bridged monolayer of colloidal crystal at water surface , CHI-CHIH HO, KENG-HUI LIN, WEN-TAU JUAN, WEI-LI LEE, INSTITUTE OF PHYSICS, ACADEMIA SINICA TEAM — We have developed a new method to prepare a 2D colloidal crystal at the water/air interace, transferred the crystal onto a substrate, and stabilized the crystal structure of domain size 200x200 μm^2 by polymer bridging effect. We analyzed the interparticle spacing from the diffraction patterns and found that even at very high area fraction there was tiny separation between particles at water/air interface due to Coulomb repulsive force and Brownian fluctuation. After adding polyethylene oxide (PEO) into the solution, the interparticle separation is further reduced. PEO is known to adsorbed onto particle surface and provide bridging between particles. During transferring the particles onto a substrate, this adsorbed polymer layer provides a repulsive barrier to prevent the pulling from the capillary force which causes cracks in the original crystal structure. The resulting large domain of single 2D crystals can be used as a mask for fabricating periodic nanostructures.

4:06PM D12.00009 ABSTRACT WITHDRAWN –

4:18PM D12.00010 Nanoparticles in Aqueous Media: Crystallization and Solvation Charge Asymmetry[1] , WILLIAM KUNG, Northwestern University, PEDRO GONZALES, Cinvestav del IPN, MONICA OLVERA DE LA CRUZ, Northwestern University — We examine the issue of whether dispersion forces can lead to crystallization in a system of charged nanoparticles in aqueous solution with NaCl salt. To this end, we determine the effective pair potential (EPP) among the nanoparticles, starting from a model system that explicitly includes the salt ions and the water molecules. In particular, we used the well-tested simple point charge extended (SPC/E) model for the water molecules and the reference interaction site model (RISM) equation complemented with the hypernetted-chain (HNC) closure to compute the pairwise correlations among the components. As such, we derive the phase diagram for our system using a mean-field approach based upon the computed EPP, for a range of (finite) nanoparticle densities and salt concentrations, and demonstrate crystallization. Findings from our model also suggest strong trends of charge asymmetry due to solvation effects.

[1]W. K. acknowledges the funding from the Nanoscale Science and Engineering Initiative by the National Science Foundation (NSF) under the Award Number EEC-0647560 and from NSF grant DMR 0907781. P. G.-M. was partially supported by the NSF grant DMR-05205

4:30PM D12.00011 Glassy dynamics of geometrically frustrated colloidal system[1] , JENNIFER M. LYNCH, PETER YUNKER, ZEXIN ZHANG, University of Pennsylvania, YAIR SHOKEF, Weizmann Institute of Science, YILONG HAN, Hong Kong University of Science and Technology, TOM LUBENSKY, ARJUN YODH, University of Pennsylvania — Geometric frustration arises when lattice structure prevents simultaneous minimization of local interaction energies. It leads to highly degenerate ground states and, subsequently, to complex phases of matter. Recently, a simple geometrically frustrated system composed of closely packed colloidal spheres confined between parallel walls was studied. Diameter-tunable microgel spheres are self-assembled into a buckled triangular lattice with either up or down displacements, analogous to an antiferromagnetic Ising model on a triangular lattice. This tunable soft-matter system provides a means to directly visualize the dynamics of frustration. In the present study, we probe spin dynamics on the single particle level by quenching our system to large packing fractions at different rates. Spin dynamics are found to exhibit behaviors characteristic of glasses.

[1]This work is supported by the National Science Foundation through DMR-080488 and the PENN MRSEC DMR-0520020.

4:42PM D12.00012 Capillary interactions between silica-particles in organic solvents , GARFIELD WARREN, DOBRIN BOSSEV, Indiana University — Small-angle neutron scattering (SANS) is used to study the interactions of silica nano-particles with an average diameter of 10 nm in methanol and methanol/toluene mixtures at 25 °C. SANS intensities are analyzed as a product of a form factor and a structure factor. Methanol is a polar solvent with a dielectric constant of e = 32 at ambient temperatures the interaction of silica in methanol is considered to be through electrostatic repulsion. The presence of toluene reduces the polarity of the solvent since toluene is a non-polar liquid with e = 2. At fractions of toluene less than 44 %, the dispersion of silica particles is stable and non-viscous. The analysis of the structure factor shows that the silica particles reduce their charge with increasing fraction of toluene. At intermediate fractions of toluene, between 44 and 65 %, the viscosity increases by two orders of magnitude which suggests formation of two dimensional network of silica particles. Computer simulations of a pearl necklace-like chain of spheres is conducted to explain the structure factor at these intermediate fraction of toluene.

4:54PM D12.00013 Capillary interactions in nano-particles suspensions , DOBRIN BOSSEV, GARFIELD WARREN, Indiana University — We have investigated the structures formed by colloidal particles suspended in solvents at volume fractions below 10% and interacting through capillary bridges. Such systems resemble colloidal gas of sticky nano-spheres that form pearl-necklace like chains that, in turn, induce strong viscoleasticity due to the formation of 3-D fractal network. The capillary force dominates the electrostatic and Van der Waals forces in solutions and can bridge multiple particles depending of the volume of the capillary bridge. Small-angle neutron scattering (SANS) is used to study nanoparticles with an average diameter of 10 nm in polar and non-polar organic solvents at ambient temperatures. Computer simulations of a pearl necklace-like chain of spheres is conducted to explain the structure factor when capillary bridges are present. We have also studied the properties of the capillary bridge between a pair of particles. The significance of this study is to explore the possibility of using capillary force as a tool to engineer new colloidal structures and materials in solutions and to optimize their viscoelastic properties.

5:06PM D12.00014 Structure of Viral Aggregates , STEPHEN BARR, University of Illinois at Urbana-Champaign , ERIK LUIJTEN, Northwestern University — The aggregation of virus particles is a particular form of colloidal self-assembly, since viruses of a give type are monodisperse and have identical, anisotropic surface charge distributions. In small-angle X-ray scattering experiments, the Qbeta virus was found to organize in different crystal structures in the presence of divalent salt and non-adsorbing polymer. Since a simple isotropic potential cannot explain the occurrence of all observed phases, we employ computer simulations to investigate how the surface charge distribution affects the virus interactions. Using a detailed model of the virus particle, we find an asymmetric ion distribution around the virus which gives rise to the different phases observed.

Tuesday, March 16, 2010 8:00AM - 11:00AM –

Session H13 DFD: Liquid Crystals: Nanoparticles and Surfaces B112

8:00AM H13.00001 Maier-Saupe-type theory of ferroelectric nanoparticles in nematic liquid crystals[1] , JONATHAN SELINGER, LENA LOPATINA, Liquid Crystal Institute, Kent State University — Several experiments have reported that ferroelectric nanoparticles have drastic effects on nematic liquid crystals–increasing the isotropic-nematic transition temperature by about 5 K, and greatly increasing the sensitivity to applied electric fields. In a recent paper [1], we modeled these effects through a Landau theory, based on coupled orientational order parameters for the liquid crystal and the nanoparticles. This model has one important limitation: Like all Landau theories, it involves an expansion of the free energy in powers of the order parameters, and hence it overestimates the order parameters that occur in the low-temperature phase. For that reason, we now develop a new Maier-Saupe-type model, which explicitly shows the low-temperature saturation of the order parameters. This model reduces to the Landau theory in the limit of high temperature or weak coupling, but shows different behavior in the opposite limit. We compare these calculations with experimental results on ferroelectric nanoparticles in liquid crystals.

[1] L. M. Lopatina and J. V. Selinger, Phys. Rev. Lett. 102, 197802 (2009).

[1]This work was supported by NSF Grant DMR-0605889.

8:12AM H13.00002 Study of Phase Transitions in Barium Titanate - Liquid Crystal Nano-colloidal Suspensions , KRISHNA SIGDEL, GERMANO IANNACCHIONE, Worcester Polytechnic Institute — A high-resolution ac-calorimetric study of the isotropic to nematic (*I*-*N*) and the nematic to smectic-*A* (*N*-Sm*A*) phase transitions in nano-colloidal suspensions of Barium Titanate ($BaTiO_3$) in the liquid crystal (LC) octylcyanobiphenyl (8CB) as a function of $BaTiO_3$ concentration is reported. Heating and cooling scans were performed for all samples (0.1 - 1.4 wt% of $BaTiO_3$ and pure 8CB) over a wide temperature range well above and below the two transitions. Both the *I*-*N* and the *N*- Sm*A* transitions evolve in character and have their transition temperatures shift lower as the wt% of $BaTiO_3$ increases. Increasing hysteresis with increasing concentration is also observed at the *I*- *N* transition between heating and cooling scans within the two- phase *I*+*N* coexistence region. These results will be contrasted with other LC colloidal dispersion systems.

8:24AM H13.00003 Optical control of nano-particles and colloidal architectures[1] , HECTOR MIRELES[2], Cal Poly Pomona, ANGEL MARTINEZ, CU-Boulder, IVAN SMALYUKH — Controlled structural assembly of micro- and nano-sized particles is essential for many technologies, ranging from optical metamaterials to photovoltaic devices. We demonstrate a low-intensity "opto-elastic" method of manipulating micron- and submicron- sized particles suspended within a nematic liquid crystal. By optically controlling a surface monolayer of an azobenzene based dye, we manipulate the surface boundary conditions and liquid crystal director in the sample bulk to form domains of uniform alignment. Large elastic deformations are thus generated at the interface between adjacent domains with different director orientations. By exploiting elastic forces acting on the particles near the misalignment walls, we manipulate micron and sub-micron-sized particles such as melamine resin polymer microspheres and silver nano-rods. This method of "opto-elastic" manipulation requires light intensities three orders of magnitude smaller than in the case of laser tweezers utilizing optical gradient forces and enables massively-parallel manipulation of multiple particles on the scales of millimeters and centimeters.

[1]Partial support for this sabbatical work made possible by the Institute for Complex Adaptive Matter (ICAM).
[2]Currently on sabbatical at CU-Boulder

8:36AM H13.00004 Interaction of a bi-molecular liquid crystal film with functionalized nanoparticles[1] , JEFFERSON W. TAYLOR, L.J. MARTINEZ-MIRANDA, University of Maryland — We investigate the properties of a bi-molecular film of liquid crystal close to a magnetic nanoparticle (CoFe) with a functionalization compound (MHDA) with the atomic force microscope (AFM). We seek to investigate if the functionalization compound has an effect on the ordering of the liquid crystal in the vicinity of the nanoparticle. Studies in bulk liquid crystals have shown that the functionalization compound influences how the liquid crystal reorganize [1]. The results of this investigation will be compared to the results of work done on phospholipids in close contact with uncovered silica nanoparticles [2]. Preliminary studies of the liquid crystal in contact with the nanoparticles show that it behaves similarly to the way the phospholipids behave. More functionalization compounds are studied in order to establish whether it behaves differently depending on the functionalization compound.

[1] L. J. Martínez-Miranda, L. K. Kurihara, J. Appl. Phys 105, 084305 (2009).
[2] Yuri Roiter, Maryna Ornatska, Aravind R. Rammohan, Jitendra Balakrishnan, David R. Heine, and Sergiy Minko, Langmuir, 25, 6287-6299 (2009).

[1]We acknowledge NSF-DMR grant No. 906433.

8:48AM H13.00005 The Role of Liquid Crystal Order in Liquid Crystal-Zno Nanoparticle Photovoltaics[1] , LUZ J. MARTINEZ-MIRANDA, University of Maryland, KAITLIN M. TRAISTER[2], Franklin and Marshall College, LOURDES SALAMANCA-RIBA, University of Maryland, IRISELIES MELENDEZ-RODRIGUEZ[3], Univerisity of Puerto Rico - Mayaguez — We investigate the role order plays in the transfer of charges in ZnO nanoparticle-8CB Liquid crystal system for photovoltaic applications. It is known that liquid crystals will align the nanoparticles in rows. We have found that in addition the nanoparticle helps align the liquid crystal when mixed in the appropriate percentage mixture in the liquid crystal. In this system, the liquid crystal acts as the hole conductor whereas the nanoparticle or nanowire acts as the electron conductor. We have used InSnO (ITO) electrodes to measure the electrical current. We have changed the percentage weight of ZnO in 8CB from 1.18% to 40%. We have observed that in this system a 30% weight of ZnO in the liquid crystal octylcyanobiphenyl (8CB) will 1. Help to further align the liquid crystal; 2. Produce the largest change in V_{oc} with respect to the V_{oc} of the nanoparticle; 3. Increase the current generated.

[1]We acknowledge grant NSF - DMR - MRSEC NO. 0520471.
[2]UMD-MRSEC-REU student
[3]UMD-MRSEC-REU student

9:00AM H13.00006 Electro-optical properties of CdSe quantum dots dispersed in a chiral nematic liquid crystal[1] , J. KIRCHHOFF, Florida State University, R.H. INMAN, S. GHOSH, L.S. HIRST, University of California Merced — The electro-optical properties of quantum dots can be significantly altered if they are assembled in close proximity to each other. The partial ordering of liquid crystal molecules can be utilized to form directed quantum dot assemblies. Typically, this results in a red shift in the emission spectrum of the dots as the induced order leads to enhanced dipolar interactions, resulting in electronically coupled states. Spherical cadmium selenide quantum dots of different diameters are dispersed in various concentrations in a chiral nematic liquid crystal phase. The quantum dots are seen to aggregate, the sizes of the aggregates depend on the size, concentration, and mixing time of the dots, and the aggregates in turn form defects in the liquid crystal texture. The effect of the dots on the electro-optical response of the liquid crystal is studied, with a decrease in a threshold electric field transition attributed to the quantum dots. Quantum dots with emission peaks ranging from 490 nm to 640 nm were studied using polarized optical microscopy, fluorescence microscopy, and scanning microscopy photoluminescence measurements.

[1]Funding from NSF grants DMR-0852791 and DMR-0821771.

9:12AM H13.00007 The Study Of Charge Carrier Transport On The Calamitic Liquid Crystals " 5, 5'-Di-(Alkyl-Pyridin-Yl) - 2' Bithiophenes" , NARESH SHAKYA, CHANDRA POKHREL, BRETT ELLMAN, Physics Department, Kent State University, YULIA GETMANENKO , ROBERT TWIEG, Chemistry Department, Kent State University — The hole and electron mobilities in both types of calamitic liquid crystals C9 [5,5'-Di-(5-n-nonyl-pyridin-2-yl)-2,2'-bithiophenes] and C10 [5,5'-Di-(5-n-decyl-pyridin-2-yl)-2,2'-bithiophenes] were studied. The charge carrier mobilities were strongly electric field dependent. The mobilities decreased continuously with increase in the electric field up to a certain value, after which it became constant. Both types of charge carrier mobilities are independent of the temperature over our temperature range. The qualitative feature of our results could be tentatively explained by the Monte–Carlo modeling proposed by H Bassler. However, the results require further study for better understanding.

9:24AM H13.00008 Bent-core alignment monolayers[1] , WILDER IGLESIAS, ANTAL JAKLI, ELIZABETH K. MANN, Kent State University — Langmuir Films have been source of high expectations not just because of the opportunity that they provide to study low-dimensional fluids, but also because of the practical and potential applications that comes from the possibility to transfer these thin films into another surface, through Langmuir-Blodgett (LB) and Langmuir-Schaefer (LS) techniques. We use these transference techniques to deposit a monolayer of a bent-core liquid crystal molecule (Z2B) into different substrates, to use later as alignment layer in a liquid crystal cell, where the direction and degree of the alignment is changed by increasing and decreasing the packing of the molecules in the monolayer (dipping the substrate on a Langmuir Trough with different surface pressures).

[1]This work was supported by NFS, grant 0907055.

9:36AM H13.00009 Island Diffusion in Freely Suspended Smectic A Films: Crossover From 2D to 3D Behavior[1] , ZOOM NGUYEN, MARKUS ATKINSON, CHEOL PARK, JOSEPH MACLENNAN, MATTHEW GLASER, NOEL CLARK, University of Colorado — Measuring the diffusion constant has been an important tool in studying the hydrodynamics of two-dimensional (2D) systems. The well-known Saffman equations predict how the diffusion of an inclusion in a 2D fluid film depends on the inclusion's size. For inclusions with radius R large compared to the characteristic Saffman length l_S, the fluid bounding the two dimensional system needs to be considered, rendering it effectively a 3D problem, and the diffusion constant varies as 1/R. In the 2D limit (if $R << l_S$), it varies as ln(1/R). We present here a clean two-dimensional system using freely suspended smectic A liquid crystal films that allows us to test this behavior in both regimes. By tracking the self-diffusion of single islands (thicker, circular domains embedded in the films), we are able to calculate the diffusion constant. The sensitivity of the measurement also allows us to detect the hydrodynamic interactions between islands.

[1]This work was supported by NASA Grant NAG-NNC04GA50G and NSF MRSEC Grant No. DMR 0213918

9:48AM H13.00010 Title: Liquid crystal cells with "dirty" substrates[1] , QUAN ZHANG, LEO RADZIHOVSKY, Department of Physics, University of Colorado, Boulder, CO 80309 — We explore liquid crystal order in a cell with a "dirty" substrate imposing a random surface pinning. Modeling such systems by a random-field xy-model with surface heterogeneity, we find that orientational order in the three-dimensional system is marginally unstable to such surface pinning. We compute the Larkin length scale, and the corresponding surface and bulk distortions. On longer scales we calculate correlation functions using the functional renormalization group and matching methods, finding a universal logarithmic and double-logarithmic roughness in two and three dimensions, respectively. For a finite thickness cell, we explore the interplay of homogeneous-heterogeneous substrate pair and detail crossovers as a function of disorder strength and cell thickness.

[1]NSF DMR-0321848, MRSEC DMR-0213918

10:00AM H13.00011 Thickness dependent phase behavior of AFLC liquid crystal films , CHENG-CHER HUANG, LIDONG PAN, SHUN WANG, University of Minnesota, CHAIN-SHU HSU, National Chiao Tung University — Free standing films of a liquid crystal compound with simple surface enhanced order were studied. The resultant phase diagram demonstrates that (1) the short helical pitch smectic-C*$_{alpha}$ phase disappears below a film thickness of 10 layers, and (2) the temperature window of a distorted 4 layer smectic-C*$_{d4}$ phase increases dramatically upon decreasing film thickness. The experimental findings were attributed to the reduced dimensionality and enhanced surface effects in thin films. The results of the smectic-C*$_{alpha}$ phase are consistent with what have been reported for helically ordered magnetic thin films, with a noticeable difference due to the opposite effect of the surface on ordering in the two systems.

10:12AM H13.00012 Colloidal crystal-liquid Interface: Anisotropy, Free energy, and Structure , DUC NGUYEN, TRIET DANG, BART WEBER, PETER SCHALL, UvA — Investigation of the crystal–liquid interface is of central importance for understanding crystal growth, and nucleation. This interface is the most difficult to study experimentally because it is buried between two condensed phases. We use micron-size colloidal particles as models to visualize atomic processes of crystal growth. Because of their larger length and time scales, by optical microscopy, we can observe and even track the motion of the individual particles in three dimensions and time. This provides an excellent opportunity to study the crystal-liquid interface on the "atomic" level. We determine all thermodynamic properties of the system: pressure, the chemical potential, and the free energy density. We use interface fluctuations to determine the interfacial tension and its dependence on the crystal orientation, important parameters of crystal growth. Remarkably, the anisotropy of the interfacial tension that we find is very similar to that measured for real metallic crystals

10:24AM H13.00013 Cooperative Ordering at Liquid Crystal Interfaces and its Role in Orientational Memory , DAVID PATRICK, Western Washington University — Orientational memory in interfacial liquid crystal films occurs when cells heated above the isotropic transition temperature return to their initial ordered texture upon cooling. First observed over 80 years ago, the origins of orientational memory, which is sometimes called the surface memory effect, remain poorly understood. In this study, films of the thermotropic liquid crystal 4'-octyl-4-cyanobiphenyl on graphite were studied by scanning tunneling and polarizing optical microscopy. Strong orientational memory was observed despite relatively weak molecule-surface interactions of the kind previously thought to be responsible for this effect. By preparing cells in a uniformly oriented initial reference state and separately measuring bulk and surface order parameters as systems were thermally disordered, cooperative interactions were found to play an important role, leading to the recovery of long-range order that neither the bulk nor surface layers alone retained. When the surface and bulk layers were partially decoupled using a magnetic field, orientational memory in the surface layer almost disappeared. The findings provide a new interpretation of the origins of orientational memory in liquid crystal films and underscore the potentially important role of cooperativity in bulk $\leftrightarrow$ interfacial liquid crystal interactions.

10:36AM H13.00014 Effect of Alignment on the Nematic to Isotropic Phase Transitions of 8CB , DIPTI SHARMA, UML — This study reports the effect of alignment on the nematic to isotropic phase transition of bulk octylcyanobiphenyl liquid crystal. This effect reveals a reduced time and temperature lag with possible solutions to the time response and backlight bleed drawbacks of liquid crystal displays (LCDs). The aligned octylcyanobiphenyl shows a quicker and early occurrence of the nematic transition with less deviation from thermal rates than the unaligned octylcyanobiphenyl using calorimetry technique. Smaller enthalpy of activation indicates less energy requirement and makes the aligned octylcyanobiphenyl suitable for LCDs. The results are discussed in terms of the formation of aligned domains of octylcyanobiphenyl molecules under the force of magnetic field.

10:48AM H13.00015 Study on the surface enhanced ordering effect of liquid crystal films , LIDONG PAN, SHUN WANG, University of Minnesota, CHAIN-SHU HSU, National Chiao Tung University, CHENG-CHER HUANG, University of Minnesota — Null Transmission Ellipsometer was employed to study the surface enhanced ordering effect in one smectic liquid crystal. In the SmA temperature window of free standing films with thickness around 15 molecular layers, we studied the response of the surface arrangement as a function of temperature and transverse electric field. From the results we obtained the interaction between the two surfaces as a function of temperature and film thickness. The effective range of surface interaction is found to be around 20 molecular layers.

Tuesday, March 16, 2010 2:30PM - 5:30PM –

Session L6 DFD: Intracellular Fluid Dynamics Portland Ballroom 253

2:30PM L6.00001 Cell Quakes: Mechanics and Microrheology of Living Cells and Active Gels

, ALEX LEVINE, UCLA — Recent experiments on molecular motor driven in vitro F-Actin networks have found anomalously large strain fluctuations at low frequency. In addition, the shear modulus of these active networks becomes as much as one hundred times larger than that of the same system in equilibrium. We develop a two-fluid mean-field model of a semiflexible network driven by molecular motors to explore these effects and show that, relying on only simple assumptions regarding the motor activity in the system, we can quantitatively understand both the low-frequency fluctuation enhancement and the nonequilibrium stiffening of the network. We discuss the implications of the fluctuation enhancement for intracellular microrheology. In particular we show that, by observing the anti-correlated motion of tracer particles in two-particle microrheology, one can calculate the density of active motor complexes and quantitatively account for these nonequilibrium forces in the analysis of the fluctuation data. Finally, we present the results of numerical work on the motor-induced gel stiffening effect in the high motor density limit, which goes beyond the analytic mean-field model. These results have implications for the interpretation of microrheology in such active networks including the cytoskeleton of living cells. In addition, they may form the basis for theoretical studies of biomimetic nonequilibrium gels whose mechanical properties are tunable through the control of their nonequilibrium steady state.

3:06PM L6.00002 Intracellular Fluid Dynamics.

, MOHAMMAD MOFRAD, UC Berkeley — No abstract available.

3:42PM L6.00003 Making the right choice: Biomechanical design making in tumor invasion

, MUHAMMAD H. ZAMAN, Boston University — Little is known about the complex interplay between the extracellular mechanical environment and the mechanical properties that characterize the intracellular environment during various stages of tumor metastasis. To date, most studies have focused on artificial 2D environments that are unrealistic and far from in vivo. In order to elucidate the cell-matrix relationship in cancer progression, we probe the intracellular and extra-cellular mechanical and biochemical environments to understand how tumor cells navigate the complex 3D environments. We simultaneously focus on cytoskeletal mechanics and intracellular signaling pathways as a function of dynamic matrix environments. Our results a non-linear dependence of focal adhesion protein (FAK) phosphorylation on matrix cross-linking and matrix mechanics. Increase in FAK phosphorylation is associated with actin cross-linking, changes in cell morphology and increased production of matrix degrading enzymes or MMPs. This production, in turn, affects adhesion through another feedback mechanism where MMPs regulate integrin expression and hence control cell shape, attachment and migration. Together, these two competing mechanisms control how cells respond to mechano-chemical changes in their local environment during single and collective migration in natural 3D environments. Our results highlight the interconnectivity of mechanical and chemical processes during 3D tumor invasion and identify key controllers of the cell decision process during tumor invasion.

4:18PM L6.00004 Intracellular Fluid Dynamics.

, DENNIS WIRTZ, Johns Hopkins University — No abstract available.

4:54PM L6.00005 Anisotropic viscoelastic properties and cytoskeletal structure of endothelial cells subject to shear flow

, JUAN C. DEL ALAMO, University of California, San Diego — The cytoskeleton of adherent cells remodels in response to mechanical stimuli leading to a redistribution of intracellular forces that modifies cell function. We have analyzed the magnitude and anisotropy of the viscoelastic properties confluent vascular endothelial cells subject to continuous flow. For this purpose we used Directional Particle Tracking Microrheology, which measures the second-order tensor of intracellular marker displacements, allowing us to determine the principal directions of highest and lowest shear modulus at each position. We studied the orientation of these principal directions relative to the actin stress fibers. Before starting the flow, the cells' average cytoskeletal organization and shear modulus are isotropic. After the application of flow shear the cells' stress fibers gradually orient parallel to the flow and the principal directions of the shear modulus become parallel and perpendicular to the flow. The role of ATP-driven myosin-II contractions in the observed anisotropy is analyzed by using cells treated with drugs inhibiting myosin-II function.

Tuesday, March 16, 2010 2:30PM - 5:30PM –

Session L12 DFD: Granular Materials I B110-B111

2:30PM L12.00001 Experimental determination of frictional families in small 2D granular[1]

, MARK D. SHATTUCK, Benjamin Levich Institute and Physics Department, City College of New York, JERZY BLAWZDZIEWICZ, COREY O'HERN, Departments of Mechanical Engineering and Physics, Yale University — We have developed a new experimental technique to explore the effects of friction in mechanically stable two-dimensional disk packings. The technique uses high frequency low amplitude vibration to relax tangential forces (friction) without significantly changing the normal forces. If short bursts ($<$10 ms) of vibration are used, the friction can be relaxed in steps. At each step the system reaches mechanical stability but from step to step the stability evolves from friction-dominated to an eventual final state that is stablized only by normal forces (frictionless). Using this protocol on a large random sample of frictional states we can determine the properties of frictional states. Previous experiments and simulations found that the *frictionless states* form a finite set of dilute points in configuration space. Our new study indicates that the *fictional states* form a finite number of families or low dimensional (usually one dimesional) branches that are connected to the frictionless points in configuration space. The branches and branch points are determined by the connectivity of the particle assembly, and the probability of the system being on a particular branch is not uniformly distributed for physical packing-generation protocols.

[1]NSF DMR-0934206, NSF DMS-0835742

2:42PM L12.00002 Bi-modal behavior and compression-induced crystallization of weakly bi-disperse granular packings

, KAMRAN KARIMI, CRIAG MALONEY, Carnegie Mellon University — We perform computer simulations of 2D bidisperse frictionless granular packings for two different particle mixtures. One which is strongly bi-disperse, the other which is only weakly bi-disperse. Despite pronounced crystalline order in the weak system, both share common features near the jamming transition. Near jamming, the probability distribution of particle-wise hydrostatic pressure has a long exponential tail. Force chains are also apparent and have similar spatial structure. At densities further above the jamming transition, the behavior of the two mixtures diverges. The strongly bi-disperse system develops an essentially Gaussian pressure distribution (in agreement with previous results on monodisperse, amorphous, 3D packings), while the weakly bi-disperse system shows bimodal behavior in which the large particles have larger average pressure than the small particles. Furthermore, we show that the ratio of average large particle pressure to small particle pressure is a non-trivial function of density, and we speculate that this effect is related to an observed compression-induced increase in crystalline order.

2:54PM L12.00003 Spatiotemporally Resolved Acoustics in a Photoelastic Granular Material

, ELI OWENS, KAREN DANIELS, Dept. of Physics, NC State University — In granular materials, stress transmission is manifested as force chains that propagate through the material in a branching structure. We send acoustic pulses into a two dimensional photoelastic granular material in which force chains are visible and investigate how the force chains influence the amplitude, speed, and dispersion of the sound waves. We observe particle scale dynamics using two methods, movies which provide spatiotemporally resolved measurements and accelerometers within individual grains. The movies allow us to visualize the sound's path through the material, revealing that the sound travels primarily along the force chains. Using the brightness of the photoelastic particles as a measure of the force chain strength, we observe that the sound travels both faster and at higher amplitude along the strong force chains. An exception to this trend is seen in transient force chains that only exist while the sound is closing particle contacts. We also measure the frequency dependence of the amplitude, speed, and dispersion of the sound wave.

3:06PM L12.00004 New Kinematic Model in comparing with Langevin equation and Fokker Planck Equation , KYOUNG LEE, ZHIJIAN WANG, ROBIN GARDNER, North Carolina State University — An analytic approximate solution of New Kinematic Model with the boundary conditions is developed for the incompressible packing condition in Pebble Bed Reactors. It is based on velocity description of the packing density in the hopper. The packing structure can be presented with a jamming phenomenon from flow types. The gravity-driven macroscopic motions are governed not only by the geometry and external boundary conditions of silos and hoppers, but by flow prosperities of granular materials, such as friction, viscosity and porosity. The analytical formulas for the quasi-linear diffusion and convection coefficients of the velocity profile are obtained. Since it was found that the New Kinematic Model is dependent upon the granular packing density distribution, we are motivated to study the Langevin equation with friction under the influence of the Gravitational field. We also discuss the relation with the Fokker Planck Equation using Detailed balance and Metropolis-Hastings Algorithm. Markov chain Monte Carlo methods are shown to be a non-Maxwellian distribution function with the mean velocity of the field particles having an effective temperature.

3:18PM L12.00005 Structure of granular clusters formed by capillary aggregation analyzed with Voronoi diagrams , MICHAEL BERHANU, ARSHAD KUDROLLI, Department of Physics, Clark University, Worcester, MA 01610 — We investigate the spatial structure of particle aggregates floating at an air-liquid interface as a model system to understand heterogeneity of cohesive granular matter. The meniscus around identical floating particles introduces short range capillary attraction between the particles. In our experimental system, we increase slowly and continuously the particle number density to observe significant structural transformations. After imaging and tracking all the particles, the structure is characterized quantitatively by using Voronoi diagrams which allow us to elucidate small and large scale properties. We show that the system is organized by attraction for low and intermediate densities, which creates a short range order and gives it heterogeneity with pores of various sizes. As the free pore space are filled at high density, the role of attraction becomes less important compared with steric effects and aggregates show characteristics similar to non-cohesive granular media. Mechanical properties of aggregates will be also discussed in light of jamming transition for attractive athermal particles.

3:30PM L12.00006 Random Packing Density of Platonic Solids , JESSICA BAKER, ARSHAD KUDROLLI, Department of Physics, Clark University — Motivated by the relation between particle shape and packing, we investigate the volume fraction occupied by faceted particles as a function of number of particle sides. Such particles are arguably better representative of natural sand than spheres. For simplicity, we focus on the highly symmetric five Platonic solids which are polygons with congruent sides, vertices and angles, and experimentally measure their packing densities. Plastic dice with 4, 6, 8, 12, and 20 sides are fluidized or shaken randomly to find configurations corresponding to the loosest stable packing and densest packing, respectively. We find that the packing fraction obtained by both protocols peak at the cube and then monotonically decrease below the corresponding values obtained for spheres. Interestingly, the overall trend is similar but systematically lower that the maximum volume fractions reported for frictionless platonic solid particles. The effect of friction of the particles and the shape of the boundary shape on observed packing fractions is also investigated.

3:42PM L12.00007 Generalized Hertz Law for Grains with Non-elliptic Contacts , DIANKANG SUN, SUNY - Buffalo, CHIARA DARAIO, California Institute of Technology, SURAJIT SEN, SUNY-Buffalo — Consider two elastic grains of radii of curvature R_1, R_2, which are in intimate contact. The contact region between the grains is assumed to be elliptical (along the contact plane). It turns out that the repulsive potential between the compressed elastic grains then behave as the overlap $\delta^{5/2}$ (Hertz law), where $\delta \equiv R_1 + R_2 - z_{12}$, z_{12} being the distance between the centers of the grains when compressed. Here we show that for paraboloidal shaped grains, by modifying the contact region from elliptical to a non-elliptical geometry, we are able to modify the repulsive potential to being dependent on δ^n, where $n > 2$. Energy transport in granular chains with different contact potential laws will be briefly discussed. (Research Supported by US ARO)

3:54PM L12.00008 Frictional effects on pressure in a column of granular material , RANDY BACK, The University of Texas at Tyler — Frictional effects in granular materials are not well understood. In Janssen's original paper he ignored internal friction completely. More recent theories that treat the granular materials as a continuum assume a slip condition for the internal friction. We report on measurements of the pressure at the bottom a column of granular material for several different frictional coefficients.

4:06PM L12.00009 Nonlinear Breathing in Compressed Granular Chains , ROBERT SIMION, SUNY at Buffalo, ADAM SOKOLOW, Duke University, SURAJIT SEN[1], SUNY at Buffalo — When a compressive applied force at the zero frequency limit is applied on confined granular alignments it is shown to result in tunable and higher frequency *nonlinear granular breathing*. We use extensive dynamical simulations and simple arguments to probe the origins of these breathing processes. In the presence of dissipation, the breathing has a lifetime that is inversely proportional to the dissipation constant. The possible use of the concept of nonlinear granular breathing in recovering the energy released at the beaches by surface gravity waves using a system made largely of non-moving parts is mentioned as a possible application. In closing, studies on the effects of time dependent applied forces will be summarized.

[1]Supported by ARO

4:18PM L12.00010 Spiral patterns in wet granular matter under vertical vibrations , KAI HUANG, FRANK GOLLWITZER, INGO REHBERG, Experimentalphysik V, Universitaet Bayreuth, 95440 Bayreuth, Germany — From the evolution of galaxy to hurricane, from the inner structure of sea shell to the cochlea of our inner ears, spirals are widely existing in nature. In the past decades, spiral patterns have been discovered and extensively studied in model systems such as Rayleigh-Bérnard convection, Belousov-Zhabotinksy reactions and various biological systems. Here we report spiral patterns observed in a thin layer of wet granular matter driven by vertical vibrations. In the phase diagram of driven wet granular matter, spirals appear close to a fluid-gas coexistence phase and show hysteresis. The trajectory and rotation velocity of the three-armed spirals are studied as a function of the driving parameters and compared with other model systems.

4:30PM L12.00011 Kinetic Energy Fluctuations in Loaded, Confined Non-Dissipative Granular Chains[1] , YOICHI TAKATO, SURAJIT SEN[2], SUNY-Buffalo — We consider confined granular alignments of sizes $N = 50,\ 100$ and 500. The grains repel according to the nonlinear Hertz potential. The effect of loading is to introduce a harmonic term in addition to the Hertz term in the grain-grain potential. We show that in the absence of dissipation, a perturbed granular alignment at zero loading asymptotically relaxes into an equilibrium-like state where the kinetic energy fluctuations can be quite significant. Introducing the harmonic term in the potential tends to eventually suppress fluctuations. The talk shall focus on why this fluctuation suppression occurs.

[1]Supported by ARO
[2]Supported by ARO

4:42PM L12.00012 Monte Carlo Library Least Square (MCLLS) Method for Multiple Radioactive Particle Tracking in BPR[1] , ZHIJIAN WANG, KYOUNG LEE, ROBIN GARDNER, North Carolina State University, CEAR TEAM — In This work, a new method of radioactive particles tracking is proposed. An accurate Detector Response Functions (DRF's) was developed from MCNP5 to generate library for NaI detectors with a significant speed-up factor of 200. This just make possible for the idea of MCLLS method which is used for locating and tracking the radioactive particle in a modular Pebble Bed Reactor (PBR) by searching minimum Chi-square values. The method was tested to work pretty good in our lab condition with a six 2" X 2" NaI detectors array only. This method was introduced in both forward and inverse ways. A single radioactive particle tracking system with three collimated 2" X 2" NaI detectors is used for benchmark purpose.

[1]This project support by NERI-C contract from DOE.

4:54PM L12.00013 Column Collapse of Rod-like Granular Materials , MELISSA TREPANIER, SCOTT FRANKLIN, Rochester Institute of Technology — We study the collapse of piles of rod-like granular materials, in particular how the particle aspect ratio (length/width) and coefficient of friction affect the runoff. Rod particles can maintain the shape of their container, something round particles cannot, and we find transitional pile heights that determine the onset of collapse. For low aspect ratios, pile heights of less than a particle length do not collapse, implying that vertically oriented rods are anchoring the pile and providing stability. There is a broad transition range of pile heights in which the probability of collapse grows linearly from 0 to 1. The scaling of the runoff distance in and above this region is independent of aspect ratio and friction, depending only on the initial pile geometry. This work could have significant implications for construction of stable structures and understanding avalanches of needle-like snow crystals (hoar).

5:06PM L12.00014 ABSTRACT WITHDRAWN –

5:18PM L12.00015 Molasses Tail in Dense Hard Core Fluids , MASAHARU ISOBE, Nagoya Institute of Technology, BERNI ALDER, Lawrence Livermore National Laboratory — The long slow decaying potential part of the shear-stress autocorrelation function has been called the "molasses tail" to differentiate it from the hydrodynamic origin of the long time tail in the velocity autocorrelation function and to emphasize its relation to the highly viscous glassy state [1]. Some twenty years ago, the molasses tail in dense liquids near the solid-fluid transition point was speculated to be due to transient crystal nuclei formation [2].This slow decaying process of the OACF and its decomposition (pair, triplet, and quadruplet) is a key factor in understanding the onset of the glass transition. With additional computer power, we are now investigating the origin of the molasses tail using a modern fast algorithm based on event-driven Molecular Dynamics (MD) simulation.We confirm the non-algebraic decay (stretched exponential) at intermediate times corresponding to the existence of various cluster sizes a solid cluster at high densities. The decay in dense systems thus consists of a three stage relaxation process, which are the kinetic regime, the molasses regime and the diffusional power regime[3]. [1] B. J. Alder, in Molecular Dynamics Simulation of Statistical-mechanical Systems, G. Ciccotti and W. G. Hoover, eds.(North-Holland, Amsterdam, 1986) 66. [2] A. J. C. Ladd, and B. J. Alder, J. Stat. Phys. 57, 473 (1989). [3] M. Isobe and B. J. Alder, Mol. Phys., 107, 609 (2009).

Tuesday, March 16, 2010 2:30PM - 5:42PM –

Session L13 DFD: Liquid crystals: Mostly Nematics B112

2:30PM L13.00001 Chirality and biaxiality in cholesteric liquid crystals[1] , SUBAS DHAKAL, JONATHAN SELINGER, Liquid Crystal Institute, Kent State University — Chiral liquid crystals commonly form a cholesteric phase, in which the molecular director is twisted into a helix. A longstanding problem in liquid-crystal science is how to determine the pitch of the cholesteric helix in terms of microscopic parameters, and how to explain why the pitch is so much larger than molecular length scales. One theory has argued that the pitch is large, i.e. the twist is small, because any twisting torque of one molecule on a neighbor requires at least short-range biaxial correlations between the molecules [1]. To investigate this concept, we develop a lattice model for chiral molecules interacting via anisotropic van der Waals forces. Through this model, we calculate the macroscopic pitch as a function of molecular chirality, molecular biaxiality, and temperature. These calculations show that the cholesteric twist decreases with increasing temperature, as seen in several experiments. Furthermore, they show that biaxial correlations enhance the twist, but are not required for a twist with this fluctuation-induced interaction. The simulation results are consistent with mean-field calculations for this model. [1] A.B. Harris, R.D. Kamien, and T.C. Lubensky, Phys. Rev. Lett. 78, 1476 (1997).

[1]This work was supported by NSF Grant DMR-0605889.

2:42PM L13.00002 Simulation studies of defect textures and dynamics in 3-d cholesteric droplets[1] , VIANNEY GIMENEZ-PINTO, SHIN-YING LU, JONATHAN SELINGER, ROBIN SELINGER, Liquid Crystal Institute, Kent State Univ. — We model defect texture evolution in droplets of cholesteric liquid crystals by solving for the dynamics of the nematic director field. In order to accommodate defects in the simulated texture, we use a finite difference formulation that is explicitly independent of sign reversal of the director at any position in the sample. Textures are visualized using either the Berreman 4x4 matrix method or by mapping free energy density. We study both planar and focal conic cholesteric textures in 3-d spherical and cylindrical droplets, with the goal to optimize device geometries for bistable display applications.

[1]Supported by Ohio Board of Regents

2:54PM L13.00003 Photopolymerization-Induced Mesophase Transition in Relation to Phase Diagram of Reactive Nematic Mesogen and Hexagonal Columnar Liquid Crystal Mixture , TSANG-MIN HUANG, THEIN KYU, Department of Polymer Engineering, University of Akron, Akron, OH — The phase diagram of columnar liquid crystal, 2,3,6,7,10,11-hexakispentyloxy triphenylene (HPTP), and nematic monomer, 4-(3-Acryloyloxypropyloxy)-benzoic acid 2-methyl-1,4-phenylene ester (RM257) mixtures has been investigated experimentally. Phase transition temperatures are determined by using polarized optical microscopy (POM), and differential scanning calorimetry (DSC). The phase diagram shows a eutectic phase behavior and consists of isotropic, nematic, order hexagonal, crystalline, and an induced mesophase which is not existed in the neat components. Wide-angle x-ray diffraction (WAXD) result shows this induced mesophase is the disordered hexagonal phase. By virtue of photocurable capability of RM257, the evolution of phase morphology of the LC mixtures subjected to photopolymerization has been also studied under UV illumination. Depending on reaction temperature and composition, the morphology of the cured mixtures can be fixed in the isotropic or anisotropic states. The existence of columnar phase of HPTP after reaction can be identified in some compositions by WAXD that undergoes reaction-driven phase transformation.

3:06PM L13.00004 Glassy correlations and thermal fluctuations in nematic elastomers , BING LU, Department of Physics and Institute for Condensed Matter Theory, University of Illinois at Urbana-Champaign, XIANGJUN XING, Department of Physics, Syracuse University, FANGFU YE, PAUL GOLDBART, Department of Physics and Institute for Condensed Matter Theory, University of Illinois at Urbana-Champaign — By means of the vulcanization theory framework we address the properties of nematic elastomers prepared in the isotropic liquid state and subsequently randomly cross-linked beyond the gelation point. We base our analysis on a model replica Landau free energy, in which the vulcanization order parameter is coupled to the order parameter describing the local degree of nematic ordering, retaining fluctuation terms to the Gaussian level. We explore how the cross-linking renormalizes the thermal correlations of the local nematic order, and also results in frozen-in, glassy nematic correlations. We examine these thermal and glassy correlations for two different preparation histories of the system: in the first, the cross-linking is done at temperatures close to the isotropic-nematic transition; in the other, the cross-linking is done at higher temperatures, but the system is subsequently cooled to near this transition temperature.

3:18PM L13.00005 Minimal model for polydomain nematic elastomers , FANGFU YE, BING LU, Department of Physics and Institute for Condensed Matter Theory, University of Illinois at Urbana-Champaign, XIANGJUN XING, Department of Physics, Syracuse University, PAUL GOLDBART, Department of Physics and Institute for Condensed Matter Theory, University of Illinois at Urbana-Champaign — Nematic elastomers are materials that possess both the elastic properties of cross-linked rubber and the orientational properties of nematic liquid crystals. When cross-linked in the isotropic phase, and subsequently cooled into the nematic regime, these materials usually form polydomain structures. To understand the formation of these polydomain structures, we develop a microscopic model based on an elastic network medium formed by the random end-linking, via springs, of rigid dimers. We assume that the dimers interact with one another through a Maier-Saupe term, and that the springs impose soft constraints, not only on the separations between the dimers that they link but also on the relative orientations of these dimers. We then use vulcanization theory to investigate: (i) how these orientational constraints lead to the emergence of polydomain structures, as the temperature is decreased; and (ii) the dependence of the characteristic size of the domains on temperature and link density.

3:30PM L13.00006 Real space analysis by direct observation in liquid crystal dynamics , BEOM-JIN YOON, MIN SANG PARK, JUNG OK PARK, MOHAN SRINIVASARAO, Georgia Institute of Technology — We describe a facile route for studying dynamics of nematic liquid crystals. We analyzed real space images of the system that can't be resolved by optical microscopes, for which the typical investigations have been done in reciprocal space. We have imaged the director fluctuations, which are slow and large enough to be detected by an optical microscope. A series of the digital images of a homogeneously aligned nematic liquid crystals were obtained under the cross-polarized microscope with a non-coherent light, white light source, and a high speed camera. We made Fourier analysis of the time and spatial series of the images, and this procedure provided a wide range of the wave vector dependent information, which is equivalent to multi-angle light scattering of the nematic liquid crystals. The characteristic times of the correlation function were measured. Dynamic properties of the liquid crystals and temperature dependence of them were evaluated through combination of real space intensity information, Fourier optics, and well known theories developed in scattering method.

3:42PM L13.00007 Prediction of flow-aligning and tumbling in a bent-core nematic liquid crystal using measurements of orienation order parameters , MIN SANG PARK, School of Polymer, Textile and Fiber Engineering, Georgia Institute of Technology, BEOM-JIN YOON, JUNG OK PARK, MOHAN SRINIVASARAO, School of Polymer, Textile, and Fiber Engineering, Georgia Institute of Technology, Georgia Institute of Technology — The flow behavior of bent-core nematic liquid crystal (A131), which has been known to exhibit a biaxial nematic phase, is predicted by measurements of 2^{nd} and 4^{th} rank orientation order parameters. Using experimentally determined uniaxial, $<P_{200}>$ and $<P_{400}>$, and biaxial orientation order parameters, $<P_{220}>$, $<P_{420}>$ and $<P_{440}>$ from polarized micro-Raman spectroscopy, we compute the tumbling parameter, λ. The relationships between the order parameters and tumbling parameter derived by 2 different groups are used and the results are computed: a molecular theory by Archer and Larson (1995), that by Kroger and Seller (1995) for uniaxial system, and Leslie's theory for 2-director continuum. Temperature evolution of tumbling parameter shows the transition from a flow alignment regime to a tumbling instability. The results of the temperature evolution of tumbling parameter of bent-core nematic LC are compared to those of pure nematic LC (5CB) and LC mixture (E7).

3:54PM L13.00008 Elastic constants and viscosities of a bent-core nematic liquid crystal studied by dynamic light scattering and magnetic Frederick transition[1] , MADHABI MAJUMDAR, Kent State University, PETER SALAMON, JAMES GLEESON, ANTAL JAKLI, SAMUEL SPRUNT, Kent State University — We present a study of determining absolute magnitudes of orientational Frank elastic constants and corresponding viscosities together with the viscoelastic ratios for director fluctuations in one of the bent-core nematic compounds *CIPbis10BB* by both the dynamic light scattering method and the magnetic and electric field induced director reorientation (Frederick transition). The values of the splay, twist and bend Frank elastic constants and viscosities are as follows K11=3.4×10^{-7} dynes, K22=3.4×10^{-8} dynes, K33=1.8×10^{-7} dynes, η_{splay}=12P, η_{twist}=4.1P and, η_{bend}=23P. Our result shows that the orientational elastic constants of the BCN studied are 3 to 5 times lower than those of typical calamitics (5CB) and K11>K33>>K22. A dramatic enhancement of orientational viscosities (4 to 100 times larger than calamitics) was confirmed in BCNs.

[1]Acknowledgement: NSF DMR-0606160.

4:06PM L13.00009 Bulk Structure and Interface Ordered Focal Conic Domains of the Dark Conglomerate Phase of a 4,4'-diphenylmethane Based Bent-Core Mesogen[1] , J. MACLENNAN, D. CHEN, Y. SHEN, C. ZHU, L. HOUGH, M. GLASER, N. CLARK, Department of Physics, University of Colorado at Boulder, USA , N. GIMENO, M. ROS, Instituto de Ciencia de Materiales de Aragón, Universidad de Zaragoza-CSIC, Spain — The saddle-splay topology of the dark conglomerate (DC) phase has been established recently [L. E. Hough, *et al. Science* **325**, 452 (2009)]. On cooling, usually amorphous or disordered focal conic domains are obtained in the bulk. However, in the dark conglomerate phase of a 4,4'-diphenylmethane based bent-core mesogen at the liquid crystal/air interface, the air imposes strong homeotropic alignment at the free surface of the liquid crystal, forcing the smectic layers to form parallel to the surface. The bulk preference for saddle-splay curvature in the DC phase is then manifested at the surface as toric focal conic domains (TFCDs). The internal fluidity of the phase allows the TFCDs to anneal into a quasi ordered array, essentially forming a hexagonal structure with a periodicity of about 400 nm, correspond to the minimum elastic free energy. This directly confirms the proposed plumber's nightmare structure for the DC phase and indicates that ordered TFCDs may be produced in this phase under suitable conditions.

[1]This work is supported by NSF MRSEC Grant DMR0820579.

4:18PM L13.00010 Blue Phase Mixtures of Bent-Core Liquid Crystals and Chiral Dopants[1] , STEFANIE TAUSHANOFF, Liquid Crystal Institute, Kent State University, KHOA VAN LE, Department of Organic and Polymeric Materials, Tokyo Institute of Techology, ROBERT TWIEG, Department of Chemistry, Kent State University, HIDEO TAKEZOE, Department of Organic and Polymeric Materials, Tokyo Institute of Technology, ANTAL JAKLI, Liquid Crystal Institute, Kent State University — Stable blue phase materials are made using nematogenic bent-core liquid crystals doped with a high twisting power chiral material. Studies show the existence of stable BPIII (blue fog) phase in a relatively wide 10-20°C temperature range. Polarizing optical microscopy, optical rotation and electro-optical studies were used to characterize the material.

[1]Support provided by the Japan Society for the Promotion of Science and the National Science Foundation's 2009 East Asia Pacific Summer Institute program

4:30PM L13.00011 Cones and Anticones: Spontaneous Mechanical Response of Disclinations in Nematic Glasses , CARL MODES, University of Cambridge, KAUSHIK BHATTACHARYA, California Institue of Technology, MARK WARNER, University of Cambridge — Nematic elastomers and glasses respond strongly to changes in ambient heat or light, and the response along the director differs significantly from that in the normal directions. This phenomena is well characterized for simple nematic director fields, less so for more complicated textures. We analytically examine the elastic ground states of a nematic glass in the membrane approximation as a function of temperature for some of these more complicated director fields. In particular, we are interested in textures arising from disclination defects with an eye towards fabricating three-dimensional shapes from flat sheets of material, at the nano-scale all the way to macroscopic objects.

4:42PM L13.00012 A Line Defect Structure in Soft-Mode Turbulence[1] , RINTO A NUR QOMARU ZAMAN, TATSUHIRO UEKI, YOSHIKI HIDAKA, Kyushu University, MICHAEL I. TRIBELSKY, MIREA Russia, SHOICHI KAI, Kyushu University — Defects have been much investigated in various physical systems. The property and symmetry in a system can be reflected by the existence of defects. For example in spin models, symmetries in the 2D XY and 2D Ising models generate point and line defects, respectively. In the soft-mode turbulence (SMT) in electroconvection of homeotropic nematic systems which is a kind of spatiotemporal chaos induced by nonlinear interaction between the Nambu-Goldstone modes and the convective modes, a curious line structure called $blackline$ has been discovered. We measured the density of the blackline as a function of control parameters, ac voltage and frequency. By detailed observations and analysis, it is clarified that the blackline is a structure of the nematic director in the x-y plane and includes a sequence of point defects. We discussed similarity with the density of the blackline and that of the point defect in the conventional 2D XY model. The occurrence of this type of defects is only due to the symmetry in the SMT and independent of the properties of fluctuations.

[1]This research was partially supported by Grant-in-Aid for Scientific Research from the Ministry of Education, Culture, Sport, Science, and Technology of Japan and the Japan Society for the Promotion of Science.

4:54PM L13.00013 Macroscopic Behavior of Nematics with D_{2d} Symmetry , HARALD PLEINER, MPI Polymer Research, Mainz, Germany, HELMUT R. BRAND, Theoretische Physik III, Universitaet Bayreuth, 95440 Bayreuth, Germany — We discuss the symmetry properties and the macroscopic behavior of a nematic liquid crystal phase with D_{2d} symmetry. Such a phase is a prime candidate for nematic phases made from banana-shaped molecules where the usual quadrupolar order coexists with octupolar (tetrahedratic) order. The resulting nematic phase is non-polar. While this phase could resemble the classic $D_{\infty h}$ nematic in the polarizing microscope, it has many static as well as reversible and irreversible properties unknown to non-polar nematics without octupolar order. In particular, there is a linear gradient term in the free energy that selects parity leading to ambidextrously helical ground states when the molecules are achiral. In addition, there are static and irreversible coupling terms of a type only met otherwise in macroscopically chiral liquid crystals, e.g. the ambidextrous analogues of Lehmann-type effects known from cholesteric liquid crystals. Finally, we discuss certain nonlinear aspects of the dynamics related to the non-commutativity of three-dimensional finite rotations as well as other structural nonlinear hydrodynamic effects.

5:06PM L13.00014 A novel soft-core spherocylinder model for liquid crystals , JING ZONG, XINGHUA ZHANG, QIANG WANG, Department of Chemical and Biological Engineering, Colorado State University — Interaction models with soft-core repulsions that allow particle overlapping give orders of magnitude faster/better sampling of configurational space than those with hard-core repulsions (e.g., hard spherocylinders or Gay-Berne potential). While several soft-core spherocylinder models were recently proposed[1], their repulsive interaction depends only on the shortest distance between two spherocylinders. Here we present a novel, computationally efficient soft-core spherocylinder model, which gives exact treatment of the excluded-volume interactions and anisotropic shape of two particles (thus the orientational interaction between them favoring their parallel alignment). It further takes into account the degree of overlap between the two particles, thus superior to other soft-core models. This model has great potential applications in the study of liquid crystals, block copolymers containing rod blocks, and liquid crystalline polymers. [1] *Z. E. Hughes et al.*, **Comput. Phys. Commun., 178**, 724 (2008); *J. S. Lintuvuori and M. R. Wilson*, **J. Chem. Phys., 128**, 044906 (2008).

5:18PM L13.00015 Nematic order on curved spherical spaces[1] , ALBERTO FERNANDEZ-NIEVES, TERESA LOPEZ-LEON, SHARAN DEVAIAH, EKAPOP PAIRAM — When nematic liquid crystals are confined to spherical shells, complex defect structures emerge. These structures are characterized by a varying number of point defects and disclination lines, depending on the elastic energy of the liquid crystal, the thickness of the shell, and the boundary conditions for the director at the confining spheres. Topology establishes restrictions that must be fulfilled, but it is the energy landscape that ultimately determines the final state of the system. By using double emulsion droplets, we can experimentally address this fascinating interplay between topology and energy. We find a wealth of defect structures in our shells and propose that the shell thickness inhomogeneity is the key parameter enabling the broad range of configurations we observe; these include long-time predicted configurations, as well as new structures and transitions between them that where never considered before. In addition, we hope to extend our studies to non-spherical surfaces, such as the torus and higher-genus surfaces. For this purpose, we have recently generated toroidal droplets and have studied their hydrodynamic stability. On these closed surfaces, the nature of the defect structure is expected to be qualitatively different from that of the spherical case.

[1]We thank NSF Career Award 0847304

5:30PM L13.00016 Diffusion in Rodlike Polymer Liquid Crystals , PAUL RUSSO, GARRETT DOUCET, JIANHONG QIU, Louisiana State University — The optical tracer self diffusion of the rodlike polymer PBLG has been studied in solutions spanning the isotropic-liquid crystalline phase boundary for two different molecular lengths (L = 92.1 nm, axial ratio x= 58 and L = 16.8 nm, x = 10.5). The results are compared to previously published data at L= 159 nm, x= 99 (*J. Chem. Phys.*, 1999, 111(4), 1746-1752). Under the conditions of the measurements, the two longer rodlike polymers align in the liquid crystalline phase with their cholesteric screw axis in the vertical direction. The diffusion is measured in a particular direction normal to this over distances long compared to the polymer lengths. Except for the shortest polymer, whose cholesteric screw axis does not assume the vertical alignment, the diffusion suddenly increases as the liquid crystalline phase is entered, then declines, signaling the disappearance of topological constraints in the isotropic phase having a vertical component. The parallel component of diffusion is little reduced in the least concentrated liquid crystalline regime, compared to dilute solutions. The solutions also contain a small, fluorescent component whose mobility was not at all affected by the isotropic-liquid crystalline phase transition. Additional measurements have been made for magnetically aligned rods, in which case the differences between parallel and perpendicular diffusion components can be measured directly.

Tuesday, March 16, 2010 2:30PM - 5:30PM –
Session L42 DFD: High Reynolds Number Flows D138

2:30PM L42.00001 On the stable hovering of an asymmetric body in oscillatory airflows , BIN LIU, Courant Institute, New York University, ANNIE WEATHERS, Department of Physics, New York University, STEPHEN CHILDRESS, Courant Institute, New York University, JUN ZHANG, Department of Physics and Courant Institute, New York University — A free rigid body, built with up-down asymmetry can hover in a vertical oscillatory airflow if the airflow amplitude and frequency exceed certain thresholds. The key to free hovering lies in the difference in drag coefficients as the airflow passes the object in two opposite directions. The hovering motion is surprisingly stable and robust, lasting for thousands of oscillation periods. We describe a series of flow visualizations of vortex shedding by the hovering object, which show how correcting moments restore its orientation, leading to stable hovering. This study may shed light on the stability of the hovering flight of insects.

2:42PM L42.00002 Modeling flexible flapping wings oscillating at resonance , ALEXANDER ALEXEEV, HASSAN MASOUD, Georgia Institute of Technology — Using a hybrid approach for fluid-structure interactions that integrates the lattice Boltzmann and lattice spring models, we study the three-dimensional aerodynamics of flexible flapping wings at hovering. The wings are a pair of flat elastic plates tilted from the horizontal and driven to oscillate according to the sinusoidal law. Our simulations reveal that resonance oscillations of flexible wings dramatically increase aerodynamic lift at low Reynolds number. Comparing to otherwise identical rigid wings, flexible wings at resonance generate up to two orders of magnitude greater lift. Within the resonance band, we identify two operation regimes leading to the maximum lift and the maximum efficiency, respectively. The maximum lift occurs when the wing tip and root move with a phase lag of 90 degrees, whereas the maximum efficiency occurs at the frequency where the wing tip and root oscillate in counterphase. Our results suggest that the resonance regimes would be optimal for the design of microscale flying machines using flexible flapping wings driven by simple kinematic strokes.

2:54PM L42.00003 Vortices within vortices: Hierarchical vortex structures in experimental, two-dimensional flow[1] , DOUGLAS H. KELLEY, NICHOLAS T. OUELLETTE, Yale University — The topology of a fluid flow is concisely described by its critical points (locations of zero flow) and the manifolds (streamlines) that connect them. Streamlines that carry fluid away from a critical point and then return it to the same critical point from another direction are known as homoclinic manifolds. Rare in three-dimensional flow, homoclinic manifolds are common in two-dimensional flow and form unambiguous topological boundaries useful for defining vortex edges. Approximating two-dimensional flow with an electromagnetically driven, stably stratified solution in a 90 cm x 90 cm pan, we use particle tracking to measure the velocity field and locate its critical points and their manifolds. Strikingly, homoclinic manifolds are often nested — the flow contains vortices within vortices. Its regions can thus be classified by an embedding number, an integer defined as the depth of vortex nesting. We will discuss the dynamics of this hierarchical vortex embedding number, particularly as a function of flow speed (Reynolds number).

[1]This work is supported by the National Science Foundation.

3:06PM L42.00004 Evolution of Triangles in Quasi-Two-Dimensional Flow , NICHOLAS OUELLETTE, SOPHIA MERRIFIELD, DOUGLAS KELLEY, Yale University — The anomalous transport of scalar fields in complex flow has recently been explained by considering the nontrivial shape dynamics of clusters of fluid elements. Here, we study the dynamics of three-particle clusters–Lagrangian triangles–that minimally parameterize planes as they are advected in a quasi-2D electromagnetically driven experimental flow. We report results for the shape distributions as a function of the initial triangle size, and discuss the impact of the flow structure on the subsequent triangle evolution. This work is supported by the National Science Foundation.

3:18PM L42.00005 Creating Turbulence with vortex rings[1] , KELKEN CHANG, Cornell Universty, GREGORY P. BEWLEY, Max Planck Institute, EBERHARD BODENSCHATZ, Cornell University, INTERNATIONAL COLLABORATION FOR TURBULENCE RESEARCH COLLABORATION — We report measurements of the small-scale statistics of turbulence created by interacting vortices at a Taylor microscale Reynolds number of 500. We study the flow using Lagrangian particle tracking technique, in which the three-dimensional motion of passive oil particles in air is followed optically using multiple high speed cameras. We compare the results with measurements obtained in a nearly homogeneous and isotropic turbulent flow at comparable Reynolds number.

[1]Max Planck Society

3:30PM L42.00006 Vortex ring refraction at large Froude numbers[1] , KERRY KUEHN, MATTHEW MOELLER, MICHAEL SCHULZ, DANIEL SANFELIPPO, Wisconsin Lutheran College — We have experimentally studied the impact of a planar axisymmetric vortex ring, incident at an oblique angle, upon a sharp gravity-induced interface separating two fluids of differing densities. After impact, the vortex ring was found to exhibit a variety of subsequent trajectories, which we have organized according to both the incidence angle, and the ratio of the Atwood and Froude numbers, A/F. For relatively small angles of incidence, the vortices tended to penetrate the interface. In such cases, the more slowly moving vortices, having values of $A/F \gtrsim .004$, tended to subsequently curve back up toward the interface. Quickly moving vortices, on the other hand, tended to refract downward, similar to a light ray entering a medium having a higher refractive index. A simplistic application of Snell's law of refraction cannot, however, account for the observed trajectories. For grazing angles of incidence, fast moving vortices tended to penetrate the interface, whereas slower vortices tended to reflect from the interface. In some cases, the reflected vortices executed damped oscillations before finally disintegrating.

[1]This work was supported by a Research Infrastructure Grant from the Wisconsin Space Grant Consortium.

3:42PM L42.00007 DNS of the Velocity and Temperature Fields in a Model of a Small Room[1] , JOHN MCLAUGHLIN, XINLI JIA, GOODARZ AHMADI, Clarkson University, JOS DERKSEN, University of Alberta — This talk presents the results of a numerical study of the velocity and temperature fields in a model of a small room containing a seated mannequin. Results are also presented for the trajectories and ultimate fate of small particles that are introduced through the air inlet as well as particles that are entrained by the mannequin's thermal plume. The study was motivated by an experimental study performed at Syracuse University. In the experimental study, air entered the room through a floor vent and exited through a ceiling vent on the other side of the room. A mannequin was seated facing the floor vent. The mannequin could be electrically heated so that its surface temperature was 31C. The objective of the simulations was to obtain a more detailed understanding of the flow in the room. Of specific interest were the effects of the mannequin on the ultimate fates of small particles. The importance of the thermal plume around the mannequin was of particular interest since the thermal plume plays a role in transporting particles from near the floor to the breathing zone. The simulations were performed with a single phase version of a lattice Boltzmann method (LBM) that was originally developed for two-phase flows by Inamuro et al.

[1]Syracuse Center of Excellence

3:54PM L42.00008 Large-eddy simulations of particle-laden turbulent swirling flows , MARCEL ILIE, University of Central Florida — In many combustion devices, a swirling flow is used to stabilize the flame through a recirculation zone. Swirling flows, however, are prone to instabilities which can trigger combustion oscillations and deteriorate the performance of the combustor. The presence of fine particles makes swirling flows of particular interest from a combustor efficiency point of view. Depending on the strength of swirl, a number of recirculation zones and central vortex breakdown regions are identified in many swirl-stabilized flames. In general these characteristics make swirling flows and flames to exhibit highly three-dimensional, large-scale turbulent structures with complex turbulent shear flow regions. The present research concerns the influence of swirl characteristics on the particle dispersion and total deposition. A Lagrangian particle tracking algorithm using large-eddy simulation is proposed. The influence of particle characteristics such size, density and shape on the particle dispersion and total deposition is subject of investigation as well. The present research shows that the total particle deposition increases with size and density. It was also observed that particles of ellipsoidal shape are more prone to deposition.

4:06PM L42.00009 Lattice Boltzmann and Pseudo-Spectral Methods for Decaying Turbulence[1] , LI-SHI LUO, YAN PENG, WEI LIAO, Old Dominion University, LIAN-PING WANG[2], University of Delaware — We conduct a comparison of the lattice Boltzmann (LB) and the pseudo-spectral (PS) methods for direct numerical simulations (DNS) of the decaying turbulence in a three dimensional periodic cube. We use a mesh size of 128^3 and the Taylor micro-scale Reynolds number $24.35 \leq \mathrm{Re}_\lambda \leq 72.37$. All simulations are carried out to $t \approx 30\tau_0$, where τ_0 is the turbulence turnover time. We compare instantaneous velocity $\mathbf{u}$ and vorticity ω fields, the total kinetic energy $K(t)$, the dissipation rate $\varepsilon(t)$, the energy spectrum $E(k,\, t)$, the rms pressure fluctuation $\delta p(t)$, the pressure spectrum $P(k,\, t)$, and the skewness $S_u(t)$ and the flatness $F_u(t)$ of velocity derivatives. Our results show that the LB method compares well with the PS method in terms of accuracy: the flow fields and all the statistical quantities — except for $\delta p(t)$ and $P(k,\, t)$ — obtained from the two methods agree well with each other when the initial flow field is adequately resolved by both methods. Our results indicate that the resolution requirement for the LB method is $\eta_0/\delta x \geq 1.0$, where η_0 and δx are the initial Kolmogorov length and the grid spacing, respectively.

[1]Supported the US AFOSR-MURI project "Hypersonic Transition and Turbulence with Non-equilibrium Thermochemistry."
[2]supported by US NSF (ATM-0527140) and NNSF of China (Project No. 10628206)

4:18PM L42.00010 ABSTRACT WITHDRAWN –

4:30PM L42.00011 Fluid-Structure Interaction based on Lattice Boltzmann and p-FEM , BENJAMIN AHRENHOLZ, SEBASTIAN GELLER, MANFRED KRAFCZYK, TU Braunschweig — Over the last decade the Lattice Boltzmann Method (LBM) has matured as an efficient method for solving the Navier-Stokes equations. The p-version of the Finite Element Method (p-FEM) has proved to be highly efficient for a variety of problems in the field of structural mechanics. The focus of this contribution is to investigate the validity and efficiency of the coupling of two completely different numerical methods to simulate transient bidirectional Fluid-Structure Interaction (FSI) problems with very large structural deflections. In this contribution the treatment of moving boundaries in the fluid solver is presented, the computation of tractions and displacements on the boundary as well as the explicit coupling algorithm itself. In addition, efficiency aspects of the two approaches for two- and three-dimensional laminar flow examples at intermediate Reynolds numbers are discussed. Finally we give an outlook on modeling turbulent FSI problems.

4:42PM L42.00012 Lattice Boltzmann Methods for thermal flows: applications to compressible Rayleigh-Taylor systems , LUCA BIFERALE, MAURO SBRAGAGLIA, ANDREA SCAGLIARINI, University of Rome, Tor Vergata, KAZUYASU SUGIYAMA, University of Tokyo, FEDERICO TOSCHI, Technische Universiteit Eindhoven — We compute the continuum thermo-hydrodynamical limit of a new formulation of Lattice Kinetic equations for thermal compressible flows, recently proposed in [*Sbragaglia et al. "Lattice Boltzmann method with self-consistent thermo-hydrodynamic equilibria", J. Fluid Mech.* **628** *299 (2009)*]. We show that the hydrodynamical manifold is given by the correct compressible Fourier-Navier-Stokes equations for a perfect fluid.We also apply the method to study Rayleigh-Taylor instability for compressible stratified flows and we determine the growth of the mixing layer at changing Atwood numbers up to $At \sim 0.4$. Both results show that this new Lattice Boltzmann Methods can be used to study highly stratified/compressible systems with strong temperature gradients, opening the way to applications to Non-Oberbeck-Boussinesq Convection and compressible Rayleigh-Taylor turbulence.

4:54PM L42.00013 The shape of fair weather clouds , YONG WANG, GIOVANNI ZOCCHI, UCLA — It is well known that cumulus clouds are formed under the influence of thermals - convection currents which channel moist air upwards. Here we introduce a simple physical model which accounts for the shape of cumulus clouds exclusively in terms of thermal plumes or thermals. The plumes are explicitly represented by a simple potential flow generated by singularities (sources and sinks) and with their motion create a flow field supporting the cloud. We discuss the parametrization of this model, which attempts a description of the cloud starting from the coherent structures in the flow. We use the model to explore transitions which occur in the dynamical state of the cloud.

5:06PM L42.00014 On the dynamics of cartoon dunes , CHRISTOPHER GROH, INGO REHBERG, Experimental Physics V, University of Bayreuth, D-95440 Bayreuth, Germany, CHRISTOF A. KRUELLE, Dept. of Mechanical Eng. and Mechatronics, University of Applied Sciences, D-76133 Karlsruhe, Germany — The spatio-temporal evolution of a downsized model for a barchan dune is investigated experimentally in a narrow water flow channel. We observe a rapid transition from the initial configuration to a steady-state dune with constant mass, shape, velocity, and packing fraction. The development towards the dune attractor is shown on the basis of four different starting configurations. The shape of the attractor exhibits all characteristic features of barchan dunes found in nature, namely a gently inclined windward (upstream) side, crest, brink, and steep lee (downstream) side. The migration velocity is reciprocal to the length of the dune and reciprocal to the square root of the value of its mass. The velocity scaling and the shape of the barchan dune is independent of the particle diameter. For small dunes we find significant deviations from a fixed height-length aspect ratio. Moreover, a particle tracking method reveals that the migration speed of the model dune is one order of magnitude slower than that of the individual particles. In particular, the erosion rate consists of comparable contributions from low energy (creeping) and high energy (saltating) particles. Finally, it is shown that the velocity field of the saltating particles is comparable to the velocity field of the driving fluid.

5:18PM L42.00015 Supernova Shear and Magnetic Field Amplification , CYRIL ALLEN, North Carolina State University — A core collapse supernova marks the death of a star over 8 times the size of the sun. Sometimes in the aftermath of these explosions a spinning, magnetized, neutron star can be left behind, also known as a pulsar. It has recently been discovered that pulsar spins can arise through a spiral spherical accretion shock instability (SASI) of a supernova. This instability produces a strong shear flow inside the supernova shock wave, which might lead to amplification of the star's magnetic field. To study this possibility, hydrodynamic simulations have been modified to include a tracer of the magnetic field by adding the magnetic induction equation to the code. Diagnostics were added to the code to measure the overall field strength and shear flow generated by the SASI. I found the magnetic field could be amplified by a factor of 100 in only 20 milliseconds. This raises the possibility that shear-induced field amplification might be able to contribute to the energy of the supernova explosion and explain the high magnetic fields of the pulsar left behind.

Wednesday, March 17, 2010 8:00AM - 11:00AM –

Session P5 DFD: Lattice Boltzmann Method and Its Applications Portland Ballroom 256

8:00AM P5.00001 Lattice Boltzmann modeling of microchannel flow in slip flow regime[1]

, LI-SHI LUO[2], Old Dominion University — We present the lattice Boltzmann equation (LBE) with multiple relaxation times (MRT) to simulate pressure-driven gaseous flow in a long microchannel. We obtain analytic solutions of the MRT-LBE with various boundary conditions for the incompressible Poiseuille flow with its walls aligned with a lattice axis. The analytical solutions are used to realize the Dirichlet boundary conditions in the LBE. We use the first-order slip boundary conditions at the walls and consistent pressure boundary conditions at both ends of the long microchannel. We validate the LBE results using the compressible Navier-Stokes (NS) equations with a first-order slip velocity, the information-preservation direct simulation Monte Carlo (IP-DSMC) and DSMC methods. As expected, the LBE results agree very well with IP-DSMC and DSMC results in the slip velocity regime, but deviate significantly from IP-DSMC and DSMC results in the transition-flow regime in part due to the inadequacy of the slip velocity model, while still agreeing very well with the slip NS results. Possible extensions of the LBE for transition flows are discussed. This work has been published in Journal of Computational Physics.

[1]LSL would like to acknowledge the support fron NSF through the grants CBET-0500213 and DMS-0807983.

[2]Collaborator: Dr. Frederik Verhaeghe, Department of Metallurgy and Materials Engineering, Katholieke Universiteit Leuven, Belgium

8:36AM P5.00002 Particle-Resolved Numerical Simulation of Turbulent Suspension Flow Using the Lattice Boltzmann Equation

, LIAN-PING WANG, University of Delaware — Particle-laden turbulent flow is of importance to many engineering applications and natural phenomena, such as aerosol and pollutant transport, interaction of cloud droplets, spay combustion, and chemical processes. In general, the dynamics of dispersed phase and that of the carrier fluid phase are closely coupled. Most previous studies utilize the point particle approach to study the effects of particles on the carrier turbulence, under the assumptions that the particle size is significantly smaller than the smallest turbulence length scale and the particle volume fraction is low. The present study focuses on the motion and hydrodynamic interactions of finite-size freely moving particles in a turbulent background flow. To simulate carrier fluid turbulence, a mesoscopic lattice Boltzmann approach is applied with the multiple relaxation-time collision model, which yields a more robust viscous flow simulation method than the single-relaxation collision model. The no-slip boundary condition on the moving surface of each particle is implemented using an interpolated bounce-back scheme. The refill problem resulting from the moving boundary is handled by a non-equilibrium correction method to reduce the unphysical force fluctuations acting on the particles. The short-range lubrication force not resolved by the simulation is represented by a physical model involving particle relative location and velocity. For the carrier fluid phase, computational results are discussed in terms of the change of energy spectrum compared with the particle-free turbulence, the time evolution of the turbulent kinetic energy and the dissipation rate. For the dispersed phase, the focus will be on the particle-pair statistics such as the relative velocity and radial distribution function as well as particle-particle collision rate. The effects of varying particle size, volume fraction, and particle-to-fluid density ratio will be examined. The results will be compared to those from the previous point-particle approach and related particle-resolved approach.

9:12AM P5.00003 Lattice Boltzmann approaches to magnetohydrodynamics and electromagnetism[1]

, PAUL DELLAR, University of Oxford — We present a lattice Boltzmann approach for magnetohydrodynamics and electromagnetism that expresses the magnetic field using a discrete set of vector distribution functions $\mathbf{g}_i$. The $\mathbf{g}_i$ were first postulated to evolve according to a vector Boltzmann equation of the form

$$\partial_t \mathbf{g}_i + \xi_i \cdot \nabla \mathbf{g}_i = -\frac{1}{\tau}\left(\mathbf{g}_i - \mathbf{g}_i^{(0)}\right),$$

where the ξ_i are a discrete set of velocities. The right hand side relaxes the $\mathbf{g}_i$ towards some specified functions $\mathbf{g}_i^{(0)}$ of the fluid velocity $\mathbf{u}$, and of the macroscopic magnetic field given by $\mathbf{B} = \sum_i \mathbf{g}_i$. Slowly varying solutions obey the equations of resistive magnetohydrodynamics. This lattice Boltzmann formulation has been used in large-scale (up to 1800^3 resolution) simulations of magnetohydrodynamic turbulence. However, this is only the simplest form of Ohm's law. We may simulate more realistic extended forms of Ohm's law using more complex collision operators. A current-dependent relaxation time yields a current-dependent resistivity $\eta(|\nabla \times \mathbf{B}|)$, as used to model "anomalous" resistivity created by small-scale plasma processes. Using a *hydrodynamic* matrix collision operator that depends upon the magnetic field $\mathbf{B}$, we may simulate Braginskii's magnetohydrodynamics, in which the viscosity for strains parallel to the magnetic field lines is much larger than the viscosity for strains in perpendicular directions. Changing the collision operator again, from the above vector Boltzmann equation we may derive the full set of Maxwell's equations, including the displacement current, and Ohm's law,

$$-\frac{1}{c^2}\partial_t \mathbf{E} + \nabla \times \mathbf{B} = \mu_o \mathbf{J}, \quad \mathbf{J} = \sigma(\mathbf{E} + \mathbf{u} \times \mathbf{B}).$$

The original lattice Boltzmann scheme was designed to reproduce resistive magnetohydrodynamics in the non-relativistic limit. However, the kinetic formulation requires a system of first order partial differential equations with collision terms. This system coincides with the full set of Maxwell's equations and Ohm's law, so we capture a much wider range of electromagnetic phenomena, including electromagnetic waves.

[1]Supported by UK EPSRC grant EP/E054625/1

9:48AM P5.00004 Massively parallel simulations of multiphase flows using Lattice Boltzmann methods

, BENJAMIN AHRENHOLZ, TU Braunschweig — In the last two decades the lattice Boltzmann method (LBM) has matured as an alternative and efficient numerical scheme for the simulation of fluid flows and transport problems. Unlike conventional numerical schemes based on discretizations of macroscopic continuum equations, the LBM is based on microscopic models and mesoscopic kinetic equations. The fundamental idea of the LBM is to construct simplified kinetic models that incorporate the essential physics of microscopic or mesoscopic processes so that the macroscopic averaged properties obey the desired macroscopic equations. Especially applications involving interfacial dynamics, complex and/or changing boundaries and complicated constitutive relationships which can be derived from a microscopic picture are suitable for the LBM. In this talk a modified and optimized version of a Gunstensen color model is presented to describe the dynamics of the fluid/fluid interface where the flow field is based on a multi-relaxation-time model. Based on that modeling approach validation studies of contact line motion are shown. Due to the fact that the LB method generally needs only nearest neighbor information, the algorithm is an ideal candidate for parallelization. Hence, it is possible to perform efficient simulations in complex geometries at a large scale by massively parallel computations. Here, the results of drainage and imbibition (Degree of Freedom $>$ 2E11) in natural porous media gained from microtomography methods are presented. Those fully resolved pore scale simulations are essential for a better understanding of the physical processes in porous media and therefore important for the determination of constitutive relationships.

10:24AM P5.00005 Lattice Boltzmann Modeling of Multi-phase Interfacial Flows[1] , TAEHUN LEE, City College of City University of New York — A free-energy based lattice Boltzmann method (LBM) for liquid-vapor and binary two-phase flows will be presented. Although very efficient and simple to implement, two-phase LBMs have been known to be unstable when the difference in material properties of two phases or the Reynolds number is large. Two major issues associated with the numerical stability of the free-energy based two-phase LBM under these conditions will be discussed. The intermolecular force needs to be in the potential form and its discretization needs to be compact and isotropic in order to eliminate parasitic currents, whose magnitude and extent usually increase as surface tension. High-order polynomial boundary conditions for free-energy are employed to correctly predict the equilibrium contact angle and the density profile at solid surfaces for large density contrast. Test cases include bubble generation in microfluidic devices, and droplet spreading and impact on flat and structured surfaces with different wetting characteristics.

[1]This work is supported in part by NSF DMS-0811046.

Wednesday, March 17, 2010 8:00AM - 11:00AM –

Session P12 DFD: Granular Materials II B110-B111

8:00AM P12.00001 From granular to Newtonian flow: three-dimensional imaging and rheology of suspensions , JOSHUA A. DIJKSMAN, Leiden University, STEVEN SLOTTERBACK, University of Maryland, ELIE WANDERSMAN, Leiden University, CHRIS BERARDI, WILLIAM DEREK UPDEGRAFF, University of Maryland, MARTIN VAN HECKE, Leiden University, WOLFGANG LOSERT, University of Maryland — We show that in sedimenting suspension flows, the microscopic dynamics mimics that of dry granular flows. To probe the dynamics of the suspension, we employ three-dimensional flow imaging and rheological measurements in a split-bottom geometry. We explore the range of flow rates from the rate-independent regime to the onset of rate dependence. In slow flows, we recover "dry granular flow" behavior, well studied in the split-bottom geometry. When the shear rate becomes comparable to the rearrangement timescale of the particles, we observe essentially Newtonian behavior. We show that these observations are consistent with the inertial number theory adapted to suspension flows.

8:12AM P12.00002 Deformation of Quasi-2D Oil-in-Water Emulsions , LAURA GOLICK, KENNETH DESMOND, ERIC R. WEEKS, Emory University — We create a quasi-2D nearly frictionless granular system, analogous to 2D granular systems of photoelastic disks but without static friction. To do this, we confine an oil-in-water emulsion between two glass plates such that the gap between the plates is smaller than the undeformed oil droplet diameter. For a range of droplet area fractions and plate separations, we observe the deformations the oil droplets experience due to contact with each other. The deformation of the droplet is correlated to the force its neighbors exert on it. As area fraction increases, the deformation of the droplets increases. By looking at the pattern of deformations throughout the system we visualize the location of force networks due to droplet-droplet interactions.

8:24AM P12.00003 Geometry Dominance in the Formation of Clusters in Systems of Rigid Gapped Rings , CHRISTOPHER LASOTA, Gonzaga University, RACHEL CARY, ARIEL HELFER — We have examined the formation of clusters in kinetically agitated collections of rigid rings with angular gaps in them. Even for small gap angles, large clusters form readily and are sufficiently tangled so as to remain tangled under semi-static gravitational stresses without decomposing. We have measured the average largest cluster size as a function of gap angle, and witness behavior similar to that of a percolation phase transition. This was done for a variety of materials having different friction coefficients. The critical gap angle at which clusters disappear appears to be nearly independent of the friction coefficient, suggesting that cluster formation is dominated by geometry effects.

8:36AM P12.00004 Constitutive relations in dense granular flows , JOHN DROZD, The University of Western Onatrio, COLIN DENNISTON, The University of Western Ontario — We use simulations in a vertical chute configuration to investigate constitutive relations in dry granular flow. We study relations describing the local stresses, heat flow, and dissipation in different granular regions or phases and compare our results to both theory and experiments. Particularly we investigate a free-fall dilute granular gas region at the top of the chute, a granular fluid in the middle and a glassy region at the bottom. We show that while the pressure can be reasonably described by hard sphere gas models, transport coefficients such as viscosity and heat conductivity cannot. In contrast to a hard sphere gas, the viscosity and heat conductivity increase with decreasing temperature in the fluid and glassy phases. In the fluid region, we compare our simulation values for viscosity and heat conductivity with published theoretical expressions based on Enskog expansions. In the glassy region, we observe signs of a finite yield stress and examine relations involving an internal friction coefficient. We show that the static sand pile is a limit of our glassy state, and we also solve for the eigenvectors of the stress tensor independent of any particular model.

8:48AM P12.00005 Properties of grains driven by an oscillating disk , KIRI NICHOL, MARTIN VAN HECKE, Leiden University — A container of glass beads driven by a rotating disk exhibits properties of a liquid - low density objects float at the depth predicted by Archimedes' law and sinking objects experience a viscous drag force. However, when the beads are driven by oscillating the disk, a surprising state emerges which exhibits unliquid-like behaviour: a light object submerged in the grains remains stuck, as if in a solid. As the oscillation amplitude is increased, the liquid-like character of the system is restored, although some surprising effects are observed due to contraction and dilation that occurs when the disk reverses direction.

9:00AM P12.00006 Ring Kinetic Theory for Granular Response Functions , JAMES DUFTY, University of Florida — The response functions for an isolated (cooling or thermostated) granular gas are described by kinetic theory [1]. The linear kinetic equation is obtained by a systematic expansion of the dimensionless BBGKY hierarchy scaled relative to the mean free time and mean free path [2]. At first order beyond Boltzmann the effects of ring (repeated) collisions and associated mode coupling are included. Qualitative differences from the Boltzmann approximation are described.

[1] "Kinetic Theory of Response Functions for the Hard Sphere Granular Fluid," A. Baskaran, J. Dufty, and J. Brey, J. Stat. Mech. 12, p12002 (2007); "Linear Response for Granular Fluids," J. Dufty, in Frontiers in Nonequilibrium Physics, Prog. of Theor. Phys. Supp., (to appear).
[2] "Kinetic Theory and Hydrodynamics for a Low Density Granular Gas," J. Dufty in Challenges in Granular Physics, T. Halsey and A. Mehta, eds. (World Scientific, N. J. 2002).

9:12AM P12.00007 Non-affinity of displacement fields in sheared granular systems , KINGA LORINCZ, PETER SCHALL, University of Amsterdam — The jamming transition, i.e. the transition in a granular system from rest to flow is a fundamental problem of great importance to the understanding of a wide class of disordered materials. Using the experimental method of laser sheet imaging we can accurately visualize individual particles in a sheared three-dimensional granular packing immersed in an index matching liquid. We study fluctuations in the displacements of the particles as a function of varying confining pressures and shear stresses. We characterize these fluctuations by investigating the non-affine regions in the displacement fields.

9:24AM P12.00008 Sound Waves in a Homogeneously Driven Granular Fluid in Steady State , KATHARINA VOLLMAYR-LEE, Bucknell University, ANNETTE ZIPPELIUS, TIMO ASPELMEIER, Georg-August-Universitaet Goettingen, Germany — We study the collective dynamics of a granular fluid of hard spheres, driven into a stationary non-equilibrium state by balancing the energy loss due to inelastic collisions with the energy input due to driving. The driving is chosen to conserve momentum, so that fluctuating hydrodynamics predicts the existence of sound modes. We present results of computer simulations which are based on an event driven algorithm. The dynamical structure factor $F(q,\omega)$ is determined for volume fractions 0.05, 0.1 and 0.2 and coefficients of normal restitution 0.8 and 0.9. We observe sound waves, determine their dispersion and compare our results with the predictions of generalized fluctuating hydrodynamics.

9:36AM P12.00009 Flow fluctuations and the local flowrule of granular suspensions , ELIE WANDERSMAN, JOSHUA DIJKSMAN, WERNER DE GROOT, MARTIN VAN HECKE, Leiden University — We study particle fluctuations and the local flowrule in slowly driven sedimenting suspension flows. We employ a fully three-dimensional particle tracking method that allows us to track the spatial trajectories of all the particles across the system. This flow information is coupled to rheometric experiments, and applied to both Couette and a split-bottom geometry. We show that the non-affine part of the particle displacements evolves nonlinearly with the local strain-rate and further discuss our results in the context of recently proposed non-local rheology models for flowing disordered materials.

9:48AM P12.00010 Packing structure of cyclically sheared dense granular spheres , ANDREEA PANAITESCU, ARSHAD KUDROLLI, Clark University — We characterize the structure of densely packed frictional granular spheres cyclically sheared between parallel walls under constant pressure boundary conditions with a fluorescent refractive index matched liquid imaging technique. This technique allows us to measure the three dimensional particles position and obtain the Voronoi tessellation corresponding to the particles in the bulk. We calculate the radial distribution function, g(r) from the measured position and show that its significant features can be captured by the Percus-Yevick formula derived for frictionless random packed spheres for initial volume fraction $\Phi = 0.59$\$. However, small but systematic deviations are observed because of the splitting of the second peak as Φ is increased by 3%. The angular correlation of the particles as measured by the bond order metric, Q_6 shows disorder compared to a close packed structure, but similar to those shown by frictionless spheres. The distribution of the Voronoi free volume is described by a three-parameter gamma distribution postulated for random packing of spheres. Overall, these measure show significant similarity of the observed granular packing compared with random packing of frictionless spheres, but some systematic differences as well.

10:00AM P12.00011 Networks of Broken Links in Granular Flows , MARK HERRERA, Institute for Research in Electronics and Applied Physics: University of Maryland, SHANE MCCARTHY, MICHELLE GIRVAN, WOLFGANG LOSERT, Institute for Research in Electronics and Applied Physics: University of Maryland — Shear zones and reproducible flow fields are key features of granular flows. We experimentally study flows in a split bottom geometry by tracking the motion of all particles in three dimensions. In particular, we investigate how shear zones emerge from individual particle rearrangements, and how the rearrangements transition from reversible to irreversible with increasing strain. In order to analyze rearrangements at the level of particle motion, we define a broken links network, the set of particle pairs that have separated from each other and are no longer in contact. The emergence of a giant component occurs at the same characteristic strain at which a steady shear zone forms. We propose network theory as a new framework to characterize granular flows at the intermediate scale.

10:12AM P12.00012 Experiments with 2D quasistatic and shaken arrays of permanent magnet N-mers ($N \geq 1$)[1] , PETER KOCH[2], SUNY Stony Brook, MARK SHATTUCK, Levich Inst., CCNY — We extend methods used to study macroscopic grains (contact forces) to 2D (x, y) arrays of N-mers of cylindrical (L=D=3.18 mm) Nd-Fe-B magnets in a rectangular cell with glass plates $\Delta z \sim$3.3 mm apart and parallel to magnet faces. Aligned monomers repel with a measured d^{-4} (dipole-dipole) force dependence, with d the separation between cylinder axes. With fixed, aligned monomers separated by 6.35 mm along the cell walls, hundreds of aligned monomers can move in the cell subject to magnet-glass friction and gravity (either $\parallel$ or $\perp$ to z) but without contacting each other or the walls. Quasistatically moving one wall to decrease volume V increases pressure P on the magnetic particles and leads to ordering observed with annealing. Driving the array, e.g., by shaking one wall, can produce disorder; we study how this varies with driving strength at fixed V or P. Replacing all non-wall monomers with similarly aligned tetramers (3 magnets magnetically bound to an inverted magnet) allows for more ordered states in quasistatic experiments; macroscopic, internal degrees of freedom into which energy can flow in driven experiments; and rearrangements ("chemical reactions") for strong driving.

[1]Supported by NSF DMR-0934206
[2]on sabbatical leave at Levich Institute, CCNY

10:24AM P12.00013 Particle velocity distribution in a 3-dimensional vibration fluidized granular medium[1] , HONG-QIANG WANG, University of Massachusetts Amherst, KLEBERT FEITOSA, NARAYANAN MENON — We report an experimental study of particle kinematics in a 3-dimensional system of inelastic spheres fluidized by intense vibration. The motion of particles in the interior of the medium is tracked by high speed video imaging, yielding a spatially- resolved measurement of the velocity distribution. The distribution is wider than a Gaussian and broadens continuously with increasing volume fraction. The deviations from a Gaussian distribution for this boundary-driven system are different in sign and larger in magnitude than predictions for homogeneously driven systems. We also find correlations between velocity components which grow with increasing volume fraction.

[1]We are grateful for support through NASA NNC05AA35A and NSF-DMR0606216

10:36AM P12.00014 The Role of Extensional Viscosity in Sedimentation , THEODORE A. BRZINSKI, PAULO E. ARRATIA, DOUGLAS J. DURIAN, University of Pennsylvania — When two particles in a viscous fluid approach contact the motion of the interstitial fluid is dominated by extensional flow. We demonstrate how the details of these flows influence the process of sedimentation. We are able to highlight the effects of extensional flows on particle motion by comparing granular dispersions in which the continuous phases have the same shear viscosities, but drastically different extensional viscosities. We enhance the extensional viscosity by adding a flexible, high molecular weight polymer. In the case of a system without polymer we observe settling rates in accordance with a typical Stokes' model until all grains have settled into a random close-packed arrangement. In the polymeric fluid we observe initial behavior not unlike that observed in the Newtonian case, however the dispersions exhibit a secondary prolonged sedimentation process before finally reaching the final close- packed state. The dependence of this secondary settling process on grainsize and initial packing fraction suggests that an ensemble of dispersed grains acts primarily to enhance the impact of interstitial flows on the system's dynamics.

10:48AM P12.00015 Sedimentation and Pressure Driven Flow in Fractures[1] , TAK SHING LO, JOEL KOPLIK, The Levich Institute and Department of Physics, City College of City University of New York — Suspended particles are commonly found in reservoir fluids, which alter the rheology of the flowing liquids and may obstruct transport by narrowing flow channels due to gravitational sedimentation. An understanding of the transport and deposition dynamics of particulate suspensions is, therefore, important to many chemical, petroleum, environmental and geological processes. Realistic geological fractures usually have irregular rough surfaces with self-affine structures. We study the combined effects of sedimentation and transport of particles suspended in a Newtonian fluid in a pressure-driven flow in self-affine channels by using the lattice Boltzmann method, which is especially relevant to clogging phenomena where sediments may block continuous fluid flows in channels. The lattice Boltzmann method is flexible and particularly suitable for handling irregular geometry. We perform a systematic study covering a broad range in Reynolds and buoyancy numbers, and in particle concentrations. In particular, the transitions between the "jammed" and the "flow" states in fracture channels are investigated.

[1]Work supported by DOE and NERSC

Wednesday, March 17, 2010 8:00AM - 11:00AM –
Session P13 DFD: Membranes: General, Surface, Biological B112

8:00AM P13.00001 Studies of the Temperature-Dependent Structure of DMPC Bilayer Lipid Membranes by Atomic Force Microscopy[1] , A. MISKOWIEC, M. BAI, H. TAUB, U. Mo., F.Y. HANSEN, Tech. U. Denmark — We are using Atomic Force Microscopy (AFM) to characterize the structure and topography of single-supported bilayer lipid membranes to complement quasielastic neutron scattering investigations of the membrane dynamics. To investigate the effect of different membrane-substrate interactions, samples of hydrated DMPC bilayer membranes have been fabricated on four different supports: 1) a bare SiO_2-coated Si(100) wafer; 2) a SiO_2-coated Si(100) wafer preplated with a monolayer of the pure alkane n-$C_{36}H_{74}$ in which the molecules are aligned with their long axis parallel to the SiO_2 surface; 3) an underlying DMPC membrane itself supported on a SiO_2 surface; and 4) a SiO_2-coated Si(100) wafer covered with a polyethylenimine (PEI) cushion. Above room temperature, our AFM images show a decrease in the DMPC membrane thickness with increasing temperature consistent with chain-melting transitions of the lipid tails. The onset temperature at which the membrane thickness begins to decrease and the temperature at which its thickness saturates both decrease with weaker binding to the support and with a greater level of hydration.

[1]Supported by Grant Nos. NSF DMR-0705974.

8:12AM P13.00002 Phospholipid-coated microbubbles: the acoustic signature of monolayer buckling , VALERIA GARBIN, MARLIES OVERVELDE, JEROEN SIJL, University of Twente, BENJAMIN DOLLET, Universite Rennes 1, NICO DE JONG, DETLEF LOHSE, MICHEL VERSLUIS, University of Twente — In medical ultrasound imaging, the echo of the blood pool is enhanced using ultrasound contrast agents. The contrast agent suspension consists of microbubbles (1 to 5 μm in radius) of an inert gas coated with a phospholipid monolayer. We characterize the changes in microbubble dynamics due to the coating, through combined micromanipulation by means of optical tweezers and ultra-high speed imaging at 15 million frames per second with the Brandaris 128 camera. The experiments reveal that buckling of the phospholipid monolayer increases the non-linear response of the contrast agent bubbles at low acoustic pressure.

8:24AM P13.00003 Coarse-grain simulation studies of lipid vesicles[1] , ROBIN SELINGER, JUN GENG, JONATHAN SELINGER, Liquid Crystal Institute, Kent State Univ. — We model the shape evolution of an initially spherical lipid vesicle when the lipid bilayer undergoes a transition from an untilted phase to a tilted phase. Our coarse-grain model is a generalization of an approach due to Lykotrafetis, Zhang, Suresh and Li [preprint], and is efficient enough to allow simulation of an entire vesicle in three dimensions. Topological defects are generated during the phase transformation with a total topological charge of +2 as required by the Gauss-Bonnet theorem. These defects couple to the curvature of the membrane. We explore the resulting complex shape evolution and compare to both theoretical predictions and experimental observations.

[1]Supported by NSF-DMR 0605889

8:36AM P13.00004 Role of Collective Degrees of Freedom in Formation and Disintegration of Spherical Micelles[1] , DMITRY KOPELEVICH, YONG NAM AHN, University of Florida, GUNJAN MOHAN — Dynamics of self-assembly and structural transitions in amphiphilic systems play an important role in various technological and biological processes. We recently demonstrated that even such a simple process as addition of a single surfactant molecule to a micelle involves a complex interplay between micellar and monomer configurations. In this talk, we present a quantitative model for collective dynamics of these degrees of freedom during the monomer addition and removal. This is accomplished by reconstruction of a multi-dimensional free energy landscape of the system and identification of the minimal energy path (MEP) on this landscape. Although analysis of MEP allows us to identify collective degrees of freedom relevant to the monomer addition and removal, MEP alone is not sufficient to adequately describe these processes. Comparable time-scales of several independent degrees of freedom during non-adiabatic stages of these processes imply that the system dynamics cannot be described by a quasi-one-dimensional motion along MEP. Therefore, we solve a multi-dimensional Langevin equation to correctly describe the non-adiabatic system dynamics.

[1]Supported by NSF CAREER Award

8:48AM P13.00005 Critical capsule deformation in several linear flows, modeled using the Immersed Boundary Method , ALEX SZATMARY, CHARLES EGGLETON, UMBC — Elastic capsules are exposed to a variety of flows in microfluidic devices. Capsules can deform continuously to bursting when exposed to sufficiently intense flows. Here, this critical behavior is modeled for several linear flows, including Couette flow, and plane, axisymmetric, and biaxial extensional flows, as well as superpositions of these. Several membrane constitutive equations are used to model behavior of a variety of capsules and biological cells. Computational modeling results using the immersed boundary method are reported.

9:00AM P13.00006 Manipulation, stability, and controlled release of micelles in AC-electric fields , VICTORIA FROUDE, Y. ELAINE ZHU, University of Notre Dame — In this work, we explore the rich AC-electrokinetic effects to manipulate micelles of varied chemical structures and examine their stability in response to applied AC-electric fields. We investigate the AC-field induced transport and instability of sodium dodecyl sulfate (SDS) micelles and cetyl trimethylammonium bromide (CTAB) micelles tagged with various hydrophilic and hydrophobic fluorescent probes by using fluorescence correlation spectroscopy (FCS) at a single-molecule resolution. Micelle concentration and dielectrophoresis (DEP) mobility are examined over a broad range of AC-field frequency from 1 KHz -10 MHz and amplitude from 5V-10V. We observe a strong AC-frequency dependence of micelle concentration between two microelectrodes, from which the DEP crossover frequency switching between the positive and negative DEP response is determined. Surprisingly, we also observe the AC-field induced instability of the micelle structure and the resultant release of fluorescent probes at a characteristic low AC-field frequency of about 1-10 kHz for specific probes in SDS micelles, which could have a potential application for controlled drug release by AC-electric fields.

9:12AM P13.00007 Investigating bile salt aggregation using coarse-grained molecular dynamics simulations , ANA VILA VERDE, AMOLF Institute, Amsterdam, Netherlands and Department of Physics, University of Minho, Portugal, DAAN FRENKEL, Department of Chemistry, University of Cambridge, Cambridge, UK — Bile salts are necessary for fat digestion due to their unusual surfactant properties: they assemble into small, polydisperse micelles and easily form mixed micelles with poorly soluble amphiphiles. Understanding these properties requires molecular scale information about bile salt micelles, something challenging to obtain experimentally but amenable to computational modeling. To address this issue we build a coarse-grained model of bile salts. We investigate their aggregation behavior through molecular dynamics simulations in a grand-canonical parallel tempering scheme. We validate our model against available solubility and light scattering data. Our results indicate that at physiological bile salt and counter ion concentrations, bile salts pack in many different orientations in pure bile micelles, contrary to standard surfactants. This feature may be physiologically relevant, allowing bile salts to solubilize the heterogeneous blends of fats typical of digestion.

9:24AM P13.00008 Mechanical properties of giant folds in a Langmuir monolayer[1] , THOMAS BOATWRIGHT, JEFFREY YU-CHIEH YANG, Department of Physics and Astronomy, University of California, Irvine, ALEX J. LEVINE, Department of Chemistry and Biochemistry, University of California, Los Angeles, MICHAEL DENNIN, Department of Physics and Astronomy, University of California, Irvine — We study the mechanical properties of giant folds in a catanionic monolayer at the air water interface. The system of study is a dioctadecyldimethylammonium bromide (DODAB) and sodium dodecyl sulfate (SDS) monolayer which folds upon compression in a Langmuir trough. Carboxylate-coated polystyrene beads (1 micron diameter) are attached to the monolayer in order to track its displacement with epifluorescence microscopy and particle image velocimetry. This analysis yields a measurement of the velocity of the monolayer around the fold. The quantities of monolayer material entering and leaving the fold are recorded as well. Maximum material velocities and fold depths are found to be on the order of 0.1 mm/s and 1 mm, respectively. Analysis also reveals that the unfolded material displacement follows a characteristic curve. Mechanical properties of the monolayer are also probed with optical tweezer microrheology.

[1]Supported by NSF-DMR-0907212, Research Corporation and the University of California Toxic Substances Research and Teaching Program.

9:36AM P13.00009 Lipid/water system with varying charge densities at the interface monitored by sum-frequency vibrational spectroscopy , WOONGMO SUNG, SANGJUN SEOK, DOSEOK KIM, Department of Physics, Sogang University — Lipids having negatively- and positively charged headgroups were mixed together and spread on water to make Langmuir monolayers with interface charge densities controlled at will. These systems were then monitored with surface-selective sum-frequency vibrational spectroscopy. Sum-frequency signal from the interfacial water molecules changed sensitively with the composition of lipids in the mixture, reflecting the electric field induced by the lipid headgroups. By comparing the interference patterns between CH stretch vibration peaks of the lipid molecules and OH stretch vibration peaks of the water molecules in the sum-frequency spectra, the change in the polar ordering of the interfacial water molecules was monitored.

9:48AM P13.00010 Attractive amphiphilic polymer layers form amorphous membranes , HO CHEUNG SHUM, Harvard University, JEROME BIBETTE, Ecole Supérieure de Physique et Chimie Industrielle, DAVID WEITZ, Harvard University — Amphiphilic polymer molecules becomes attractive and form aggregates in a poor solvent. By confining two layers of attractive polymer layers at neighboring interfaces, we form a thin amorphous membrane instead of aggregates. The rigidity of the membrane is shown to be controlled by the magnitude of attractive interaction between the two layers. At very high attractive interactions, possibly glassy membranes are formed. We demonstrate these using microfluidics to form polymer vesicles with amorphous membranes. By measuring the energy of adhesion between the two layers, we propose a physical explanation behind the membrane formation process. The amorphous membranes are shown to have a similar structure as lipid bilayers, but with a significantly improved rigidity. Our system provides a simple way to look into membrane formation and suggests that the membrane rigidity is closely related to the interactions between the constituent molecules.

10:00AM P13.00011 The Effects of Concentration and Temperature on Vesicle Adsorption and Bilayer Formation , KIMBERLY WEIRICH, JACOB ISRAELACHVILI, DEBORAH FYGENSON, University of California, Santa Barbara — Supported lipid bilayers (SLBs) are pursued as thin surface coatings and as model systems in which to study membrane-bound processes. We investigate the adsorption of small unilamellar phospholipid vesicles onto glass and the subsequent formation of planar SLBs using temperature-controlled, time-resolved fluorescence microscopy. We report the effects of vesicle concentration and temperature on the time course of lipid adsorption. Our results suggest that isolated vesicle rupture is a rare event and that bilayer edge plays a key role in SLB formation. It enhances vesicle-surface affinity and promotes further rupture.

10:12AM P13.00012 Coarse-graining, Electrostatics and pH effects in phospholipid systems[1] , ALEX TRAVESSET, Iowa State University and Ames Lab, SWETA VANGAVETI, Iowa State University — We introduce a minimal free energy describing the interaction of charged groups and counterions including both classical electrostatic and specific interactions. The predictions of the model are compared against the standard model for describing ions next to charged interfaces, consisting of Poisson-Boltzmann theory with additional constants describing ion binding, which are specific to the counterion and the interfacial charge ("chemical binding"). It is shown that the "chemical" model can be appropriately described by an underlying "physical" model over several decades in concentration, but the extracted binding constants are not uniquely defined, as they differ depending on the particular observable quantity being studied. It is also shown that electrostatic correlations for divalent (or higher valence) ions enhance the surface charge by increasing deprotonation, an effect not properly accounted within chemical models. The model is applied to the charged phospholipids phosphatidylserine, Phosphatidc acid and Phosphoinositides and implications for different biological processes are discussed.

[1]funded by NSF CAREER DMR-0748475

10:24AM P13.00013 Measurement of red blood cell mechanics during morphological changes[1] , GABRIEL POPESCU, University of Illinois at Urbana-Champaign, YONGKEUN PARK, MIT, CATHERINE BEST, UIUC, RAMACHANDRA DASARI, MICHAEL FELD, MIT, TATIANA KURIABOVA, University of Colorado, MARK HENLE, Harvard, ALEX LEVINE, UCLA — The human red blood cell (RBC) membrane, a fluid lipid bilayer tethered to an elastic 2D spectrin network, provides the principal control of the cell's morphology and mechanics. These properties, in turn, influence the ability of RBCs to transport oxygen in circulation. Current mechanical measurements of RBCs rely on external loads. Here we apply a Noncontact optical interferometric technique to quantify the thermal fluctuations of RBC membranes with 3 nm accuracy over a broad range of spatial and temporal frequencies. Combining this technique with a new mathematical model describing RBC membrane undulations, we measure the mechanical changes of RBCs as they undergo a transition from the normal discoid shape to the abnormal echinocyte and spherical shapes. These measurements indicate that, coincident with this morphological transition, there is a significant increase in the membrane's shear and bending moduli. This mechanical transition can alter cell circulation and impede oxygen delivery.

[1]NIH ((P41RR02594-18 to MSF) and NSF CAREER (08-46660 to GP)

10:36AM P13.00014 Molecular Transport through Flexible Membranes: Coupling between Solute Dynamics and Membrane Fluctuations[1] , YONG NAM AHN, YOUNG-MIN BAN, DMITRY KOPELEVICH, University of Florida — Mechanism of solute transport through self-assembled membranes, such as lipid bilayers and surfactant monolayers, is investigated. It is demonstrated that dynamics of the solute molecule significantly deviates from the Markovian Brownian motion. Specifically, the correlation time of the random force acting on the solute increases by two orders of magnitude within a very narrow (less than 1 nm wide) region within or near the membrane. We demonstrate that the slow fluctuations of the random force in this narrow region are caused by dynamic coupling of the solute transport with the membrane undulations. This coupling is the strongest near a free energy barrier for the solute transport through the membrane. Therefore, the coupling is expected to play significant role in the mass transport through a membrane. A stochastic model for the coupled solute-membrane dynamics is developed using results of molecular dynamics simulations. The observed mechanism appears to be very general and is expected to affect mass transport through other flexible membranes.

[1]Supported by NSF

10:48AM P13.00015 Experimental and Numerical Investigation of the Equilibrium Geometry of Liquid Lenses , J. C. BURTON, University of Chicago, F. M. HUISMAN, P. ALISON, D. ROGERSON, P. TABOREK, University of California Irvine — The equilibrium configuration of a non-wetted fluid/fluid/gas system takes the form of a floating liquid lens. We have computed the shapes of lenses for various liquid/liquid combinations in air for a wide range of droplet volumes by numerically solving the Young-Laplace equation, including the effects of gravity. The results of the calculations are compared to laser shadowography photographs of various alkane-water liquid lens systems, which were analyzed using basic ray-tracing to determine the lens profiles. Moiré imaging was also used to measure the deformation of the water interface due to the lens' presence. The agreement between experiment and theory is good for pure fluids. We also introduced a surfactant, dodecyltrimethylammonium bromide (DTAB), into the sub-fluid phase (water) at concentrations between 0 and 20 mmol/kg. In agreement with other experiments, we find a minimum contact angle at low concentrations corresponding to a pseudo-partial wetting transition of the alkane/water/surfactant system.

Wednesday, March 17, 2010 11:15AM - 2:15PM –

Session Q12 DFD DCMP: Self-Assembly: Equilibrium and Non-Equilibrium B110-B111

11:15AM Q12.00001 Two-parameter sequential adsorption model of microfiber clustering , JAYSON PAULOSE, DAVID NELSON, JOANNA AIZENBERG, Harvard University — Capillary-mediated self-assembly and self-organization are useful techniques for constructing ordered superstructures from nanoscale and microscale building blocks. Square arrays of microfibers attached to a substrate have been shown to form highly ordered patterns of 2x2 fiber clusters (tetramers) under the influence of capillary forces at the surface of an evaporating liquid layer. We model this pattern formation as an irreversible sequential adsorption process on a square lattice, in which tetramers form sequentially on an initially empty lattice and locally enhance the formation of nearby tetramers, giving rise to ordering over several lattice lengths. Two parameters regulate the enhancement in tetramer formation at third- and fourth-near neighbor positions. The model is studied using computer simulations and compared to a particular realization of a self-organization experiment. We show that the model quantitatively reproduces many features of the observed patterns when the two parameters are chosen by a least-squares fit to a single experimental quantity.

11:27AM Q12.00002 Directed Self-assembly of Gold Nanoparticles using Chemically Patterned Templates[1] , ROBERT NIDETZ, JINSANG KIM, University of Michigan — Templated assemblies of metallic nanoparticles are useful for sensors, medical diagnostics, catalysts, and optical devices. We controlled the loading density of gold nanoparticles on a chemical template by manipulating the dimensions of the chemical template. Electron beam lithography was used to fabricate the template on Si wafers, which was chemically patterned with functional silanes that form self-assembled monolayers. The lithographically patterned regions were given a positive charge via aminopropyldimethylethoxysilane, while the remainder of the substrate was made hydrophilic via dodecyltrimethoxysilane. The charge-charge interaction between the negatively charged gold nanoparticles and the positively charged chemical template cause the nanoparticles to self-assemble onto the template. By altering the diameter of the chemical template, it was possible to control the number of 40 nm diameter gold particles that self-assemble. We are currently expanding the directed assembly strategy to nanorods assembly. The developed templated assembly method will find various applications of nano-size objects.

[1]We gratefully acknowledge the support from the Air Force Office of Scientific Research under contract FA 9550-06-01-0279 through the Multidisciplinary University Research Initiative Program.

11:39AM Q12.00003 Isomers of Janus colloidal clusters , QIAN CHEN, STEVE GRANICK, University of Illinois at Urbana Champaign — Colloidal clusters formed by the reversible assembly of amphiphilic Janus spheres show time-dependent isomerization between different isomeric shapes. Here, the rate constant is obtained experimentally by decoupling isomerization from other interconversions between clusters of different mass. The equilibrium constant is found to be controlled by ionic strength, volume fraction and Janus balance. This isomerization between clusters of the same mass but different shape has bearing on understanding nucleation that precedes subsequent growth.

11:51AM Q12.00004 Design Rules for Ordered SAMs on Patchy Nanoparticles , AARON SANTOS, SHARON GLOTZER, University of Michigan — Recently, the self-assembly of ordered stripe-like domains of ligands on the surface of spherical nanoparticles was reported. Molecular ligands tethered to nanoparticle surfaces play an important role in the self-assembly of many systems. These tethers contribute significantly to the free energy of the system because of their large conformational entropy. In general, the stable state can be determined by minimizing the free energy of the system. We have developed a coarse-grained model to rapidly simulate the phase separation of ligands on a surface. The model uses mean field and two-body approximations to compute the conformational entropy of tethers. Using these approximations, one can quickly compute the phase diagrams using a simple Metropolis Monte Carlo simulation. In contrast to traditional coarse-grained simulation methods, which can take hundreds to thousands of hours of CPU time, our coarse-grained model can generally find free energy minimum states in under a few hours. We use this model to study the self-assembly of monolayers on nanoparticle surfaces into a variety of patterns and predict design rules for assembling patchy particles. This work has profound implications for the design and synthesis of ordered patchy particles.

12:03PM Q12.00005 Free Energy Landscape of Colloidal Clusters at Small N , GUANGNAN MENG, Harvard University, Physics & SEAS, NATALIE ARKUS, MICHAEL BRENNER, Harvard University, SEAS, VINOTHAN MANOHARAN, Harvard University, Physics & SEAS — We confine small number of micron-sized colloidal particles within micro-wells, and we directly measure the structures and free energies of colloidal clusters, in which the particles act as hard spheres with short-range attractions. We find that highly symmetric clusters are strongly suppressed by rotational entropy and the most stable clusters have anharmonic vibrational modes or extra bonds. The experimental results can be explained well by the classical statistical mechanics and sphere packing theories.

12:15PM Q12.00006 Epitaxial growth of colloidal nanoparticles , Y. KRYUKOV, C. JOSHI, T.P. BIGIONI, J.G. AMAR, University of Toledo — In recent drop-drying experiments involving gold nanoparticles suspended in an evaporating droplet, the formation of large highly-ordered nanoparticle monolayers growing at the liquid air-interface has been observed. While this process appears to be analogous to epitaxial growth, there are also some important differences. For example, in analogy to epitaxial growth on a solid substrate, our experimental results indicate the existence of a sharp island-size distribution as well as a well-defined critical island-size. However, in contrast to epitaxial growth, we find a power-law decay of the island density with coverage due to the coalescence of large diffusing clusters. In order to better understand these results, we have carried out kinetic Monte Carlo simulations of a realistic model which takes into account (i) "deposition" of nanoparticles at the liquid-air interface (ii) two-dimensional diffusion of nanoparticles, and (iii) cluster diffusion and coalescence, as well as the effects of monomer detachment and van der Waals attraction. A comparison between our simulation results and experimental results will be presented.

12:27PM Q12.00007 Self assembly of magnetically interacting cubes by a turbulent Fluid Flow , MADHAV MANI, Harvard SEAS, FILIP ILIEVSKI, Harvard Chemistry, MICHAEL BRENNER, Harvard SEAS, GEORGE WHITESIDES, Harvard , BRENNER COLLABORATION, WHITESIDES COLLABORATION — We self-assemble macroscopic objects using a turbulent flow field and find agreement with a statistical theory. Here we choose to mimic a simple process, linear aggregation, that takes place during several cellular polymerization processes via magnetic interactions between centimeter-sized cubes. The cubes are suspended in a density matched fluid which is driven into a turbulent state, modeled as a gaussian white noise source, with statistics that are well described by energy cascade models for turbulence. Employing the steady-state approximation in the Fokker-Planck equation for the system, dervied directly from the equation of motion of the particles, we can derive the stationary distribution. We find good agreement between the experimental data and the predicted yield-curve taking particular care to evaluate the statistical error due to the finite sampling of the distribution.

12:39PM Q12.00008 Phase separation induced by ladder-like polymer-polymer complexation , ISSEI NAKAMURA, AN-CHANG SHI, McMaster University — Complexation between donor and acceptor polymers in solvent through specific binding interactions such as hydrogen bonding is studied using a self-consistent field theory. In the model, two donor and acceptor polymers are capable of forming a ladder-like duplex structure. The duplex formation discontinuously occurs with an abrupt variation in entropy, resulting in a first-order transition. Moreover, solvent-induced complexation is discussed. In this case, the duplex polymer is stabilized by solvent-polymer interactions rather than the specific binding interactions. Various types of unconventional coexistence curves are derived from the model. A phase separation with decreasing the χ-parameter between duplex polymer and solvent can be induced, leading to a lower critical solution temperature (LCST) behavior. Critical points at which two, three, and four phases coexist are also obtained. Under certain conditions a homogeneous phase becomes unstable when the polymer chain length is decreased, in contrast to the standard Flory-Huggins theory.

12:51PM Q12.00009 Liquid-Vapor Like Phase Transition in DNA-Coated Colloids , FRANCISCO MARTINEZ-VERACOECHEA, DAAN FRENKEL, Chemistry Department, University of Cambridge — Colloidal particles coated with DNA-molecules can be designed to bind with high specificity. The result is an unprecedented flexibility for the design of self-assembling systems. Specific interactions can be used to mimic chemical systems at the colloidal level, virtually opening a window to the re-invention of chemistry at a totally new length-scale. Molecular simulations are expected to play a decisive role in the understanding of these materials. In the present work, we use advanced Monte Carlo simulations to study binary systems of DNA-coated colloids, wherein a given type of DNA can only bind to DNA of the opposite type. The system is represented using a coarse-grained model where the DNA interacts through soft-repulsive potentials while the colloids present hard-core interactions only. Binding between DNA is modeled as a harmonic spring between the center of masses of the DNA-chains. The systems are observed to undergo a liquid-vapor like transition for systems where the number of DNA chains per colloid is equal or greater than three. The phase transition is shown to be driven by the entropy gain in bond re-arrangements when the dimers observed in dilute phase form the percolating network typical of the dense phase.

1:03PM Q12.00010 Self-limited self-assembly of chiral filaments[1] , MICHAEL HAGAN, YASHENG YANG, ROBERT MEYER, Brandeis University — The assembly of filamentous bundles with controlled diameters is common in biological systems and desirable for the development of nanomaterials. We discuss dynamical simulations and free energy calculations on patchy spheres with chiral pair interactions that spontaneously assemble into filamentous bundles. The chirality frustrates long-range crystal order by introducing twist between interacting subunits. For some ranges of system parameters this constraint leads to bundles with a finite diameter as the equilibrium state, and in other cases frustration is relieved by the formation of defects. While some self-limited structures can be modeled as twisted filaments arranged with local hexagonal symmetry, other structures are surprising in their complexity. We discuss the relation between model structures and finite bundles in biological or biomaterials systems, and implications for the design of nanostructured materials with controlled sizes.

[1]this project was supported by the NSF Brandeis MRSEC

1:15PM Q12.00011 Optimal arrangement of lamellar and triangular lattices confined to cylindrical fibers , KEVIN KOHLSTEDT, University of Michigan, GRAZIANO VERNIZZI, Northwestern University, FRANCISCO SOLIS, Arizona State University, MONICA OLVERA DE LA CRUZ, Northwestern University — The optimal packing of ionic lamellar and triangular lattices on the surface of a nanofiber is computed to determine the effects of the surface curvature. In ionic triangular lattices, electrostatic interactions prefer chiral arrangements only for special families of lattices that depend on the fiber diameter. However, there are families of triangular lattices that energetically promote achiral configurations. We also consider the behavior of short-range elastic forces, represented by interconnected springs between neighboring components. In this case a different family of achiral lattices is preferred. We also determine the optimal packing of lamellar lattices of cationic-anionic components. In lamellar packing of cylinders a chiral angle emerges that depends on the cylinder radius and the different dielectric constants of the interior and exterior of the cylinder. We discuss the effect of salt concentration inside and outside the cylinders on the chiral angle, and the implication of our results in ion channels structures.

1:27PM Q12.00012 Self-Assembled Membranes and Chirality Driven Transitions from 2D Surfaces into 1D Ribbons[1] , EDWARD BARRY[2], ZVONIMIR DOGIC, ROBERT MEYER, NADIR KAPLAN, THOMAS GIBAUD, MARK ZAKHARY, Martin Fisher School of Physics at Brandeis University, HAO TU, ROBERT PELCOVITS, Brown University, RUDOLF OLDENBOURG, Marine Biological Laboratory — We briefly outline conditions under which homogeneous non-amphiphilic colloidal rods self-assemble into two-dimensional fluid-like surfaces or membranes. Stabilized by entropic forces, these membranes have properties that are identical to lipid bilayers. We then focus on experiments in which the chirality of the constituent particles induces the transition from achiral 2D membranes into 1D twisted ribbons. The model system developed is unique, both in our ability to tune chiral interactions between constituent particles and directly visualize the structure and fluctuations of the final assemblage on all relevant lengthscales. These features allow us to test the theoretical model describing the transition from chiral ribbons to achiral membranes in great detail.

[1]Supported by NSF, MRSEC at Brandeis University, and NIH.
[2]Supported by the HHMI-NIBIB Quantitative Biology Program

1:39PM Q12.00013 Organic crystal needle formation via solvent-annealing: coarsening, wetting, and crystallization in a thin liquid film , TONY S. YU, A. E. HOSOI, MIT — Single-crystal, organic semiconductors are attractive because of their highly-nonlinear optical properties and, relative to their amorphous counterparts, they exhibit higher charge mobilities and improved morphological stability. But for such materials to be practical, researchers must develop methods for controlled growth of organic single-crystals. Here we investigate the growth of high-aspect-ratio "needles" of single-crystal Alq_3—tris(8-hydroxyquinoline) aluminum—from amorphous Alq_3 films. During deposition, thin films of amorphous Alq_3 are locked in an energetically-unfavorable state. When exposed to solvent, these films evolve into three distinct states: Alq_3-rich droplet regions, solvent-rich wetting regions, and Alq_3 needles. To understand the experimental results, we model the dynamics of a thin fluid film driven by capillary pressure and intermolecular forces. The resulting flow, coupled with diffusion, transports Alq_3 to a growing needle, which is represented by a moving, absorbing interface bounding the fluid.

1:51PM Q12.00014 A Monte Carlo Free Energy Approach to Microphase study and Its Application on the ANNNI Model , KAI ZHANG, PATRICK CHARBONNEAU, Duke University — Microphases are complex and interesting patterns that self-assemble in systems with competing short-range ordering and long-range frustrating interactions. They form in certain colloidal suspensions and in diblock copolymers, but controlling the morphology is notoriously difficult. Knowing the equilibrium behavior of model systems would help understand how to tune the modulated phases. But even for these systems, reliable results for the microphase regime are notoriously difficult to obtain, because of the presence of long-lived metastable states. We develop a Monte Carlo simulation method based on thermodynamic integration that resolves this problem. With our method, we determine with high accuracy the phase behavior of the canonical three-dimensional axial next nearest-neighbor Ising (ANNNI) model, which is one of the simplest models to form lamellas. The XY nature of the modulated-disorder phase transition is confirmed and critical exponents are obtained. We discuss how to generalize our simulation approach to particle-based microphase-forming model.

2:03PM Q12.00015 From gas-liquid to liquid crystalline phase behavior via anisotropic attraction: A computer simulation study in three and two dimensions , REINHARD HENTSCHKE, Fachbereich Mathematik und Naturwissenschaften, Bergische Universitaet, 42097 Wuppertal, Germany, WEN-ZE OUYANG, National Microgravity Laboratory, Institute of Mechanics, Chinese Academy of Science, Bejing 100190, P. R. China — The partial phase behavior of a continuum molecular model for self-assembling semiflexible equilibrium polymers is studied via Monte Carlo and Molecular Dynamics simulation. We investigate the transfer from ordinary gas-liquid coexistence to the appearance of liquid crystallinity driven by excluded volume interaction between rod-like aggregates. The transfer between the two types of phase behavior is governed by a tunable anisotropic attractive interaction between monomer particles. The relation to dipolar fluid models, which are also known to form reversible chains, is discussed. In two dimensions, depending on the strength of the anisotropy, we find the formation of reversible networks as well as stiff rod-like aggregates. The phase transition observed in the presence of the network structures is compared to predictions of the Tlusty-Safran defect model.

Wednesday, March 17, 2010 2:30PM - 5:30PM –

Session T12 DFD: Microfluidics II: Devices B110-B111

2:30PM T12.00001 Mechanical actuators at the nanoscale: molecular propellers, paddles and wheels , LELA VUKOVIC, BOYANG WANG, PETR KRAL, University of Illinois at Chicago — We model by molecular dynamics simulations nanosystems that could realize mechanical action in nanofluidics. First, we study molecular propellers formed by carbon nanotube rotors with attached aromatic blades that can pump liquids with efficiency dependent on the chemistry of the liquid-blade interface [1]. Next, we investigate nanorods with photoactive surfaces that can roll on water when driven by light [2]. Their rolling motion is realized when chromophores attached to their surfaces become anisotropically polarized by light and attracted to water. Finally, we examine nanoscale pumping induced by deformable nanoscale blades [3]. We show that the length, polarity, frequency and amplitude of oscillations of the nanoblades control their efficiency of water pumping.

[1] B. Wang and P. Král, . Rev. Lett. 98, 266102 (2007).
[2] L. Vukovic and P. Král, submitted.
[3] L. Vukovic, D. Astumian and P. Král, in preparation.

2:42PM T12.00002 Smart Capsules: Engineering New Temperature and Pressure Sensitive Materials with Microfluidics , LAURA ADAMS, JAMES WILKING, ANDERSON HO CHEUNG SHUM, SEBASTIAN SEIFFERT, SHMUEL RUBINSTEIN, YUANJIN ZHAO, DAVID WEITZ, Harvard University — New smart materials that are responsive to external stimuli such as pressure and temperature can be carefully designed using microfluidics with double emulsions as building blocks. Here we introduce the synthesis of new smart core-shell structures with two different aqueous drops in the interior. By triggering the capsules with pressure and temperature, coalescence and mixing of the interior drops occurs and is studied with high speed video imaging techniques.

2:54PM T12.00003 Directed Fluid Flow Produced by Arrays of Magnetically Actuated Core-Shell Biomimetic Cilia , B. L. FISER, A. R. SHIELDS, Department of Physics and Astronomy, University of North Carolina at Chapel Hill, B. A. EVANS, Department of Physics, Elon University, R. SUPERFINE, Department of Physics and Astronomy, University of North Carolina at Chapel Hill — We have developed a novel core-shell microstructure that we use to fabricate arrays of flexible, magnetically actuated biomimetic cilia. Our biomimetic cilia mimic the size and beat shape of biological cilia in order to replicate the transport of fluid driven by cilia in many biological systems including the determination of left-right asymmetry in the vertebrate embryonic nodal plate and mucociliary clearance in the lung. Our core-shell structures consist of a flexible poly(dimethylsiloxane) (PDMS) core surrounded by a shell of nickel approximately forty nanometers thick; by using a core-shell structure, we can tune the mechanical and magnetic properties independently. We present the fabrication process and the long-range transport that occurs above the beating biomimetic cilia tips and will report on progress toward biomimetic cilia induced flow in viscoelastic fluids similar to mucus in the human airway. These flows may have applications in photonics and microfluidics, and our structures may be further useful as sensors or actuators in microelectromechanical systems.

3:06PM T12.00004 Microfluidic Mixing and Confined Flows with Biomimetic Cilia Arrays , A.R. SHIELDS, B.L. FISER, Department of Physics and Astronomy, University of North Carolina at Chapel Hill, B.A. EVANS, Department of Physics, Elon University, R. SUPERFINE, Department of Physics and Astronomy, University of North Carolina at Chapel Hill — We present results on fluidic mixing produced by the collective beating of arrays of biomimetic cilia. Our artificial cilia are arrays of free-standing microstructures, at the scale of biological cilia, which we actuate with permanent magnets to mimic their biological counterparts. The presence of mixing in biological ciliated systems has been a subject of recent speculation, with possible implications for a variety of biochemical processes. We have observed that biomimetic cilia actuation induces fluid mixing within the cilia layer that can be characterized as an enhanced diffusivity. Due to the similarity in size and hydrodynamic regime between our system and biology, our results provide the first experimental suggestion of mixing in ciliated systems. In addition, we have mapped three-dimensional flows in confined fluidic cells that recreate the flows observed in the embryonic node, where cilia-driven fluid transport determines vertebrate left/right body asymmetry.

3:18PM T12.00005 Devices for the production and sorting of microfluidic droplets , DONALD AUBRECHT, Harvard University, JOHN HEYMAN, HabSel, Inc., JEREMY AGRESTI, Fluid Discovery, Inc., SARAH KÖSTER, Universität Göttingen, DAVID WEITZ, Harvard University — Droplets produced in microfluidic devices are a great set of tools for studying large cell populations and permutations of reactions. Sample populations of 10^6 - 10^7 can be studied with relative ease, as encapsulation and screening rates in the kHz range are accessible. Previous droplet work has shown encapsulation of cells in droplets allows individual cells and their products to be studied. Advantages include correlation between detected products and initial drop contents, as well as minimized sample cross-contamination. Most microfluidic-based biological assays rely on fluorescent labeling of cells or use of cellular products to initiate a fluorescence-producing reaction. Detection of the fluorescence provides a trigger for sorting those cells or cell-containing droplets away from the general population. Though this allows some cellular processes to be studied, detection and quantification of all products, not just those expressed to the cell surface or those that catalyze reactions, would impact development of better therapeutics. We are currently working to adapt benchtop biological assays that label and detect cellular products for use in a droplet-based system. The work presented here details the chain of modular microfluidic devices we use to encapsulate, incubate, interrogate, and sort a population of droplets containing a model system.

3:30PM T12.00006 Surface-functionalized Microelectrofluidic Biosensors , MICHAEL A. STANTON, UC Santa Barbara, GUILHERME N.M. FERREIRA, Universidade do Algarve, Institute for Biotechnology and Bioengineering, JEAN-LUC FRAIKIN, A. N. CLELAND, UC Santa Barbara — We are developing all-electronic, label-free biosensors for the rapid, selective and label-free detection of viruses and viral proteins. We are using a thiol-based self assembled monolayer (SAM) on gold as the functional element, sensed using radiofrequency reflectometry, with the functionalized sensor embedded in a microfluidic channel. We are exploring using mixed-length SAMs to bind single-chain fragments and single domain antibodies for the recognition of HIV1 and other virus targets. RF reflectometry is used to measure impedance changes in the sensors, which occur upon binding of viral or antibody targets. With an active sensing volume of a few hundred attoliters and sensitivity to impedance changes of order 1 part in 10^5 we expect to be able to detect the binding of small numbers of viral antibodies or viral particles.

3:42PM T12.00007 Electrode-based detection technique for microfluidic devices , EVGENIYA MOISEEVA, ADRIAN FLETCHER, CINDY HARNETT, University of Louisville — We report on a droplet-producing microfluidic device with electrode-based detection techniques. The microfluidic devices are made of polydimethylsiloxane (PDMS) and glass. Immiscible fluids containing the hydrophobic and hydrophilic phases are injected into the microfluidic device using syringe pumps. When a particle passes between a pair of electrodes in a medium having different electrical conductivity, the resulting impedance change signals the presence of the particle for closed-loop feedback during processing. The circuit produces a digital pulse for input into a computer control system. The detected signal can be used for evaluating droplet size, droplet shape, and droplet formation frequency. The detector also allows estimation of a droplet's arrival time at the microfluidic chip outlet for dispensing applications. Electronic feedback provides the ability to count, sort, and direct microfluidic droplets. Microelectrode-based techniques should find several applications in digital microfluidics and in three-dimensional printing technology for rapid prototyping and biotechnology.

3:54PM T12.00008 Microfluidic high-throughput nanoparticle counter , JEAN-LUC FRAIKIN, University of California Santa Barbara, ANDREW CLELAND, UCSB Physics — We have developed a high-throughput sensor for the all-electronic sizing of synthetic and biological nanoparticles suspended in a fluid. We have demonstrated detection of unlabeled particles with diameters ranging from 50 nanometers to 1 micron, and the rapid response time of the sensor permits detection of particles at rates greater than 200000 particles per second. Our current efforts focus on developing the sensor to detect single virus particles suspended in complex cytoplasmic fractions.

4:06PM T12.00009 Analysis and fabrication of micro scale self-terminated electrochemical growth by a pressure-driven method[1] , FATEMEH SOLTANI, ALEX WLASENKO, GEOFF STEEVES — A self-terminated electrochemical method was used to fabricate microscopic-scale contacts between two Au electrodes in a microfluidic channel. The conductance of contacts varies in a stepwise fashion with a tendency to quantize near the integer multiples of the conductance quantum (G_0). The mechanism works by a pressure-driven flow parallel with a pair of Au electrodes with a gap in order of micron in an electrolyte of HCl. When applying a bias voltage between electrodes, metal atoms are etched off the anode and deposited onto the cathode. Consequently, the gap decreases to the atomic scale and then completely closed as the two electrodes form a contact. The electrochemical fabrication approach introduces large variance in the formation and location of individual junctions. Controlling this process will enable the precise positioning of reproducible geometries into nano-electronic devices. To investigate the high speed behavior of a QPC, it can be integrated with a transmission line structure patterned on a photoconductive GaAs substrate. The nonlinear conductance of the QPC (due to the finite density of states of the conductors) can be examined and compared with recent theoretical studies. Samples are fabricated in situ using an electrochemical procedure to produce QPCs along the transmission line structure. This method may provide insight into Terahertz Optoelectronic devices and ultrafast communication systems.

[1]NSERC

4:18PM T12.00010 Improved Performance of Deterministic Lateral Displacement Arrays with Triangular Posts[1] , KEVIN LOUTHERBACK, KEVIN CHOU, Dept. of Electrical Engineering, JASON PUCHALLA, ROBERT AUSTIN, Dept. of Physics, JAMES STURM, Dept. of Electrical Engineering, Princeton University — Deterministic lateral displacement arrays have shown great promise for sized-based particle analysis and purification in medicine and biology. Here we demonstrate that use of an array of triangular rather than circular posts significantly enhances the performance of these devices by reducing clogging, lowering hydrostatic pressure requirements and increasing the range of displacement characteristics. Experimental data and theoretical models are presented to create a compelling argument that future designs of deterministic lateral displacement arrays should employ triangular posts

[1]This work was supported by the AFOSR (FA9550-05-01-0365), NIH (HG01506), and DARPA

4:30PM T12.00011 Hydrodynamic Trap for Single Cells and Particles[1] , MELIKHAN TANYERI, CHARLES SCHROEDER, University of Illinois at Urbana-Champaign — The ability to trap individual particles, cells and macromolecules has revolutionized many fields of science during the last two decades. Several methods of particle trapping and micromanipulation have been developed based on optical, magnetic and electric fields. In this work, we describe an alternative trapping method, the hydrodynamic trap, based on the sole action of hydrodynamic forces in a microfluidic device. A microfluidic cross slot device is fabricated consisting of two perpendicular microchannels where opposing laminar flow streams converge. In this device, a purely extensional flow field is created at the microchannel junction, thereby resulting in a semi-stable potential well at the stagnation point which enables particle trapping. We implement an automated feedback-control mechanism to adjust the location of the stagnation point which facilitates active particle trapping. Using the hydrodynamic trap, we successfully demonstrate trapping and manipulation of single particles and cells for arbitrarily long observation times. This technique offers a new venue for observation of biological materials without surface immobilization, eliminates potentially perturbative optical, magnetic and electric fields, and provides the capability to change the surrounding medium conditions of the trapped object.

[1]NIH Pathway to Independence (PI) Award, 4R00HG004183-03

4:42PM T12.00012 Control of Molecular Transport and Chemical Reaction Dynamics in Confined Volumes , PAT COLLIER, Oak Ridge National Laboratory — Understanding how confinement, crowding and reduced dimensionality modulate biochemical reactivity and reaction dynamics will aid in the discovery of functionality unique to nanoscale systems. Biochemical reaction kinetics in biomimetic reaction vessels with confined volumes present in microfabricated structures have been determined, including monitoring single-enzyme reaction kinetics in femtoliter-volume (10^{-15} L) chambers with millisecond mixing times, and the discovery and characterization of shear-induced redistribution of surfactant at the oil-water interface in femtoliter-volume droplets split off from larger aqueous plugs at a microfabricated T-junction, which resulted in increased interfacial adsorption of enzymes. The fabrication capabilities at the Center for Nanophase Materials Sciences at ORNL are extending these studies to nanoscale structures, interfaces and architectures, with the ability to control chemical reaction kinetics with precise spatiotemporal control of molecular/mass transport via integration with microfluidics.

4:54PM T12.00013 Cost effective fabrication method for microscaled interdigitated electrodes for fast 3D ACEO pumps , YEHYA SENOUSY, CINDY HARNETT, University of Louisville — Electro-osmotic pumping is a promising battery-powered replacement for traditional pumping systems at the micro scale when dilute electrolytes are used. To avoid the drawbacks of pumping using DC, "ac electro-osmotic" (ACEO) pumps have been recently introduced. The advantages over DC electro-osmotic pumps include lower operating voltages at integrated electrodes, and absence of gas generation from electrolysis. The microchannels of these ACEO pumps consisted first of asymmetric, planar electrodes. A non-planar ACEO pump geometry was then introduced with electroplated three dimensional (3D) stepped electrodes. This design had a faster flow rate than the planar ACEO pump by an order of magnitude, but the fabrication process was complex. In this paper, we demonstrate a new fabrication method for these 3D interdigitated microelectrode arrays. The method eliminates the need for electroplating thick 3D electrodes; instead 3D interdigitated electrodes are created by shadow evaporation of thin films on 3D structures that could be injection molded. The pumps were characterized for flow speed versus applied voltage amplitude and frequency.

5:06PM T12.00014 Interaction of thin-film microcoils with the air/water interface and applications in microfluidics , CINDY K. HARNETT, THOMAS M. LUCAS, JULIA W. AEBERSOLD, University of Louisville — Capillary forces at the air-water interface are widely regarded as a nuisance in fabricating micro- and nanoelectromechanical (MEMS/NEMS) devices, since the forces can pull suspended cantilevers permanently to the substrate. However, this phenomenon leads to interesting and potentially useful behavior with highly strained three-dimensional metal/oxide microcoils that can balance the capillary forces. These out-of-plane coiled filaments have typical curvature radii of 100 microns, but the fabrication technique scales from sub-10 nm to more than 1mm. Hydrophobic and hydrophilic self-assembled monolayers (SAMs), applied selectively to metal and oxide surfaces, enable fine control over the wettability of these structures. The resulting microcages and microtubes can contain nonpolar fluids (air, oils) in a polar fluid, or vice versa. Applications include controlled bubble capture for dry sample storage, quantification of the reaction rate of electrolytic reactions by detection of gas bubbles exceeding a threshold size, and confinement of liquids in porous microcontainers that enable diffusion of gaseous reactants.

5:18PM T12.00015 Development of an AFM-based hanging fiber rheometer for interfacial microrheology[1] , SHUO GUO, XIAOMIN XIONG, ZULI XU, PING SHENG, PENGER TONG, Department of Physics, Hong Kong University of Science and Technology — A new interfacial microrheology technique using atomic force microscope (AFM) as a force sensor is developed. The probe used for microrheology contains a long vertical glass fiber with one end glued onto a rectangular shaped cantilever beam and the other end immersed through a water-air interface. The motion of the modified cantilever can be accurately described by the Langevin equation for a damped harmonic oscillator, from which we obtain the friction coefficient ξ of the glass fiber in contact with the water. It is found that ξ contains two contributions. One is generated by the bulk fluid, which increases with the immersion length of the glass fiber. The other contribution comes from the contact line between the water-air interface and the glass fiber, which is obtained by a linear extrapolation of the measured ξ at the limit of zero immersion length. The experiment thus demonstrates an application of AFM in the studies of interfacial microrheology and contact line dynamics.

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

Thursday, March 18, 2010 8:00AM - 11:00AM –

Session V8 GSNP DFD: Spots, Stripes, and Turbulence Portland Ballroom 255

8:00AM V8.00001 Turbulent-Laminar Patterns in Pipes and Channels[1] , DWIGHT BARKLEY, University of Warwick — When fluid flows through a channel, pipe, or duct, there are two basic forms of motion: smooth laminar motion and complex turbulent motion. The discontinuous transition between these states is a fundamental problem that has been studied for more than 100 years. What has received far less attention is the large-scale nature of the turbulent flows near transition once they are established. We have carried out extensive numerical computations in pipes and channels to investigate the nature of transitional turbulence in these flow. We show the existence of three fundamentally different turbulent states separated by two distinct Reynolds numbers. In the case of pipe flow for example, below Re approximately 2200, turbulence takes the form of familiar equilibrium (or long-time transient) puffs. The turbulence is intensive – puffs are localized and the ratio of turbulent to laminar flow is not dictated by system size but by factors such as initial conditions. At $Re = 2200$ the flow makes a striking transition to extensive turbulence where the amount of turbulent flow scales with pipe length. The asymptotic state is an irregular (intermittent) alternation of turbulent and laminar flow whose complexity is inherent and does not result from random initial disturbances. Intermittency continues until $Re = 2500$ where the intermittency factor, and other measures, reveal a continuous transition to a state of uniform turbulence along the pipe. We argue that these states are a manifestation of universal large-scale structures in transitional shear flows.

[1]Centre for Scientific Computing, University of Warwick

8:36AM V8.00002 Laboratory measurements of Exact Coherent Structures in 2D and 3D Turbulence[1] , MICHAEL SCHATZ, Georgia Institute of Technology — Recent theoretical advances suggest ways to find unstable exact Navier Stokes solutions that capture many features of coherent structures, which have long been observed in turbulent flow. At present, it remains unknown whether these solutions, termed Exact Coherent Structures, can describe observations of turbulent flow in laboratory experiments. We describe experimental measurements of Exact Coherent Structures in two settings: (1) quasi-2D flows driven by electromagnetic forces and (2) shear-driven turbulence in circular Couette flow. In both cases, time series of velocity fields are obtained from images of the visualized flow. Analysis of velocity field data provides evidence for the existence of Exact Coherent Structures in the form of unstable fixed points and periodic orbits.

[1]Supported by NSF

9:12AM V8.00003 Homoclinic Snaking in Simple PDE Systems , JOHN BURKE, Boston University — Spatially localized structures occur in many systems of physical interest, and are often organized in a so-called "snakes-and-ladders" structure. In simple PDE systems this is a consequence of a related phenomena called homoclinic snaking. In recent years the Swift-Hohenberg equation has garnered much attention as the canonical model exhibiting this behavior. In this talk I will review the standard features of homoclinic snaking in the Swift-Hohenberg equation, and also discuss the generalization of these results to other simple PDE systems.

9:48AM V8.00004 Localized states in convective systems , EDGAR KNOBLOCH, University of California at Berkeley — Many fluid systems exhibit spatially localized structures in response to spatially homogeneous forcing. Such structures are examples of dissipative solitons and in convective systems are called convectons. This talk will focus on the origin and properties of convectons in binary fluid convection [1], i.e., a mixture of two miscible components heated uniformly from below. In this system the convectons come in two types, with odd and even parity. The convectons are located in parameter space in a region called the pinning region and are organized in the so-called snakes-and-ladders structure of this region [2]. This region also contains a variety of hole-like states as well as bound states of two or more convectons. The talk will describe this structure on large periodic domains and its modification in finite domains due to the suppression of concentration pumping across odd parity convectons [3]. The geometry responsible for this rich behavior implies applicability of the results to a wide variety of physical systems, including natural doubly diffusive convection, surface tension driven convection and shear flow instability, in addition to other pattern-forming systems.
[1] O. Batiste, E. Knobloch, A. Alonso, and I. Mercader, J. Fluid Mech. 560, 149 (2006)
[2] J. Burke and E. Knobloch, Chaos 17, 037102 (2007)
[3] I. Mercader, O. Batiste, A. Alonso and E. Knobloch, Phys. Rev. E 80, 025201(R) (2009)

10:24AM V8.00005 Localization and homoclinic snaking in plane Couette flow[1] , TOBIAS M. SCHNEIDER, Harvard University, SEAS — For linearly stable shear flows such as pipe and plane Couette flow exact equilibrium and traveling wave solutions of the Navier-Stokes equations have recently been shown to play key roles in the transition to turbulence and the turbulent dynamics itself. Until now such solutions have been computed only for small, spatially periodic domains. Here we examine a new class of spatially localized solutions to plane Couette flow. Under continuation in Reynolds number these solutions exhibit a sequence of saddle-node bifurcations strikingly similar to the "homoclinic snaking" phenomenon observed in the Swift-Hohenberg equation. The localized solutions originate from bifurcations off the spatially periodic equilibria discovered by Nagata and others and retain their physical structure, demonstrating the relevance of exact solutions to turbulent flows in spatially extended domains, where localized perturbations are observed to induce spatially localized patches of turbulence which slowly invade the surrounding laminar flow.

[1]In collaboration with John F. Gibson, GeorgiaTech and John Burke, Boston University.

Thursday, March 18, 2010 8:00AM - 11:00AM –
Session V11 DFD: Focus Session: Nonlinear Hydrodynamics of Swimming Cells A107-A109

8:00AM V11.00001 The hydrodynamics of chiral micro-swimmers , ERIC KEAVENY, SHAWN WALKER, MICHAEL SHELLEY, Courant Institute of Mathematical Sciences, New York University — Many species of bacteria utilize rotating rigid helical flagella to propel themselves in a low Reynolds number environment. Recent experiments demonstrate that artificial micro-swimming employing this kind of locomotion is realizable by using magnetic fields to rotate colloidal structures that possess chiral symmetry. We perform a series of numerical simulations to investigate the hydrodynamics of the helical shapes found in natural swimmers as well as those developed for artificial systems. We quantify the dependence of the rotation-translation coupling on the geometry of the swimmer and assess the hydrodynamic efficiency for different chiral shapes. From this analysis, we identify optimal shapes and provide insight into artificial micro-swimmer design.

8:12AM V11.00002 Paramecium swimming in a capillary tube , SAIKAT JANA, SUNGHWAN JUNG, Engineering Science & Mechanics, Virginia Tech — Micro-organisms exhibit different strategies for swimming in complex environments. Many micro-swimmers such as paramecium congregate and tend to live near wall. We investigate how paramecium moves in a confined space as compared to its motion in an unbounded fluid. A new theoretical model based on Taylor's sheet is developed, to study such boundary effects. In experiments, paramecia are put inside capillary tubes and their swimming behavior is observed. The data obtained from experiments is used to test the validity of our theoretical model and understand how the cilia influence the locomotion of paramecia in confined geometries.

8:24AM V11.00003 Experimental measurement of the flow field around a freely swimming microorganism , MARCO POLIN, KNUT DRESCHER, RAYMOND GOLDSTEIN, DAMTP, University of Cambridge, NICOLAS MICHEL, Ecole Polytechnique, IDAN TUVAL, DAMTP, University of Cambridge — Despite their small size, the fluid flows produced by billions of microscopic swimmers in nature can have dramatic macroscopic effects (e.g. biogenic mixing in the ocean). Understanding the flow structure of a single swimming microorganism is essential to explain and model these macroscopic phenomena. Here we report the first detailed measurement of the flow field around an isolated, freely swimming microorganism, the spherical alga Volvox, and discuss the implications of this measurement for other species.

8:36AM V11.00004 The nonlinear hydrodynamics of swimming cells , ERIC LAUGA, UCSD — No abstract available.

9:12AM V11.00005 Swimming Microorganisms in Gels , HENRY FU, VIVEK SHENOY, Brown University, CHARLES WOLGEMUTH, Universiy of Connecticut Health Center, THOMAS POWERS, Brown University — Many swimming microorganisms must move through viscoelastic fluids and gels. In this talk I focus on swimming through gels. First, unlike incompressible fluids, a gel can have compressional modes with relative motion between polymer and solvent fractions. In a continuum model for a gel, we show that compressibility can increase the swimming speed of Taylor's swimming sheet. The zero-frequency shear modulus of a gel requires altered boundary conditions on the swimmer. Second, many biological gels are heterogeneous on the lengthscale of swimming microorganisms, necessitating non-continuum models that treat the gel network and swimmer on equal footing. We show that a random network modeled as dilute, immobile spherical obstacles increases the average swimming speed of a Golestanian three-sphere swimmer.

9:24AM V11.00006 Model for hydrodynamic synchronization of beating cilia in a viscoelastic fluid , THOMAS POWERS, HENRY FU, Brown University — The synchronization of beating flagella or cilia is important for swimming microorganisms such as Chlamydomonas as well as transport processes such as the clearing of foreign bodies from the airway. Many of these situations involve Newtonian fluids, but some such as the airway involve viscoelastic fluids. A hypothesis currently under intense investigation is that hydrodynamic interactions between nearby beating cilia lead to synchronization. Theoretical studies of simple models consisting of orbiting spheres in Newtonian liquids show that the spheres lock phases when they are subject to suitable normal forces. This talk describes a theoretical study of how synchronization arises in viscoelastic fluids.

9:36AM V11.00007 Viscosity of suspension of swimming bacteria[1] , IGOR ARANSON, Argonne National Laboratory , ANDREY SOKOLOV, Princeton University — Measurements of the shear viscosity in suspensions of swimming *Bacillus subtilis* in free standing liquid films have revealed that the viscosity can decrease by up to a factor of seven compared to the viscosity of the same liquid without bacteria or with non-motile bacteria. The reduction in viscosity is observed in two complimentary experiments: one studying the decay of a large vortex induced by a moving probe and another measuring the viscous torque on a rotating magnetic particle immersed in the film. The viscosity depends on the concentration and swimming speed of the bacteria. The viscosity reduction is attributed to the effect of self- propulsion of swimming bacteria.

[1]The work was supported by the U.S. Department of Energy, Office of Basic Energy Sciences, Division of Materials Science and Engineering, under the Contract No. DE AC02-06CH11357.

9:48AM V11.00008 Flagellated bacteria trace out a parabolic arc under low shear condition , YONGTAE AHN, University of Vermont, SARA HASHMI, Yale University, SHARON WALKER, University of California, Riverside, JANE HILL, University of Vermont — The measurement and prediction of bacterial transport of bacteria in aquatic systems is of fundamental importance to a variety of fields such as groundwater bioremediation ascending urinary tract infection. The motility of pathogenic bacteria is, however, often missing when considering pathogen translocation prediction. Previously, we reported that flagellated E. coli can translate upstream under low shear flow conditions (Hill *et al.*, 2007). The upstream swimming of flagellated microorganisms depends on hydrodynamic interaction between cell body and surrounding fluid flow. In this study, we use a breathable microfluidic device to image swimming *E. coli* and *P. aeruginosa* at a glass surface under low shear flow condition. We find the dominant experimental variables that lead to upstream swimming are: fluid shear, bacterium velocity, and bacterium length. We will present data showing that the sum of forces and torques acting on a bacterium lead to them tracing out a parabolic arc as they turn into the flow to swim upstream.

10:00AM V11.00009 The Stampeding Crowd: Guiding Micro-Organisms in Microfabricated Environments[1] , GUILLAUME LAMBERT, ROBERT AUSTIN, Princeton University — Custom-made microstructures are used to influence the motion of micro-organisms. By exploiting the runs-and-tumble swimming dynamics of bacteria, we show that their motion can be rectified using asymmetric funnel-shaped structures [Galajda et al. J. Bact. 2007]. However, a large enough population of cells is able to chemotactically "escape" an array of funnel barriers by collectively modifying their chemical micro-environment[Liao and Lambert, Submitted 2009]. This invasion-like behavior relates to that of metastatic cancer cells: cells leave an initially confined environment to populate neighboring tissues. We extend the use of microstructured devices to the study of cancer cells motility. We use microscopic channels and funnel-shaped barriers to physically constrain and guide mammalian cells. Cells with different motility are inoculated inside the devices and their collective motion is studied. We find that the difference in cell motility between cancer cells at different stages of progression may be used to sort them. These studies could prove important to the understanding of the dynamics of tissue invasion and metastasis.

[1]Partially supported by and performance at CNF ECS-0335765, NBTC ECS-9876771, NSF PHY-0750323, NSERC.

10:12AM V11.00010 Hydrodynamic Synchronization in a Multiple-Paddle Model System[1] , BIAN QIAN, DAVID GAGNON, Brown University, HONGYUAN JIANG, Johns Hopkins University, THOMAS POWERS, KENNETH BREUER, Brown University — Hydrodynamic synchronization is important in many biological systems such as beating cilia and cell motility. Here we study a model problem, in which flexible paddles rotate in a viscous liquid. We examine a three-paddle system and show that, depending on the arrangement, paddles can exhibit either a periodic phase difference variation or converge to a synchronization state. The phase difference in the synchronized state is determined not only by the symmetry of the paddle but also by the paddles' relative position. Measurement of paddles' rotational speeds shows that the drag between paddles is minimized during synchronization. Theoretical approaches developed for two-paddle systems are extended to the current geometries, and numerical simulations, using the method of regularized stokeslets, are also used to explore the dynamics of multiple paddle systems.

[1]Supported by NSF

10:24AM V11.00011 Swimming bacteria power microscopic gears[1] , ANDREY SOKOLOV, Princeton University, IGOR ARONSON, Argonne National Laboratory, MARIO APODACA, BARTOSZ GRZYBOWSKI, Northwestern University — While the laws of thermodynamics prohibit extraction of useful work from the Brownian motion of particles in systems at equilibrium, under non-equlibrium conditions their motions can be "rectified", for example, in the presence of asymmetric geometrical obstacles. We describe a class of systems in which aerobic bacteria *Bacillus subtilis* moving randomly in a fluid film power submillimeter gears and primitive systems of gears decorated with asymmetric teeth. The directional rotation is observed only in the regime of collective bacterial swimming and the gears' angular velocities depend on and can be controlled by the amount of oxygen available to the bacteria. The ability to harness and control the power of collective motions appears an important requirement for further development of mechanical systems driven by microorganism.

[1]U.S. Department of Energy, Office of Basic Energy Sciences, Division of Materials Science and Engineering, under the Contract No. DE-AC02-06CH11357.

10:36AM V11.00012 Fluid Mixing by Active particles , NIDHI KHURANA, JERZY BLAWZDZIEWICZ, NICHOLAS T. OUELLETTE, Yale University — For systems with low Reynolds number, mixing is efficient only via chaotic advection. We investigate the dynamics of active particles suspended in chaotic two-dimensional, incompressible fluid flows. The spheroidal particles have their own intrinsic velocity and they strongly affect the bulk mixing dynamics. We observe that swimmers break transport boundaries in the flow that fluid elements could not cross. We also show that in some limits, swimming can lead to interesting phenomena like particle trapping and formation of patterns.

10:48AM V11.00013 The fidelity of adaptive phototaxis , KNUT DRESCHER, IDAN TUVAL, RAYMOND GOLDSTEIN, DAMTP, University of Cambridge — Along the evolutionary path from single cells to multicellular organisms with a central nervous system are species of intermediate complexity which move in ways suggesting high-level coordination, yet have none. Instead, organisms within this category possess many autonomous cells which are endowed with programs that have evolved to achieve concerted responses to environmental stimuli. We examine the main features of the program underlying high-fidelity phototaxis in colonial algae which spin about a body-fixed axis as they swim. Using micromanipulation and particle image velocimetry of flagella-driven flows in *Volvox carteri*, we show that there is an adaptive response at the single-cell level that displays a pronounced maximum in its frequency dependence for periodic light signals. Moreover, the natural rotational frequency of the colony is tuned to match this optimal response. A hydrodynamic model of phototactic steering further shows that the phototactic ability decreases dramatically when the colony does not spin at its natural frequency, a result confirmed by phototaxis assays in which colony rotation was slowed by increasing the fluid viscosity.

Thursday, March 18, 2010 8:00AM - 11:00AM –
Session V12 DFD: Colloidal Particles and Clusters B110-B111

8:00AM V12.00001 Optical trapping of small particles: The breakdown of the ray optics regime , RACHAEL HARPER, ALEX LEVINE, University of California, Los Angeles — Laser trapping, or the manipulation small particles by a highly focused light beam, is now a ubiquitous experimental technique. The understanding of how forces on these particles are generated by their interaction with the light beam was developed by Ashkin in the context of geometric optics. However, recent experiments [1] on the laser trapping of dielectric particles having complex shapes and characteristic dimensions in the micron range suggest that the geometric optics based theory is inadequate. Solving the ray optics problem for a variety of complex particle shapes and comparing to the experiments of Ref. [1], we explore the limits of the ray optics based theory. Using a combination of numerics and analytic calculations in the physical optics regime, we extend the theory of optical trapping to the case where at least some of the dimensions of the particles are smaller than the wavelength of the light. By using these calculations, one can design particle shapes to program their dynamics in the light field, creating spinners and gliders, as well as particles that can and cannot be trapped. [1] JN Wilking, TG Mason, Europhys Lett, 81, 58005 (2008).

8:12AM V12.00002 Multidimensional optical fractionation with holographic verification , KE XIAO, DAVID GRIER, Center for Soft Matter Research, New York University — Colloidal particles driven through a periodic potential energy landscape can become kinetically locked in to symmetry-selected directions. The path a given particle follows has been predicted to depend sensitively on such properties as the particle's size and refractive index. These predictions, however, have not been tested experimentally. We present experimental observations of colloidal silica spheres' trajectories through specially structured arrays of holographic optical traps, using quantitative methods of holographic video microscopy to track the particles' motions in three dimensions and simultaneously to measure their radii and refractive indexes with part-per-thousand resolution. Single-particle tracking and characterization enable us to demonstrate sorting of colloidal particles into spatially separated fractions with part-per-thousand resolution in either particle size or refractive index. Even more dramatically, these results agree quantitatively with previously untested predictions for the threshold of kinetically locked-in transport.

8:24AM V12.00003 Dielectrophoresis Force of PMMA Colloidal Clusters , HYUNJOO PARK, New York University, MING-TZO WEI, H. DANIEL OU-YANG, Lehigh University, DAVID PINE, New York University — DEP has long been applied to be a means for manipulating and separation of colloidal subjects. Here, we report quantitative analysis of DEP force under controlled parameters has been missing due to the difficulty in the direct measurements of the forces. Using IR laser to trap an individual colloidal cluster in a DEP field and to function as a pico-Newton force sensor, we were able to measure the frequency dependent DEP force for PMMA colloidal clusters with different aggregation number (n). We found that the crossover frequencies decrease with increasing size and follow a power-law dependence R^{-2} where R is the effective radius of the clusters.

8:36AM V12.00004 Measurement of barrier potentials between colloidal particles and liquid-liquid interfaces , DAVID KAZ, RYAN MCGORTY, VINOTHAN MANOHARAN, Harvard University — We measure the repulsive barrier between micron-sized colloidal particles and liquid-liquid interfaces. Particles of polystyrene and silica (suspended in water/glycerol) are confined individually to an optical trap, and translated towards an interface between the aqueous phase and an oil (decane) phase. We fit holographic micrographs of the particles to Lorentz-Mie theory to calculate the positions of the particles within the trap, including axial displacement. Since the force between a particle and the interface is directly related to the particle's displacement from the trap center, we are able to measure the particle-interface repulsion. We compare the force profiles with those predicted by DLVO theory resulting from "image charges" in the oil phase.

8:48AM V12.00005 Formation of colloidal-particle "tails" at oil/water interfaces[1] , KAN DU, Univ. Massachusetts Amherst, Dept. of Physics, T. EMRICK, T.P. RUSSELL, Univ. Massachusetts Amherst, Dept. of Polymer Sci. Eng., A.D. DINSMORE, Univ. Massachusetts Amherst, Dept. of Physics — The spontaneous assembly of microparticles at liquid interfaces is a well known and commonly observed process. Here we report a surprising phenomenon that occurs when the interfacial microparticles are displaced by nanoparticles. We used 2.1-um-diameter polystyrene particles, functionalized with amidine, which assemble at the surface of a fluorohexane droplet in water. The particles are strongly bound, with an adsorption energy of 0.9×10^6 k_BT per particle. Then, 4.5-nm-diameter gold nanoparticles, stabilized with (1-mercaptoundec-11-yl)tetra(ethylene glycol) ligand are added to the suspension. The nanoparticles assemble at the interface, lowering the interfacial tension and displacing the microparticles. As the microparticles desorb, they flow along the droplet's surface and form a tail-like structure that flows into the solution. The tails are a few microns in diameter and flow a distance of several cm before disappearing from view. We discuss the desorption of the microparticles and the role of hydrodynamic flow and particle interactions in the formation and stability of the tails.

[1]We acknowledge support from the NSF through NIRT CTS-0609107 and the UMass MRSEC on Polymers (DMR-0820506).

9:00AM V12.00006 Capillary interactions among colloidal spheres at a curved liquid interface , CHUAN ZENG, UMass Amherst, F. BRAU, Universite de Mons, B. DAVIDOVITCH, A. D. DINSMORE, UMass Amherst — Colloidal particles tend to adsorb on liquid interfaces, where in-plane interactions can arise from a variety of mechanisms. We focus on capillary interactions induced by the curvature of the liquid interface, where particles were assumed to have a constant Young-Laplace contact angle at the three-phase contact line. Whereas spherical particles can adsorb on flat or spherical interfaces without deforming the interface, we predict that adsorption on a cylindrical interface deforms the interface because of the lack of azimuthal symmetry around the contact line. We present an analytical model of the interfacial shape and energy upon adsorption of single particle as well as the interaction between two particles. Long-range deformation of interface was found from the solution of a partial differential equation based on constant mean curvature of the interface. The binding energy will be discussed as well as interactions between particles. The results will be compared to predictions of a simpler model that assumes a nearly flat interface near the adsorbed sphere. This study provides an important step toward understanding the interactions among interfacial particles when the interface is distorted by an external field. We acknowledge support from the NSF-supported MRSEC on Polymers at UMass (DMR-0820506).

9:12AM V12.00007 Dynamics of colloidal particles sticking to an oil-water interface , RYAN MCGORTY, Harvard University, Physics Department, D. M. KAZ, V. N. MANOHARAN — We observe micron sized colloids as they adsorb to an oil-water interface. We make a flat oil-water interface and can use an optical trap to bring particles from either phase to the interface. Using digital holographic microscopy, colloids are tracked as they encounter and stick to the interface. We observe particles slowly adsorbing to the interface over the course of seconds. We also observe the dynamics of stuck particles and track their out-of-plane motion.

9:24AM V12.00008 Critical Casimir Effect provides novel Control of Colloidal Interactions , PETER SCHALL, University of Amsterdam — The Casimir Effect is a celebrated phenomenon in quantum physics. It manifests itself as the effective attraction between two dielectrics brought close to each other to confine fluctuations of the electromagnetic field. A similar force arises between two surfaces in a liquid mixture close to its critical point: Confinement of critical fluctuations of the liquid results in an attractive force between the walls, when the wall separation is of the order of the correlation length of the liquid. We use this effect for a fine control of colloidal interactions. The temperature dependence of the correlation length allows us to 'freeze' a colloidal gas into a colloidal liquid, and a liquid into a solid. This offers novel opportunities for the assembly of micro- and nanomaterials. I will present recently developed optically transparent systems that allow use of conventional light scattering and confocal microscopy to study Critical Casimir-mediated particle assembly.

9:36AM V12.00009 Elastic Excitations in Colloidal Crystals Confined in an Emulsion Droplet , N.L. GREEN, Department of Chemical Engineering, MARGAUX GUICHE, Department of Materials Science & Engineering, C.E. MALONEY, Department of Civil & Environmental Engineering, M.F. ISLAM, Department of Chemical Engineering and Department of Materials Science & Engineering, Carnegie Mellon University, Pittsburgh, PA 15213 — We confine colloidal crystals in emulsion droplets and study the lattice dynamics using video microscopy. The colloids are temperature-sensitive spherical microgels; the diameter of the microgel particles and hence the volume fraction of the crystal can be changed by tuning the temperature. We measure the vibrational modes in this system as a function of volume fraction and degree of confinement. Finally, we compare our measurements to simulations on vibrational modes in crystal drops. This work has been partially supported by the NSF through Grants DMR-0619424 and DMR-0645596, by ACS-PRF, and by the Alfred P. Sloan foundation.

9:48AM V12.00010 Lock and Key Colloids through Polymerization-Induced Buckling of Monodispersed Silicon Oil Droplets[1] , STEFANO SACANNA, WILLIAM T.M. IRVINE, PAUL M. CHAIKIN, DAVID J. PINE, NYU — Colloidal particles can spontaneously associate into larger structured aggregates when driven by selective and directional interactions. Colloidal organization can be programmed by engineering shapes and interactions of basic building blocks in a manner similar to molecular self-assembly. Examples of successful strategies that allow non-trivial assembly of particles include template-directed patterning, capillary forces and, most commonly, the functionalization of the particle surfaces with "sticky patches" of biological or synthetic molecules. The level of complexity of the realizable assemblies, increases when particles with well defined shape anisotropies are used. In particular depletion forces and specific surface treatments in combination with non spherical particles have proven to be powerful tools to self-assembly complex microstructures. We describe a simple, high yield, synthetic pathway to fabricate monodisperse hybrid silica spheres with well defined cavities. Because the particle morphologies are reproducible and tunable with precision, the resulting particles can be used as basic building blocks in the assembly of larger monodisperse clusters. This is demonstrated using depletion to drive the self-assembly.

[1]S. Sacanna was supported by the Netherlands Organization for Scientific Research (NWO) through a Rubicon fellowship.

10:00AM V12.00011 Rational Self-Assembly of Nano-Colloids using DNA Interaction , MARIE T. UNG, RAYNALDO SCARLETT, TALID R. SINNO , JOHN C. CROCKER, Department of Chemical and Biomolecular Engineering, University of Pennsylvania, Philadelphia, PA — DNA is an attractive tool to direct the rational self-assembly of nano-colloids since its interaction is specific and reversible. This tunable attractive interaction should lead to a diverse and rich phase diagram of higher ordered structures which would not otherwise be entropically favored.[1] We compare our latest experimental observations to a simulation framework that precisely replicates the experimental phase behavior and the crystal growth kinetics.[2] We will discuss the crystallography of novel structures and address how particle size and heterogeneity affect nucleation and growth rates.

[1]Tkachenko AV, Morphological Diversity of DNA-Colloidal Self-Assembly, Phys. Rev. Lett 89 (2002)

[2]Kim AJ, Scarlett R., Biancaniello PL, Sinno T, Crocker JC, Probing interfacial equilibration in microsphere crystals formed by DNA-directed assembly, Nature Materials 8, 52-55 (2009)

10:12AM V12.00012 Getting a grasp of sticky ends: numerical simulations of DNA-mediated particle interactions , MIRJAM LEUNISSEN, AMOLF/University of Cambridge, DAAN FRENKEL, University of Cambridge — We will present the results of a Monte Carlo model for particles functionalized with short, rigid DNA constructs. We determine the dependence of the particle-particle interaction on the DNA grafting density, the binding strength of the sticky ends and the size of the beads, and predict the resulting phase behavior. We will also highlight the unique entropic costs and gains associated with the hybridization of tethered sticky ends and we will give some guidelines for experiments aimed at the DNA-mediated self-organization of micro- and nano-particles.

10:24AM V12.00013 Different modulation mechanisms of attractive colloidal interaction by lipid and protein functionalization , YUPENG KONG, RAGHUVEER PARTHASARATHY, Department of Physics, University of Oregon — The nature of attractions observed between like-charged colloidal particles near a confining wall is still mysterious, due in part to the lack of experimental systems with tunable interparticle interactions. Biomembranes are appealing candidates for colloidal functionalization, enabling access to electrostatic and chemical properties that influence inter-particle relations. We have generated two classes of particles, derivatized with lipid-only and lipid-plus-protein membranes, each of which show attractive pair interactions whose magnitude can be tuned over a range of about $1 k_B T$. However, the two particle types exhibit profoundly different correlations between the depth of the attractive potential well and the spatial range of the interaction as well as between well depth and distance to the confining wall. This indicates that separation from the wall is not the decisive determinant of like-charge attraction and, more importantly, that there may be more than one mechanism responsible for observed attractive phenomena.

10:36AM V12.00014 Direct measurement of modified drag coefficient for a colloidal particle near flat walls , CHUNGIL HA, Lehigh University, HYUK KYU PAK, Pusan National University, H.D. OU-YANG, Lehigh University — For colloidal particles, the Stokes drag force is well known for particles in a virtually infinite reservoir of quiescent fluid, since boundary effects can drastically alter drag on the particle. To investigate the effects of a physical boundary on the drag force, we directly measured the hydrodynamic drag exerted on a particle for two different cases; near a single flat wall and sandwiched between two flat walls. Measurements of drag coefficients were made using a calibrated oscillating optical tweezer composed of two lasers, one for trapping and one for particle tracking. A lock-in amplifier used to detect the harmonically modulated particle motion allowed us to isolate the response of the particle to the tweezers force against the effects of Brownian motion. Results of measured drag coefficients are presented for both the single and two-wall cases as a function of particle separation from the wall, and are compared to the expected results from the rigorous hydrodynamic flow calculations.

10:48AM V12.00015 Shear-Induced Rotation of Axisymmetric Particles in Poiseuille Flow in the Electric Field[1] , MARIJA NIKOLIC-JARIC, DOUGLAS J. THOMSON, GREG E. BRIDGES, GRAHAM A. FERRIER, University of Manitoba, Dept. of Electrical Engineering — Rotation of axisymmetric ellipsoidal particles in a slow viscous flow with uniform shear is described by Jeffery orbits; spherical models for biological particles and cells ignore this effect. We investigate fundamental aspects of Jeffery rotation and its effects on the change of impedance associated with a particle passing over a pair of coplanar electrodes in a microfluidic channel. Periodically changing orientation of a rotating non-spherical particle as it passes the electrodes results in impedance anisotropy and a varying signal amplitude. This periodic variation places limits on the uncertainty in flow impedance detection of axisymmetric model particles and biological cells. Conversely, calculations of Jeffery orbits predict that the period of these variations will yield estimates of the ellipticity of a single cell, an outcome that can be exploited in studies of composition, cycles and kinetics of a wide variety of biological cells in a short period of time. This work will lead to the ability to better discriminate between the particles exclusively on the basis of the electrical signal, vital to highly integrated lab-on-chip applications.

[1]This work supported in part by the M. Hildred Blewett Scholarship of the APS (www.aps.org), NSERC, and NINT.

Thursday, March 18, 2010 11:15AM - 2:03PM –

Session W12 DFD: Foams and Suspensions B110-B111

11:15AM W12.00001 Rheology of a dilute suspension of cubic nanoparticles , RAJESH KUMAR MALLAVAJULA, DONALD KOCH, LYNDEN ARCHER, School of Chemical and Biomolecular Engineering, Cornell University — The rheological properties of suspensions of Brownian cube-shaped particles are interesting because of the greater increase in the translational freedom caused by layering relative to suspensions of Brownian spheres. As a first step toward understanding suspensions of these particles, we present theoretical (multipole and finite element) solutions of simple shear flow around an isolated cube and use this solution to obtain the intrinsic viscosity. The stress stress-strain-rate relationship is anisotropic with different particle stresslets when the extensional axis is parallel to an axis or a diagonal of the cube. The suspension viscosity, μ_{eff}, in the limit of zero shear rate can be obtained as an isotropic orientational average, yielding a prediction $\mu_{eff} = \mu(1+5.45\phi)$ where ϕ is the particle volume fraction and the coefficient 5.45 is the intrinsic viscosity, [η] of the cube. The calculated [η] for cubes is therefore more than twice that computed by Einstein, [η] = 2.5, for spheres. To evaluate our prediction, we have synthesized cube-shaped Fe_3O_4 particles and characterized their rheological properties in dilute suspensions.

11:27AM W12.00002 Hydrodynamic Interaction of Colloid Suspension in Ribbon Channels[1] , BINHUA LIN, SERGEY NOVIKOV, STUART A. RICE, University of Chicago — We report the results of an experimental study of hydrodynamic interaction in colloid suspensions that are intermediate between quasi-one-dimensional (q1D) and quasi-two-dimensional (q2D) systems. Specifically, the systems examined are one-layer deep colloid suspensions confined in ribbon channels with widths from one to twelve particle diameters. The current research follows up our earlier studies of the structure of q1D ribbon colloid suspension as a function of the ribbon width, of pair diffusion in single-file q1D channels and planar q2D colloid suspensions. Given the stratification of the density distribution transverse to the ribbon channel, the pair diffusion coefficient within one stratum behaves as if the colloids are confined in a single-file q1D channel, and the diffusion coefficient does not vary from stratum to stratum across the channel. When the stratification of the transverse density distribution in the ribbon channel is disregarded, the pair diffusion coefficient for the confined suspension differs from that in an infinite q2D suspension.

[1]This work was supported by the University of Chicago MRSEC program of the NSF (DMR-0820054), and by ChemMatCARS, which is supported by NSF/DOE under Grant No. CHE-0822838.

11:39AM W12.00003 Jamming of Solid-Stabilized Emulsions , SUJIT DATTA, Department of Physics, Harvard University, KOSTA LADAVAC, RODRIGO GUERRA, DAVID WEITZ — Emulsions – metastable suspensions of droplets of one fluid dispersed within another – can be concentrated over a wide range of volume fractions, due to droplet deformability. Here, we study the rheological properties of solid-stabilized (versus surfactant-stabilized) emulsions over a range of volume fractions. These experiments allow us to explore the role of interfacial effects in determining bulk mechanical behavior, potentially yielding further insight into the elasticity of jammed emulsions.

11:51AM W12.00004 ABSTRACT WITHDRAWN –

12:03PM W12.00005 Liquid organic foams for formulation optimization: an assessment of foam linear viscoelasticity and its temporal dependence , JAMIE KROPKA, LISA MONDY, MAT CELINA, Sandia National Labs — Liquid foams are viscoelastic liquids, exhibiting a fast relaxation attributed to local bubble motions and a slow response due to structural evolution of the intrinsically unstable system. In this work, these processes are examined in unique organic foams that differ from the typically investigated aqueous systems in two major ways: the organic foams (1) posses a much higher continuous phase viscosity and (2) exhibit a coarsening response that involves coalescence of cells. The transient and dynamic relaxation responses of the organic foams are evaluated and discussed in relation to the response of aqueous foams. The change in the foam response with increasing gas fraction, from that of a Newtonian liquid to one that is strongly viscoelastic, is also presented. In addition, the temporal dependencies of the linear viscoelastic response are assessed in the context of the foam structural evolution. These foams and characterization techniques provide a basis for testing stabilization mechanisms in epoxy-based foams for encapsulation applications. Sandia is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under Contract DE-AC04-94AL85000.

12:15PM W12.00006 Characterization of Intermittent and Continuous Dynamics in Jammed Aqueous Foam , SAM STANWYCK, MICHAEL FOLKERTS, OLEG SHPYRKO, UC San Diego — We use optical laser diffraction in a multi-speckle detection scheme to investigate the mesoscale dynamics in aqueous foam. Using linear correlation and time-resolved correlation, we are able to analyze the slowing down of the rate of bubble rearrangement events during foam aging. We introduce Temporal Contrast Analysis, a novel statistical tool for analyzing these dynamics. Using Temporal Contrast Analysis we are able to show that there are two distinct dynamical components present in the foam: intermittent, avalanche-like dynamics and continuous, flow-like dynamics. We are able to separate these two components from each other and from the intrinsic statistical noise contribution, and independently analyze the slowing down of each component with age.

12:27PM W12.00007 The Search for Precursor and Aftershock Dynamics in Aqueous Foam , MICHAEL M. FOLKERTS, SAMUEL W. STANWYCK, OLEG G. SHPYRKO, Department of Physics, University of California, San Diego — We probe the dynamics of an aqueous foam sample using optical photon correlation spectroscopy. Using a multi-speckle detection scheme to record the changes in a coherent laser speckle pattern, we gain insight into the nature of the dynamics in the foam during the aging process. We introduce Temporal Contrast Analysis, an approach that couples to intermittent, "avalanche"-like events, and enables us to study the magnitude, duration and temporal spacing of such events. We will discuss the application of Temporal Contrast Analysis to search for precursor and aftershock events that precede or succeed major structural rearrangements in the foam.

12:39PM W12.00008 Structural Inhomogeneities in a Dense Emulsion[1] , S. K. DUTTA, E. D. KNOWLTON, D. L. BLAIR, Department of Physics, Georgetown University — A dispersion of emulsion droplets under a shear stress near the jamming transition can be characterized by the distribution of contact forces between neighboring drops. Due to the inherent structural disorder, we expect that during flow, the motion of the particles is highly spatially correlated. We directly access these quantities in a dense oil-in-water emulsion by determining the magnitude and location of deformations on individual droplets. We perform measurements on a dense polydisperse emulsion using a customized confocal rheometer which is capable of simultaneously acquiring three-dimensional images and measuring the bulk viscoelastic properties of a sample with a precise shear.

[1]This work is funded by the NSF through Grant DMR: 0847490.

12:51PM W12.00009 Coarsening in Two Dimensional Foams , ADAM ROTH, University of Pennsylvania, CHRISTOPHER JONES, DOUGLAS DURIAN, University of Pennsylvania — Coarsening in two dimensional foams is governed by Von Neumann's law, which relates rate of change of size of a bubble to its number of sides. We have built an apparatus that allows us to measure individual bubble statistics, such as area and number of sides, as they coarsen. We can also control the liquid fraction of the foam, which allows us to control the rate of coarsening. We observe correspondence to Von Neumann's law except for a deviation for small bubbles. Small bubbles are observed to coarsen more slowly than expected based on the number of sides. This effect is due to increased local liquid fraction contributed by the Plateau borders.

1:03PM W12.00010 Structure and dynamics of a coarsening emulsion[1] , KLEBERT FEITOSA, Dept. of Chemical and Biomolecular Engineering, University of Pennsylvania, JOHN CROCKER, Dept. of Chemical and Biomolecular Engineering. University of Pennsylvania — We investigate the structure and dynamics of a non-aqueous coarsening emulsion. The experiment is performed on an index and density matched emulsion prepared by homogenization with droplets occupying approximately 80% of the volume fraction. Three dimensional visualizations of the droplets are obtained by fluorescent confocal microscopy at different time intervals as the emulsion coarsens. We find that the droplet size distribution matches a Weibull distribution. The pair coordination function as a function of droplet core size shows a peculiar liquid structure where small droplets fill the interstices between big ones. While we observe self similar behavior in droplet growth, the evolution of the droplet size distribution departs from that predicted by mean field theory.

[1]NSF-DMR

1:15PM W12.00011 Critical transition in fiber suspension , ALEXANDRE FRANCESCHINI, 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 — A single buoyant fiber in a low Reynolds shear flow has a fully determined motion, so-called Jeffery orbit. However, the behavior of a concentrated fiber suspension remains unclear; even slight interactions between objects can disturb the system [1]. The non-reversible motion of the fiber suspension in oscillatory flow is monitored with a) quantitative image analysis and b) measurement of the in-phase torque response. A dynamical phase transition from a quasi-reversible state to a fluctuating one is observed as the strain amplitude is increased over a threshold at which the transient time exhibits a power law divergence. We discuss here the nature of this transition and its universality class. The main features of this transition are consistent with earlier results on sphere suspensions [2, 3], such systems might be one of the few realizations of conserved directed percolation [4].

[1] Okagawa A and al, Science, Volume 181, Issue 4095, p159 (1973)
[2] Pine DJ and al, Nature, vol 438, Issue 7070, p997 (2005)
[3] Corte L and al, Nature physics, vol 4, Issue 5, p420 (2008)
[4] Menon GI and al, PrE, vol 79, 061108 (2009)

1:27PM W12.00012 Viscous properties of aluminum oxide nanotubes and aluminium oxide nanoparticles - silicone oil suspensions[1] , RAM THAPA, STEVEN FRENCH, ADRIAN DELGADO, CARLOS RAMOS, JOSE GUTIERREZ, MIRCEA CHIPARA, KAREN LOZANO, The University of Texas - Pan American — Electrorheological (ER) fluids consisting of γ-aluminum oxide nanotubes and γ-aluminum oxide nanoparticles dispersed within silicone oil were prepared. The relationship between shear stress and shear rate was measured and theoretically simulated by using an extended Bingham model for both the rheological and electrorheological features of these systems. Shear stress and viscosity showed a sharp increase for the aluminum oxide nanotubes suspensions subjected to applied electric fields whereas aluminum oxide nanoparticles suspensions showed a moderate change. It was found that the transition from liquid to solid state (mediated by the applied electric field) can be described by a power law and that for low applied voltages the relationship is almost linear.

[1]This material is based on research sponsored by Air Force Research Laboratory under agreement number FA8650-07-2-5061.

1:39PM W12.00013 Exploring the phase behavior of microgel suspensions with Neutron Scattering and Hydrostatic Pressure , JUAN-JOSE LIETOR-SANTOS, Georgia Institute of Technology, URS GASSER, Laboratory for Neutron Scattering, ETH, Zurich and Paul Scherrer Institute, 5232, Villingen, PSI, Switzerland, ALBERTO FERNANDEZ-NIEVES, Georgia Institute of Technology — Gels are crosslinked-polymeric networks immersed in a solvent, whose size is sensitive to changes in environmental properties such as temperature, pH or light. Microgels are gels in the colloidal domain. The intrinsic particle elasticity allows microgel suspensions to display a very rich phase behavior as opposed to a system of hard spheres in which liquid, crystal and glassy phases are observed depending solely on the volume fraction of the particles. We study the phase behavior of microgel suspensions varying the volume fraction of the system by using the swelling properties of the particles, which we tune using hydrostatic pressure; the use of pressure allows fast particle size changes that occur homogeneously throughout the sample. To characterize the structural and dynamical properties of the system we use Light and Small Angle Neutron Scattering. We observe formation of crystal and glassy phases, reminiscent of the behavior of colloidal hard spheres. However, our data seems to suggest that the suspension polydispersity changes with particle volume fraction; through these changes, the system manages to crystallize and forms glasses with unusual structural features.

1:51PM W12.00014 Influence of Boundary Mobility on the Dynamics of Confined Colloidal Suspensions , GARY L. HUNTER, KAZEM V. EDMOND, ERIC R. WEEKS, Emory University (Physics) — We use fast confocal microscopy to study the influence of interfacial mobility and confinement on the dynamics of dense colloidal suspensions. Experiments on confined molecular super-cooled liquids have shown that hard/immobile boundaries result in an increase in relaxation times relative to bulk measurements, whereas soft/mobile boundaries lead to a decrease in relaxation times. We confine suspensions of PMMA microspheres within emulsion droplets of different sizes, thereby probing the consequences of confinement. By changing the viscosity of the external, continuous phase, we also control the interfacial mobility of our samples. In this way, we separate the two effects and draw comparisons between mobility within colloidal suspensions and molecular liquids.

Thursday, March 18, 2010 2:30PM - 5:30PM –

Session X12 DFD: General Fluid Mechanics: Surface and Thermal Effects B110-B111

2:30PM X12.00001 Watching heat flow near a nucleating bubble , SCOTT PARKER, DAVID CAHILL, STEVE GRANICK, University of Illinois, Department of Materials Science and Engineering — When a liquid boils on surface, heat must flow out of the solid substrate and into both the nucleating bubble and the fluid surrounding the bubble. We have developed a high speed thermal imaging technique to observe the spatial distribution of the temperatures on functionalized surfaces in contact with water. This system is used to observe temperatures while growing individual vapor bubbles from a local hot spot on the surface. By varying the average surface temperature and fluid pressure, we tune the growth of the bubble. We report on how the static contact angle and local curvature of a bubble near the surface affect localized heat transfer and the corresponding bubble dynamics.

2:42PM X12.00002 Fluctuations of interfacial forces near a moving contact line[1] , YONGJIAN WANG, SHUO GUO, PING SHENG, PENGER TONG, Department of Physics, Hong Kong University of Science and Technology — Atomic force microscope (AFM) is used as a force sensor to measure the capillary forces on a long vertical glass fiber with one end glued onto a rectangular shaped cantilever beam and the other end immersed through a liquid-air interface. Using a cleaned glass fiber of $\sim 2\mu$m in diameter, we were able to determine the surface tension of a class of liquids with good accuracy. For this class of liquids, no detectable hysteresis is found when the contact line between the liquid and glass fiber moves at a constant speed. The AFM force measurements, however, revealed considerable fluctuations in the force amplitude. The probability density function of the force fluctuations all shows a Gaussian form. Investigations are carried out to find the relationship between the mean squared value of force fluctuations and the chemical properties of the liquid.

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

2:54PM X12.00003 Slip boundary conditions for the moving contact line in molecular dynamics and continuum simulations , ANOOSHEH NIAVARANI, NIKOLAI PRIEZJEV, Michigan State University — The problem of the moving contact line between two immiscible fluids on a smooth surface is revisited using molecular dynamics (MD) and continuum simulations. In MD simulations a finite slip is allowed by choosing incommensurate wall-fluid densities and weak wall-fluid interaction energies. The shear stresses and velocity fields are extracted carefully in the bulk fluid region as well as near the moving contact line. In agreement with previous studies, we found slowly decaying partial slip region away from the contact line. In steady-state shear flows we extract the friction coefficient along the liquid-solid interface, the local slip length, and the dynamic contact angle. The MD results show that both dynamic contact angle and slip velocity near the contact line increase with increasing the capillary number (Ca). Also, at high Ca the break up of fluid-fluid interface is observed. The slip boundary conditions near the moving contact line extracted from MD simulations were then used in the continuum solution of the Navier-Stokes equation in the same geometry to reproduce velocity profiles and the shape of the fluid-fluid interface.

3:06PM X12.00004 Sub-Micron Velocity Measurements near a Moving Contact Line , JEREMIAH ZIMMERMAN, MARK M. WEISLOGEL, DEREK C. TRETHEWAY, Portland State University — The displacement of one fluid by an immiscible second fluid (i.e. dynamic wetting), governs many natural and technological processes. Despite extensive studies, understanding and modeling the displacement process remains one of the outstanding problems in fluid mechanics. In this work, we explore the physics of the moving contact line (the idealized line of intersection between two fluids and a solid) with micron resolution particle image velocimetry (μPIV), which enables sub-micron two-dimensional velocity measurements. The measured flow is generated by dynamic wetting in a glass microchannel. The microchannel is mounted on an automated microscope stage with precise velocity control allowing for the static placement of the contact line within the field of view. Full-field velocity measurements within 1 μm of the contact line were made in water/glycerol and fructose/glucose/water solutions. Preliminary results appear to show remarkable similarity to controversial theoretical predictions.

3:18PM X12.00005 Drop Impact on Superhydrophobic Electrospun Nanomats[1] , ALEXANDER YARIN, University of Illinois at Chicago, ANDREAS LEMBACH, ILIYA ROISMAN, TATIANA GAMBARYAN-ROISMAN, CAMERON TROPEA, PETER STEPHAN, Center for Smart Interfaces, Technische Universität Darmstadt, Germany — Experiments were conducted to study peculiarities of drop impact on electrospun polymer nanofiber mats. The nanofiber cross-section diameters were of the order of several hundred nanometers, the pore sizes in the mats of about several microns. Polymers which are partially wettable by water, and non-wettable by water were used to electrospin nanofiber mats. The experiments revealed that drop impacts on nanotextured surfaces of nanofiber mats produce spreading similar to the one on impermeable surfaces. However, at the end of the spreading stage the contact line is pinned and drop receding and bouncing is completely prevented. At higher impact velocities, prompt splashing events with formation of tiny drops were observed. It was shown that the well-known splash parameter K_d can be used as an acceptable scaling for splashes, however the threshold value of number$K_{d,s}$for the nanomats is higher than that for dry flat substrates. The enhanced efficiency of drop cooling in the presence of nanofiber mats was also observed experimentally.

[1]Supported by National Science Foundation through Grant NIRT CBET-0609062, DFG (German Science Foundation).

3:30PM X12.00006 Controlling ice formation on nanostructured superhydrophobic surfaces[1] , TOM KRUPENKIN, University of Wisconsin - Madison, LIDIYA MISHCHENKO, BENJAMIN HATTON, Harvard University, J. ASHLEY TAYLOR, University of Wisconsin - Madison, VAIBHAV BAHADUR, JOANNA AIZENBERG, Harvard University — In this work we describe anti-icing properties of nanostructured superhydrophobic surfaces with well-defined regular arrays of micron and submicron surface features. Both open-cell and closed-cell structures are investigated. Dependence of ice formation dynamics on the temperature, details of the surface topography, substrate material, and other factors are investigated. We find that ice formation on these surfaces can be substantially retarded, with some of the surfaces showing no ice accumulation at temperatures as low as -20 C. The experimental results are in good quantitative agreement with the simple theoretical model based on the classical heterogeneous nucleation theory and wetting dynamics. The results of the work can provide new insight into design and optimization of anti-icing structures and coatings.

[1]funding support from DARPA Grant HR0011-08-C-0114 is appreciated

3:42PM X12.00007 Morphology of air nanobubbles trapped at hydrophobic nanopattened surfaces[1] , ANTONIO CHECCO, TOMMY HOFMANN, ELAINE DIMASI, CHARLES BLACK, BENJAMIN OCKO, Brookhaven National Laboratory, Upton NY USA — By using wettability and X-ray scattering measurements we study the trapping of air nanobubbles at the interface between water and a hydrophobic silicon surface patterned with 20 nm-wide cavities. Hydrophobic cavities of various depths were fabricated over a large area of the substrate using diblock-copolymer lithography followed by silane functionalization. We have found that the contact angle of millimiter-sized water drops wetting the nanostructured surfaces increases with the cavity's depth eventually reaching a plateau. This behavior results form the stable trapping of air in the cavities consistent with Small-angle X-rays scattering (SAXS) measurements. The latter also show that water always penetrates slightly in the cavities independent on their depth which can be rationalized considering the geometry of the cavities. The ability to form high-density arrays of nanobubbles of well-defined morphology at the water/solid interface is relevant to the fabrication of surfaces with reduced liquid slippage for integration in micro- and nano-fluidic devices.

[1]Work supported by the U.S. DOE under Contract No. DE-AC02-98CH10886.

3:54PM X12.00008 Correlation of Bulk Viscosity and Liquid Slip on Smooth Hydrophobic Surfaces[1] , SEAN MCBRIDE, BRUCE LAW, Kansas State University — In this study we examine the slip behavior of eighteen Newtonian liquids from the two homologous series, the n-alcohols and n-alkanes, with viscosities covering the range $\sim$ 0.4 – 11.0 mPa s. Colloidal probe atomic force microscopy (AFM) is used to extract the slip length from experiments, which were conducted against molecularly smooth n-hexadecyltrichlorosilane (HTS) coated surfaces. The primary feature of this work is that the slip length b is found to be a function of the bulk viscosity η with b $\sim \eta^x$ where x $\sim$ 0.33. The slip length is also shown to be independent of the shear rate, therefore, validating the use of Vinogradova's slip theory. An important aspect of this study is that the same surfaces are used for each liquid, allowing any relative trends in slip behavior to be attributed to the properties of the liquid.

[1]This research was supported by the National Science Foundation under grant DMR-0603144.

4:06PM X12.00009 On Features of Capillary Flows as Predicted from Direct Comparison between Network Models and Experiments , B. MARKICEVIC, K. HOFF, H. LI, A. ZAND, H. K. NAVAZ, Kettering University — Having imbibed a particular volume of a wetting liquid by porous medium, a spontaneous capillary flow of liquid within porous medium itself takes place. The flow has been investigated experimentally for the unidirectional flow conditions, where the spatial and temporal changes of the liquid saturation are measured. The axial saturation profiles and their changes in time are also predicted numerically using the capillary network models. For each specific porous medium|liquid pair, the experimental and numerical saturation profiles are matched, and from numerical calculations, a unique capillary pressure and relative permeability as functions of saturation are found. The fine and medium grain sands as porous media are used, which are not significantly different in their structure. Starting with this assumption, we are able to reduce both relative permeability and capillary pressure into single dependencies. It is found that the relative permeability falls onto the same curve without any further reducing factor, whereas for the capillary pressure, the Leverett J-functions scales are sufficient. For two distinct liquids, the liquid surface tension and contact angle are used. For two sands, the scale is obtained from the sand permeability and porosity. Two network parameters: pore size distribution and liquid residual saturation are used in predicting the experimental data.

4:18PM X12.00010 Direct Imaging of Two-phase Flow in Porous Media at the Pore Level , AMBER KRUMMEL, STEFAN MUNSTER, STEFAN LINDSTROEM, DAVID WEITZ, Harvard University — The dependence of residual oil saturation on capillary number is investigated during a series of two-phase flow experiments. We exploit the spatial and time resolution of confocal microscopy to collect three-dimensional images during the course of two-phase flow experiments. The engineering of an optically transparent, three-dimensional micromodel affords direct imaging of the fluid configurations while the physical characteristics of the flow are measured. An optimal capillary number for oil production is observed. Beyond this point the entrapped residual oil actually increases while the relative permeability of the medium increases. The origin of this counterintuitive behavior lies in the size distribution of the residual oil ganglion.

4:30PM X12.00011 Surface Tension Driven Instability in the Regime of Stokes Flow , ZHENWEI YAO, MARK BOWICK, XIANGJUN XING, Syracuse University — A cylinder of liquid inside another liquid is unstable towards droplet formation. This instability is driven by minimization of surface tension energy and was analyzed first by [1,2] and then by [3]. We revisit this problem in the limit of small Laplace number, where the inertial of liquids can be completely ignored. The stream function is found to obey biharmonic equation, and its analytic solutions are found. We rederive Tomotika's main results, and also obtain many new analytic results about the velocity fields. We also apply our formalism to study the recent experiment on toroidal liquid droplet[4]. Our framework shall have many applications in micro-fluidics. [1] L.Rayleigh, On The Instability of A Cylinder of Viscous Liquid Under Capillary Force, Scientific Papers, Cambridge, Vol.III, 1902. [2] L.Rayleigh, On The Instability of Cylindrical Fluid Surfaces, Scientific Papers, Cambridge, Vol.III, 1902. [3] S.Tomotika, On the Instability of a Cylindrical Thread of a Viscous Liquid surround by Another Viscous Fluid, Proceedings of the Royal Society of London. Series A, Mathematical and Physical Sciences, Volume 150, Issue 870, pp. 322-337. [4] E.Pairam and A.Fernández-Nieves, Generation and Stability of Toroidal Droplets in a Viscous Liquid, Physical Review Letters 102, 234501 (2009).

4:42PM X12.00012 Thermal Performance of Surface Wick Structures.[1] , YONGKANG CHEN, NOEL TAVAN, JOHN BAKER, LAWRENCE MELVIN, MARK WEISLOGEL, Portland State University — Microscale surface wick structures that exploit capillary driven flow in interior corners have been designed. In this study we examine the interplay between capillary flow and evaporative heat transfer that effectively reduces the surface temperature. The tests are performed by raising the surface temperature to various levels before the flow is introduced to the surfaces. Certainly heat transfer weakens the capillary driven flow. It is observed, however, the surface temperature can be reduced significantly. The effects of geometric parameters and interconnectivity are to be characterized to identify optimal configurations.

[1]This work is supported by NSF CTS-0521890. We would like to thank MEMS Exchange for fabrication support.

4:54PM X12.00013 Cold Water Jets on a Hot Si surface , JI YONG PARK, CHANG-KI MIN, DAVID CAHILL, STEVE GRANICK, Department of Materials Science and Engineering, University of Illinois — We are using a femtosecond pump-probe apparatus to study heat transfer when a pulsed jet of liquid water impinges on a hot Pt-coated Si surface (Leidenfrost Effect). The light source in the experiment is a 100 mW Er:fiber laser operating at a wavelength of λ=1550 nm; the total volume of the pulsed water jet is $\sim$0.9 mm^3. The temperature change within the Si substrate at a distance of 50 microns from the interface is measured by a novel time-resolved thermometry based on two-photon absorption. We measure the thermal conductance of the water layer within 50 nm of the interface by time-domain thermo-reflectance; changes in the thermal conductance provide a direct measurement of the contact time of the liquid. We convert the integral of the temperature excursion to the energy transferred using a Green's function solution of heat conduction in the Si substrate. Both the energy transferred and contact time show a smooth evolution from high values at 110C to low values at 210C without any clear indication of a Leidenfrost point.

5:06PM X12.00014 Optimal convective mixing by forced two-dimensional Stokes flows , DAVID SAINTILLAN, QIZHENG YAN, MechSE, University of Illinois at Urbana-Champaign — Numerous mixing strategies in the Stokes flow regime rely on time-dependent body forces. The question of determining the required forcing function to achieve optimal mixing at a given power input remains however open. Using optimal control theory, we numerically determine general optimal mixing flows in a two-dimensional periodic geometry as truncated sums of time-modulated Fourier modes. The time-averaged power spectra of these flows are calculated to investigate the effect of scale, and demonstrate that best mixing is achieved when a wide range of scales are present in the flow. We also determine the frequency spectra of the time-modulating functions and characterize the importance of non-harmonic forcing.

5:18PM X12.00015 Self-sustaining oscillations of the falling sphere in some viscoelastic fluids[1] , YOUNG JU LEE, Rutgers, The State University of New Jersey, CHENSONG ZHANG, The Pennsylvania State University, 1 TEAM — We investigate the mathematical models for the unusual phenomenon observed in motion of the sphere falling through the wormlike micellar fluids;a sphere falling in a wormlike micellar fluids undergoes nontransient and continual oscillations. Using a novel numerical techniques, we identified right models in our simulations by exploring the parameter regimes of models that have been unexplored previously for the flow past a sphere and reproduce the self-sustaining, continual, (ir)regular and periodic oscillations. Our results show that the flow instability can be correlated with the critical value of the velocity gradient as observed in experiments.

[1]Lee is partially supported by NSF-DMS 0753111, DMS-0915028 and Zhang is partially supported by NSF-DMS 0915153

Friday, March 19, 2010 8:00AM - 10:48AM –

Session Y12 DFD: Disordered and Glassy Systems I B110-B111

8:00AM Y12.00001 Fragile granular jamming[1] , MAHESH BANDI[2], MICHAEL RIVERA, Los Alamos National Laboratory, FLORENT KRZAKALA, ESPCI, Paris, France and CNLS, Los Alamos National Laboratory, ROBERT ECKE, Los Alamos National Laboratory — We demonstrate experimentally that the route to a jammed state for a set of bi-dispersed frictional disks, subjected to uni-axial compression from a random initial unjammed state, consists of a consolidation state, a fragile jammed state, and finally a rigid jammed state. In the consolidation regime, the pressure on the sides increases very slowly with the packing fraction ϕ, and there are no detectable stress chains. In the fragile jammed state, stress chains are visible, the pressure increases exponentially with ϕ, and the fraction of moving disks drops exponentially. Eventually, a final regime where particle displacements are below our resolution and the pressure varies approximately linearly with ϕ is reached. We argue that this scenario is generic for athermal frictional compressed particles.

[1]This work was carried out under the auspices of the National Nuclear Security Administration of the U.S. Department of Energy at Los Alamos National Laboratory under Contract No. DE-AC52-06NA25396.
[2]Current Affiliation: SEAS, Harvard University

8:12AM Y12.00002 Jamming under shear[1] , JIE ZHANG, JIE REN, SOMAYEH FARHADI, ROBERT BEHRINGER, Duke University — We describe experiments in which we consider the jamming of 2D granular materials under shear. We consider experiments involving both pure and simple shear. The particles making up the material are either disks or ellipses, and in both cases, they are fabricated from a photoelastic material. It is then possible to obtain quantitative data for contact forces, and all other relevant grain-scale information. A key observation from these experiments is that initial states with densities below isotropic jamming can be jammed under applied shear in a range of packing fractions between $\phi_{min} \leq \phi \leq \phi_J$, where ϕ_J corresponds to the isotropic (zero shear stress) jamming point. We explore the behaviour of the above systems for ϕ's in and near this regime. Specifically, we determine particle contacts and the mean contact number per particle, Z, the number of nearest neighbors, the shear and normal stresses, τ and P, and kinematic properties such as particle rotation and displacement. We find that the states of the system lie on a surface in a space consisting of ϕ, P, and τ. As time permits, we will explore the affine and non-affine motion of particles.

[1]Supported by NSF grants DMR-0555431 and DMR-0906908 and by ARO grant W911NF-07-1-0131-00

8:24AM Y12.00003 Clogging Tranistion in a Tilted Silo , CHARLES THOMAS, DOUGLAS DURIAN, University of Pennsylvania — Granular media flow freely from large horizontal holes at the bottom of a container. However, if the hole is too small, or tilted too far from horizontal, a clog will eventually form at the exit and halt the flow. The number of beads which exit before a clog forms follows an exponential distribution. The average of this distribution increases with increasing hole size and with decreasing angle from horizontal, diverging above a critical hole size. We measure these hole sizes at different angles. The critical hole size as a function of angle constitutes the system's phase transition on a clogging phase diagram. In comparison, the hole sizes where the Beverloo equation predicts the flux to vanish are less than half these critical hole sizes.

8:36AM Y12.00004 Kinetic Heterogeneities at Dynamical Crossovers[1] , THOMAS HAXTON, ANDREA LIU, Department of Physics and Astronomy, University of Pennsylvania — We perform molecular dynamics simulations of a model glass-forming liquid to measure the spatial and temporal extent of kinetic heterogeneities as functions of distance a and time t. We locate local maxima $\chi^\star$ of the dynamic susceptibility $\chi_{\rm ss}(a,t)$ at distances $a^\star$ and times $t^\star$. We find two types of maxima, both correlated with crossovers in the dynamical behavior: a smaller, early-time maximum corresponding to the crossover from ballistic to sub-diffusive motion, and a larger, late-time maximum corresponding to the crossover from sub-diffusive to diffusive motion. Our results indicate that dynamic heterogeneities are not necessarily signatures of an impending glass or jamming transition. To quantify the lifetime of heterogeneities, we measure the decay of the time correlation function of the overlap parameter. We find that the ratio of the lifetime to the relaxation time increases as temperature is decreased towards the glass transition.

[1]This work was supported by DE-FG02-05ER46199 and in part by the MRSEC program under NSF-DMR05-20020.

8:48AM Y12.00005 Elasticity near jamming probed in bidisperse foams , ALEXANDER SIEMENS, MARTIN VAN HECKE, Universiteit Leiden — One of the hallmarks of the jamming transition is the difference in scaling of the shear and bulk modulus of frictionless soft particles near jamming. Here we probe this scaling by compressing and shearing a bidisperse foam monolayer sandwiched between a glass plate and a fluid surface.

9:00AM Y12.00006 Structural signature of jamming transition[1] , NING XU, Department of Physics, University of Science and Technology of China — In thermal amorphous systems, the first peak of the pair correlation function $g(r)$ reaches the maximum height $g_1^{\max}$ at a crossover volume fraction ϕ_v when the volume fraction ϕ is varied. In the $T=0$ limit, ϕ_v approaches ϕ_c, the critical volume fraction of the $T=0$ jamming transition, accompanied by a diverging $g_1^{\max}$. The occurrence of $g_1^{\max}$ at $T>0$ thus reminisces the $T=0$ jamming transition. By measuring typical quantities such as the pressure, bulk modulus, shear modulus, and characteristic frequency of the boson peak, which all show power law scalings with $\phi-\phi_c$ in marginally jammed solids at $T=0$, we observe that $\phi=\phi_v$ separates the thermal amorphous systems into two regimes with distinct material properties: these quantities show similar power law scalings with $\phi-\phi_c$ to marginally jammed solids when $\phi>\phi_v$, which break down when $\phi<\phi_v$. Therefore, the occurrence of $g_1^{\max}$ signifies the jamming transition at $T>0$. Because the scalings are manipulated by ϕ_c, the $T=0$ jamming transition should be the only critical point that controls the jamming transition and properties of jammed solids at $T>0$.

[1]Supported by Hong Kong Research Grants Council (Grant No. CUHK 400708).

9:12AM Y12.00007 Investigating Jamming percolation using renormalization group methods , SAMUEL SCHOENHOLZ, AMY BUG, Swarthmore College, ANDREA LIU, University of Pennsylvania — We develop renormalization group-based methods to determine the percolation threshold and exponents for jamming-percolation models. Such models exhibit mixed phase transitions in finite dimensions, with a discontinuous jump in the order parameter and an exponentially diverging length scale: $\xi \approx \exp(|p-p_c^\infty|^\mu)$, where p_c^∞ marks the percolation transition for the infinite system. To extract p_c^∞ we use a Monte-Carlo scheme to find $p_c(L)$ for increasing L and extrapolate to $L\to\infty$. We investigate several models in two dimensions to test for universality of the exponent μ.

9:24AM Y12.00008 Yielding of colloidal glasses and gels , GEORGE PETEKIDIS, NICK KOUMAKIS, IESL-FORTH, Crete, Greece, JOHN BRADY, Chemical Engineering, Caltech, USA — Simple hard sphere glasses exhibit a single step yielding under oscillatory or steady shear that is related with the entropic elasticity and breaking of the near neighbours cage. However, when attractions are added, for example in the form of a short range depletion, the system yields in a two step manner. It has been proposed that these processes reflect an initial particle bond breaking and a subsequent breaking of an attractive cage [1]. Here we attempt to elucidate the origin of the two step yielding by examining the rheological response of a series of samples with the same interparticle attraction ranging from high volume fraction attractive glasses to the low volume fraction colloidal gels ($0.1< \phi <0.6$). We examine the linear and non-linear properties with both oscillatory and steady shear rheology. We find that the transition from a highly concentrated attractive glass to a low volume fraction colloid-polymer gel takes place gradually with the cage breaking process being substituted by a cluster dominated process as the volume fraction is decreased. Rheological measurements are complemented by Brownian Dynamics simulations in order to gain insight on the microscopic rearrangements and structural changes that occur during yielding. Different ranges of attraction are implemented both experimentally and in simulations to validate the main mechanisms involved.

[1] K. Pham et al. J Rheology (2008).

9:36AM Y12.00009 Dynamics of a colloidal glass during stress-mediated structural arrest[1] , AJAY NEGI, CHINEDUM OSUJI, Department of Chemical Engineering, Yale University — We employ parallel superposition rheology to study the dynamics of an aging colloidal glass in the presence of a mean field stress. Over a range of intermediate stresses, the loss modulus exceeds the storage modulus at short times but develops a maximum concomitant with a crossover between the two as the system ages. This is attended by a narrowing of the loss peak on increasing stress. We show that this feature is characteristic of the structural arrest in these materials, which is made observable on reasonable timescales by the activating influence of the stress. The arrest time displays an exponential dependence on inverse stress. These results provide experimental validation of the role of stress as an effective temperature in soft glassy systems as has been advanced in recent theoretical frameworks.

[1]Support from the NSF via CBET-0828905 is gratefully acknowledged.

9:48AM Y12.00010 Visualization of shear banding in colloidal glasses , VIJAYAKUMAR CHIKKADI, University of Amsterdam, ANDREW SCHOFIELD, University of Edinburgh, BERNARD NIENHUIS, PETER SCHALL, University of Amsterdam — Shear banding, i.e. the localization of shear flow, occurs in a manifold of systems ranging from hard materials such as metallic glasses to soft materials such as clays, shaving cream or mayonnaise. We investigate this phenomenon in a dense colloidal system using confocal microscopy that enables to track individual particles in 3D space and time. The particle motions reveal a transition from homogeneous flow to shear localization above a critical shear rate. We elucidate this transition using spatial correlations in the displacement of the particles. The diffusive motion of the particles is correlated over large length, and shows intermittent, scale-free behavior, reminiscent of crystal plasticity. Further, we associate an order parameter with the mobility of particles and demonstrate that shear banding is phase coexistence of regions differing in mobilities.

10:00AM Y12.00011 Density of states and soft modes in ordered and disordered colloidal systems: Experimental observations , ANTINA GHOSH, VIJAYAKUMAR K. CHIKKADI, PETER SCHALL, University of Amsterdam, JORGE KURCHAN, ESPCI, Paris, DANIEL BONN, University of Amsterdam — Glasess are structurally disordered systems that exhibit mechanical properties of solids. At low temperature the thermodynamic properties (heat capacity) of such glassy disordered materials are found to be markedly different from the respective crystal indicating a richer microscopic dynamics. Such deviations are attributed to an "excess" of modes at low frequencies observed in the density of states. Further insight in this problem could be gained by understanding the nature of such anomalous modes. In the present study, we compute and compare the vibrational density of states and corresponding long wavelength modes of colloidal hard sphere glasses with its crystalline counterpart from the experimental data. This identifies the observed "excess" modes in glasses as transverse modes. These modes appears to be quasi-localized for glasses: the participation ratio provides a quantative measure of such localization.

10:12AM Y12.00012 ABSTRACT WITHDRAWN –

10:24AM Y12.00013 Dynamics of soft spheres beyond the hard-sphere limit , MICHAEL SCHMIEDEBERG, ANDREA J. LIU, University of Pennsylvania, Department of Physics and Astronomy, 209 South 33rd Street, Philadelphia, PA 19104-6396 — In the limit of low pressures the dynamics of model glass-forming liquids with finite-ranged repulsive interactions are universal. In that limit, where the product of the pressure and the particle volume is small compared to the interaction energy, soft sphere systems behave as hard spheres, so that the dynamics correspond to those of the hard-sphere glass transition and depend only on the ratio of temperature to the product of pressure and the particle volume. However, at higher pressures relative to the interaction energy, there are deviations from this universal behavior that depend on the inter-particle potential. We consider a bidisperse system consisting of soft spheres that repel each other according to a power law potential δ^α where δ is the particle overlap. By using molecular-dynamics simulations, we determine relaxation times as a function of temperature and pressure. We find that the deviations from hard-sphere behavior can be collapsed onto a single curve that depends on $p^{1/\alpha}$.

10:36AM Y12.00014 Effects of Shape on Diffusion and Shear Flows , ROBERT SHAW, NORMAN PACKARD, ProtoLife, Inc. — Diffusion of point particles is well-understood, likewise the motion of simple particles under shear flow. However if the particles are extended objects with shape, more complicated behavior can occur. For example, objects might enter a shaped channel in a configuration that requires them to back up a finite distance in order to proceed further. A configuration that blocks flow through the channel might be statistically preferred, an attracting metastable state of the system. In the bulk, the configuration space of a set of closely packed rigid objects can become convoluted, with many dead-end alleys. If such a system is subjected to a shear, it may naturally tend to settle in such a dead-end, and have to retrace its path in order to continue further, a configuration can become locally locked. The requirement that the system backtrack to unlock distinguishes this process from ordinary jamming, there need be no dissipation or friction per se. We have a number of computer simulations of the motions of closely packed shaped objects, under both Hamiltonian and Monte Carlo dynamics. In addition we will present a simple analytic model, describing the entry and escape of the system from the attracting locked metastable states.

Friday, March 19, 2010 11:15AM - 2:03PM –

Session Z12 DFD: Disordered and Glassy Systems II B110-B111

11:15AM Z12.00001 Microscopic statistical dynamical theory of correlated motion in glassy fluids and suspensions , DANIEL SUSSMAN, KEN SCHWEIZER, University of Illinois at Urbana-Champaign — The naive mode coupling theory and the stochastic nonlinear Langevin equation theory of single particle activated glassy dynamics has been extended to treat the correlated motion of two tagged particles in a dense fluid. Starting with a generalized Langevin equation deduced using projection and mode coupling approximations, we derive an effective nonequilibrium free energy surface for the stochastic motion of the tagged degrees of freedom. The dynamical free energy surface involves contributions from an ideal entropic term, the potential of mean force, and a many particle 'caging' term that is explicitly dependent on the relative separation between the particles. The theory allows the study of space-time dynamic heterogeneity effects, including the length scale beyond which single particle motion of two tagged particles becomes independent and how the emergence of irreversible rearrangements affects the equilibrium pair structure relaxation. Numerical results for hard sphere fluids and colloidal suspensions will be presented.

11:27AM Z12.00002 Improved model for the transit entropy of monatomic liquids , ERIC CHISOLM, NICOLAS BOCK, DUANE WALLACE, Los Alamos National Laboratory — In the original formulation of vibration-transit (V-T) theory for monatomic liquid dynamics, the transit contribution to entropy was taken to be a universal constant, calibrated to the constant-volume entropy of melting. This implied that the transit contribution to energy vanishes, which is incorrect. Here we develop a new formulation that corrects this deficiency. The theory contains two nuclear motion contributions: (a) the dominant vibrational contribution $S_{vib}(T/\theta_0)$, where T is temperature and θ_0 is the vibrational characteristic temperature, and (b) the transit contribution $S_{tr}(T/\theta_{tr})$, where θ_{tr} is a scaling temperature for each liquid. The appearance of a common functional form of S_{tr} for all the liquids studied is deduced from the experimental data, when analyzed via the V-T formula. The theoretical entropy of melting is derived, in a single formula applying to normal and anomalous melting alike. An *ab initio* calculation of θ_0 for Na and Cu, based on density functional theory, provides verification of our analysis and V-T theory. In view of the present results, techniques currently being applied in *ab initio* simulations of liquid properties can be employed to advantage in the further testing and development of V-T theory.

11:39AM Z12.00003 Free energy landscape theory of glass transition , TAKASHI ODAGAKI, Tokyo Denki University — I first present a free energy landscape (FEL) description of statistical mechanics, which is an exact reformulation of statistical mechanics and can be applied to non-equilibrium systems. Then, I discuss thermodynamic and dynamic properties of the vitrification process on the basis of the FEL formalism. I show that thermodynamic and dynamic anomalies at the glass transition, including the cooling rate dependence, can be understood in a unified manner which has not been achieved by any other theories of the glass transition. Namely, I show that the vitrification is a transition from annealed to quenched averages in the FEL and that the fast beta, the JG and the slow alpha relaxations are attributed to stochastic dynamics within a basin of FEL, jumping motion among locally connected basins and diffusive dynamics over barriers of the FEL.

11:51AM Z12.00004 Observation of the Disorder-Induced Crystal-to-Glass Transition , PETER YUNKER, University of Pennsylvania, ZEXIN ZHANG, ARJUN YODH — The role of frustration and quenched disorder in driving the transformation of a crystal into a glass is investigated in quasi-two-dimensional binary colloidal suspensions. Frustration is induced by added smaller particles. The crystal-glass transition is measured to differ from the liquid-glass transition in quantitative and qualitative ways. The crystal-glass transition bears structural signatures similar to those of the crystal-fluid transition: at the transition point, the persistence of orientational order decreases sharply from quasi-long-range to short-range, and the orientational order susceptibility exhibits a maximum. The crystal-glass transition also features a sharp variation in particle dynamics: at the transition point, dynamic heterogeneity grows rapidly, and a dynamic correlation length-scale increases abruptly.

12:03PM Z12.00005 Characteristic length scale of the inhomogeneous mode-coupling theory: beyond scaling predictions , ELIJAH FLENNER, GRZEGORZ SZAMEL, Colorado State University - Chemistry Department — The inhomogenous mode-coupling theory of Biroli *et al.* [Phys. Rev. Lett. **97**, 195701 (2006)] allows for the identification of a characteristic length scale that diverges as the mode-coupling transition is approached. We numerically investigate this length scale as a function of time, wave-vector, and distance from the transition by examining the small $\mathbf{q}$ expansion of the dynamic susceptibility $\xi_{\mathbf{q}}(\mathbf{k};t)$ defined by Biroli *et al.* We confirm the scaling predictions of Biroli *et al.*. In addition, we show that the characteristic length is in qualitative agreement with simulations where the length scale is obtained from four-point correlation functions. Finally, we show that the length scale has virtually no k dependence and thus it is well defined. The k-independence of the length contrasts with the very strong k dependence of $q \to 0$ limit of the dynamic susceptibility.

12:15PM Z12.00006 On the Molecular Structure of $Ge_xSb_xSe_{1-2x}$ glasses[1] , K. GUNASEKERA, P. BOOLCHAND, University of Cincinnati, A. JACKSON, Central Michigan University — The $Ge_xSb_xSe_{100-2x}$ternary is isovalent to the phase-change material, $Ge_xSb_xTe_{100-2x}$, except the Selenides can be prepared as bulk alloy glasses while the Tellurides exist only as amorphous thin-films. Here we report on the Selenides synthesized over a wide composition range, $0 < x < 25\%$, and examined in modulated-DSC, Raman scattering and molar volume experiments. The enthalpy of relaxation at T_g shows the opening of a reversibility window or Intermediate Phase (IP) in the $13\% < x < 18\%$ range, or $2.40 < \mathbf{r} < 2.54$ mean coordination number range, where $\mathbf{r} = 2 + 3x$. FT- Raman studies reveal frequency of the CS mode of $GeSe_4$ tetrahedra to steadily blue-shift with increasing x as networks stiffen. New vibrational modes are observed near 150 cm^{-1} and near 220 cm^{-1} at $x > 18.18\%$, the chemical threshold, and are thought to result from homopolar bonds. Ab-initio cluster calculations place pyramidal $SbSe_3$ units and ethylene-like Sb_2Se_2 units to reveal Raman activity near 215 cm^{-1} and 228 cm^{-1} respectively. Evolution of glass structure with composition x will be discussed.

[1]Supported by NSF grant DMR- 08-53957

12:27PM Z12.00007 Relating the Dynamics of Supercooled Liquids to the Sensitivity of Modes to Small Perturbations , VASILE IULIAN CLAPA, TSAMPIKOS KOTTOS, FRANCIS STARR, Physics Dept., Wesleyan University, Middletown, CT — We propose an alternate method to relate the structural and dynamical properties of a model supercooled binary Lennard-Jones (BLJ) liquid approaching the glass transition. Our proposal builds on methods from random matrix theory and transport theory of disordered systems, where it was shown that the diffusivity/localization can be probed by an appropriate statistical analysis of the eigenvalues and eigenvectors of the Hamiltonian function. Specifically, we examine the viability of connecting the diffusion constant of the BLJ liquid to: (i) the mean level velocities (MLV) of eigenmodes, (ii) the variance of MLVs, and, (iii) the participation number of the eigenmodes.

12:39PM Z12.00008 Direct evidence of enhanced surface mobility in molecular glass forming system 1,3-bis-(1-naphthyl)-5-(2-naphthyl)benzene , CHAD DALEY, Dept. of Physics and Astronomy, University of Waterloo, DAN SCIFO, ZAHRA FAKHRAAI, MARK EDIGER, Department of Chemistry, University of Wisconsin-Madison, JAMES FORREST, Dept. of Physics and Astronomy, University of Waterloo — We have performed nanoparticle embedding studies on the organic glass forming system 1,3-bis-(1-naphthyl)-5-(2-naphthyl)benzene (TNB). Films are prepared by vapor deposition onto a Si substrate held at a temperature near T_g – 50K (T_g = 347K) and subsequently annealed. The surfaces of the films are covered with 20 nm diameter gold nanoparticles. Atomic force microscopy is used to track the apparent height of specific nanoparticles as a function of time elapsed at embedding temperatures of 323K, 333K, and 343K. The experiments reveal direct evidence for surface mobility at temperatures below the bulk glass transition. In addition to changes in the apparent heights of the nanoparticles, there is clear evidence that material surrounding the nanoparticles is being drawn up to engulf the nanoparticles; something not observed in polymeric films. These results directly establish the presence of enhanced surface mobility in molecular glass forming systems.

12:51PM Z12.00009 On the Elastic behavior of Sodium Borate Glasses[1] , K. VIGNAROOBAN, P. BOOLCHAND, University of Cincinnati, R. KERNER, M. MICOULAUT, University of Paris — Alkali Borates are industrial glasses and their physical properties are of general interest. We have made a special effort to synthesize dry $(Na_2O)_x(B_2O_3)_{100-x}$ glasses over a wide composition range, $0 < x < 70\%$, and have examined them in modulated-DSC, Raman scattering, FTIR, and molar volume experiments. The enthalpy of relaxation at T_g shows a global minimum in the $20\% < x < 40\%$ range, which we identify with the rigid but stress-free Intermediate Phase (IP). The Boroxyl ring vibrational mode near 808 cm^{-1} in B_2O_3, steadily softens by about 4 cm^{-1} as the soda content increases to about 20%. A vibrational mode of mixed rings[2] (containing 3-fold and 4-fold B) is also observed near 775 cm^{-1} at low x, and it also steadily softens by nearly 10 cm^{-1} as x increases in the $20\% < x < 40\%$ soda range (IP). We are examining the underlying optical elasticity power-laws to ascertain the nature of the elastic phases. IR reflectance experiments provide the 4-fold coordinated B fraction to increase from 0.17 near $x = 20\%$ to 0.44 near $x = 40\%$ in broad agreement with NMR results. Evolution of physical properties of these glasses with soda content will be reviewed.

[1]Supported by NSF Grant DMR 08-53957.

[2]Kamitsos et al., Jour. Mol. Struct 247, 1 (1996).

1:03PM Z12.00010 Aging of the generalized density susceptibility in a strong glass , AZITA PARSAEIAN, HORACIO E. CASTILLO, Department of Physics and Astronomy, Ohio University, KATHARINA VOLLMAYR-LEE, Department of Physics and Astronomy, Bucknell University — We investigate dynamical heterogenities in a strong glass below the glass transition temperature. Our model is produced by molecular dynamics simulations of an amorphous silica system, where the atoms interact via the BKS potential. We quantify the heterogenous dynamics by measuring the four-point generalized dynamic susceptibility, i.e., the volume integral of the spatial correlations. We study this quantity as a function of the waiting time and as a function of the global intermediate scattering function. We test for universality by comparing the fluctuations in this model to those of fragile glasses which consist of either small molecules or polymers.

1:15PM Z12.00011 Glass transition and dynamic scaling in soft repulsive particles: a mode-coupling theory study , GRZEGORZ SZAMEL, Department of Chemistry, Colorado State University, LUDOVIC BERTHIER, Laboratoire des Colloides, Verres et Nanomateriaux, Universite Montpellier II , HUGO JACQUIN, Laboratoire Matiere et Systemes Complexes, Universite Paris 7, ELIJAH FLENNER, Department of Chemistry, Colorado State University — We combine the hypernetted chain approximation with the mode-coupling theory to analyze structure and dynamics of dense systems consisting of soft repulsive particles (harmonic spheres). We investigate the phase diagram for a broad range of temperatures and volume fractions. We find that in the vicinity of the T=0 mode-coupling transition for hard spheres, the dynamics obey a power-law form of dynamic scaling. We find that the critical MCT exponent describing the divergence of the relaxation time at the mode-coupling transition decreases with increasing volume fraction.

1:27PM Z12.00012 Time reparametrization symmetry in a short-range p-spin model , GCINA MAVIMBELA, Dept of Physics and Astronomy, Ohio University, HORACIO E. CASTILLO, Dept of Physics and Asatronomy, Ohio University — We explore the existence of time reparametrization symmetry in the p-spin model. We follow closely the approach previously used to prove the presence of this symmetry in the Edwards-Anderson model. Using the Martin-Siggia-Rose generating functional, we analytically probe the long-time dynamics.We introduce a cut-off in the time difference $\tau_0 \leq t - t'$ and perform a Renormalization Group analysis where we systematically integrate over short-time scale fluctuations. We find that the RG flow converges to a fixed point that is invariant under reparametrizations of the time variable. This continuous symmetry is broken in the glass state and we argue that this gives rise to the presence of Goldstone modes. We expect the Goldstone modes to determine the properties of fluctuations in the glass state.

1:39PM Z12.00013 Brillouin scattering study of glass-transition dynamics in glycerol at pressures up to 60 kbar[1] , WILLIAM OLIVER III, TITUS MORRIS, University of Arkansas, TAYLOR BYRUM, Oklahoma Baptist University — Isothermal pressurization data for glycerol, a prototypic intermediate glass-forming system, will be presented. Brillouin scattering studies were performed at constant temperature to pressures as high as 60 kbar. An equal-angle forward scattering geometry is used for which the pressure dependence of the refractive index is not required to convert Brillouin frequency shift data to sound velocities. Through a careful optical setup acoustic mode frequencies and linewidths are measured, and from data analysis methods that include convolution with the instrument function, both pressure-dependent sound velocities and true linewidths are extracted from these data. Further analysis allow us to model the relaxation time of the glass-forming system as a function of pressure and to calculate the equation of state for this important system to previously unexplored regions of the pressure-temperature phase space.

[1]We gratefully acknowledge support from the NSF under grant No.: DMR 0552944.

1:51PM Z12.00014 Triangular Relations in Structural Glasses , KARINA E. AVILA, HORACIO E. CASTILLO, AZITA PARSAEIAN, Ohio University — Structural glasses exhibit the phenomenon of dynamical heterogeneity: different regions of the system present different dynamical behavior. To study this phenomenon, we analyze simulations of four models of structural glasses performed in the aging regime. We compute the triangular relations of the local and global two-time correlation functions, i.e., the mathematical relationships among correlators calculated for the time pairs (t1,t2), (t2,t3) and (t1,t3) with t1> t2> t3. We plot the triangular relations of the global and local correlations together to compare their behavior. We find that the probability distribution of local correlations is concentrated along the curve representing the global correlations. Our results provide evidence of time reparametrization invariance and also point toward universality in the aging.